# Supporting Materials of "Identifying regime transitions for water governance at a basin scale"

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## 1 YRB Regions

We divide the YRB into four regions to calculate the indicators considering both socio-economic and natural conditions. The division aligns with the customary schema from publications and the YRCC [1–3], so four important hydrological stations can distinguish the regions (see Figure 1).

- **Source Region (SR):** Over 50% of natural runoff originates from this region. The most ecological function here is water yield, 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, irrigation efficiency is relatively much lower than its lower reaches.
- **Middle Region (MR):** Crossing Loess Plateau, a famous rich-sand area, Yellow River loads most of its sediments here with the highest soil erosion risk. The "grain for the green" project changed the water utilization here strikingly to reverse this situation [4].
- **Lower Region (LR):** With a dense population and the traditional agricultural trajectory, the lower region used to be the largest water use region. However, as the industrial transformation going, the proportion of agriculture keeps decreasing, but LR is still the largest water use region in each aspect.

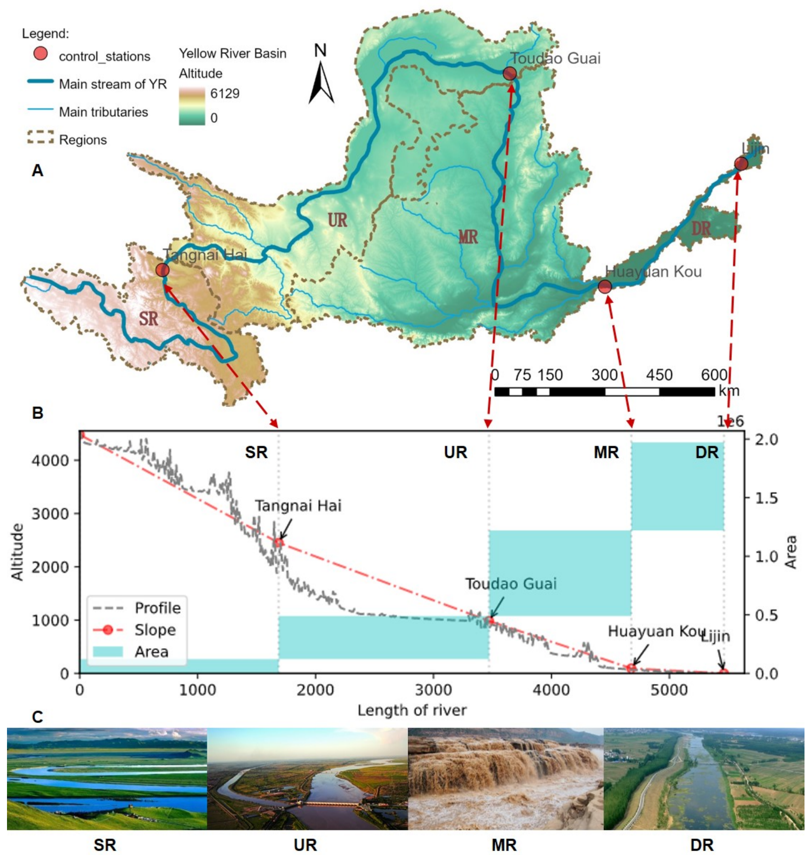


**Fig. 1** The study area. **A.** Diagram of the YRB and the subdivision of the basin (SR: Source Region, UR: Upper Region, MR: Middle Region, DR: Downstream region). **B.** Profile of the main channel of the Yellow River. The hydrological stations control the SR, UR, MR and DR. **C.** Typical landscapes in different regions in the YRB.

## 2 SFV-index

By taking water flexibility and variability into account, the scarcity-flexibility-variability (SFV) index focus more on dynamic responses to water resources in a developing perspective, which is a valid metric of temporal changes in water stresses [5]. To apply this method, we need to combine three metrics following:

First, for scarcity, $A_{i,j}$ is the total water consumption as a proportion of regional multi-year average runoff volume in year $j$ and region $i$ (in this study, four regions in the YRB, *Appendix* 1):

$$A_{i,j} = \frac{WU_{i,j}}{R_{i,avg}} \tag{1}$$

Second, for flexibility, $B_{i,j}$ is the inflexible water use $WU_{inflexible}$ (i.e. for thermal power plants or humans and livestock) as a proportion of average multi-year runoff, in year $i$ and region $j$:

$$B_{i,j} = \frac{WU_{i,j,inflexible}}{R_{i,avg}} \tag{2}$$

Finally for variability, the capacity of the reservoir and the positive effects of storage on natural runoff fluctuations are also considered.

$$C_i = C1_i * (1 - C2_i) \tag{3}$$

$$C1_{i,j} = \frac{R_{i,std}}{R_{i,avg}} \tag{4}$$

$$C2_i = \frac{RC_i}{R_{i,avg}},\ ifRC < R_{i,avg} \tag{5}$$

$$C2_i = 1,\ ifRC >= R_{i,avg} \tag{6}$$

In all the equations above, $R_{i,avg}$ is the average runoff in region $i$, $RC_i$ is the total storage capacities of reservoirs in the region $i$, $R_{i,std}$ is the standard deviation of runoff in the region $i$.

Finally, assuming three metrics (scarcity, flexibility and variability) have the same weights, we can calculate the $SFV$ index after normalizing them:

$$V = \frac{A_{normalize} + B_{normalize} + C_{normalize}}{3} \tag{7}$$

$$a = \frac{1}{V_{max} - V_{min}}; \tag{8}$$

$$b = \frac{1}{V_{min} - V_{max}} * V_{min} \tag{9}$$

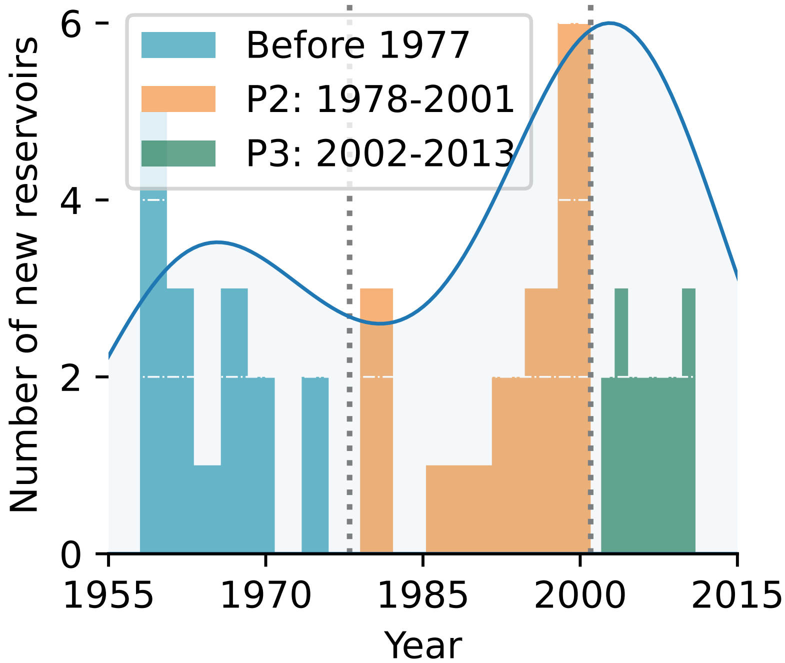


**Fig. 2** Numbers of new reservoirs in each year.

$$SFV = a * V + b \tag{10}$$

## 3 Datasets

### Descriptions

This study used multiple types of data (see Table 1): statistical datasets, hydrological datasets, and political datasets.

### Statistical datasets

The water resources use dataset was published by Zhou et al. [6], which records water utilization in different sectors along with social-economic situations at the Prefectures level. 2nd National Water Resources Assessment Program mainly extracted this dataset 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 with the 2013 administrative divisions.

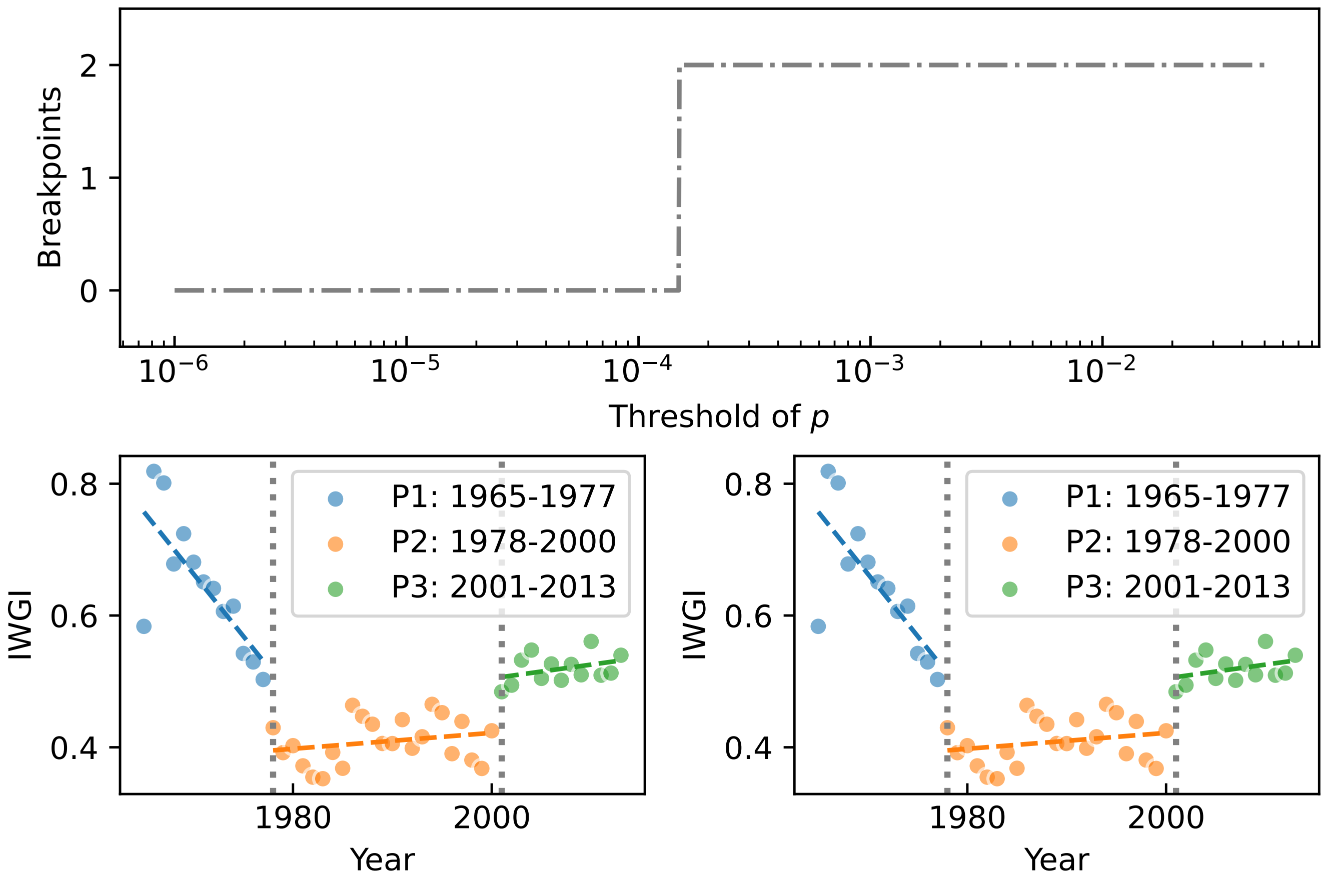


**Fig. 3** Sensitivity analysis of the threshold of p-values. **A.** number of breakpoints in different p-values, the scheme with two-breakpoints are the dominant situation. **B.** Threshold of p-values $\alpha = 0.0005$. **C.** Threshold of p-values $\alpha = 0.05$.

The data covers a total of subcategories of water use under four broad categories: agriculture (IRR), industry (IND), urban (URB) and rural (RUR) water use (see Zhou et al., for details [6]).

### Hydrological datasets

The reservoir dataset was collected by Wang et al. [2], which introduced includes the significant new reservoirs built in the YRB since 1949 (Figure 2). YRCC labelled the regulation-oriented reservoirs among them, see http://www.yrcc.gov.cn/hhyl/sngc/). In addition, annual runoff data derived from hydrological station measurements are the same as the datasets used in [2] and [3].

### Political datasets

The policy dataset collects laws and policies listed in the book [1], which are related to the Yellow River basin promulgated and implemented by departments at (such as YRCC) and above (such as national institutions) at the Basin's level (Table 2). In addition, some are difficult to categorize; not a landmark, but numerous water governance practices in the YRB had been recorded in "Yellow River Events" by the YRCC; we collected them from http://www.yrcc.gov.cn/hhyl/hhjs/.

## Methods S3. Harmonization

Due to the wide sources of our data set and the different spatial scales, we need to harmonize them into a practical scale.

- 1. Datasets at watersheds scales: We directly divided the annual hydrological data and measured runoff data according to their watersheds' corresponding hydrological stations (see Figure 1 A and B).
- 2. Prefecture: We calculate the area of each prefecture to determine whether they belong to a region, with the threshold of 95%:

$$S_{ij} = MAX(S_i j/S_i) \tag{11}$$

  Where $i$ refers to a specific prefecture and $j$ refers to a region within YRB, i.e. SR, UR, MR, or DR. $S_i$ refers to the area of perfect $i$, and $S_{ij}$ refers intersecting area between perfect $i$ and region $j$. We define perfecture $i$ belongs to region $j$ if their intersecting area $S_{ij}$ over 95% of $S_i$, i.e.:

$$MAX(S_{ij}) > 0.95 * S_i \tag{12}$$

- 3. Province: According to the major provinces contained in different regions, we determine which region the data of that province is merged into by referring to the traditional division practice:
  - SR: Qinghai Gansu and Sichuan,
  - UR: Ningxia and Inner Mongolia,
  - MR: Shanxi and Shaanxi,
  - DR: Shandong, Hebei and Henan.

Finally, when we process the location data (i.e., the location data of the reservoirs), we judge the province it belongs to according to its location and then fit it to the regional scale.

**Table 1** Used datasets and their sources.

| Dataset | Type | Spatial scale | Time scale | Source |
|---|---|---|---|---|
| 1. Administrative water use | Statistical | Prefectures | 1965-2013 | 2nd National Water Resources Assessment Program [6] |
| 2. GDP | Statistical | Province | 1949-2019 | Wind database |
| 3. Streamflow withdrawals | Statistical | Watershed | 2003-2019 | Yearbooks http://www.yrcc.gov.cn/other/hhgb/ |
| 4. Reservoirs | Hydrological | Location | 1949-2015 | Publication [2] |
| 5. Measured runoff | Hydrological | Location | 1949-2019 | Measured data [2, 3] |
| 6. Laws | Political | Documents | 1949-2013 | YRCC [1] |
| 7. History of YRCC | Political | Documents | 1949-2002 | YRCC [7] |
| 8. YRB Events | Political | Documents | 1949-2015 | YRCC: http://www.yrcc.gov.cn/hhyl/hhjs/ |

# References


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**Table 2** Policies and regulations above YRB level which affected the whole basin in water utilization

| Name | Year | Agency |
|---|---|---|
| 1. Water Law of PRC | 1988 | National People's Congress of the PRC |
| 2. Water Law of PRC -revised 1 | 2009 | National People's Congress of the PRC |
| 3. Water Law of PRC -revised 2 | 2016 | National People's Congress of the PRC |
| 4. Regulations on the Administration of Water Drawing Licences and The Collection of water resource fees | 2006 | State Council of the PRC |
| 5. Regulations on the Administration of Water Drawing Licences and The Collection of water resource fees -revised 1 | 2017 | State Council of the PRC |
| 6. Regulations on the Allocation of Water in the Yellow River | 2006 | State Council of the PRC |
| 7. Yellow River water supply distribution scheme | 1987 | State Council of the PRC |
| 8. Measures for the Administration of Water Drawing Permits | 2008 | Ministry of Water Resources of the PRC |
| 9. Measures for the Administration of Water Drawing Permits -revised 1 | 2015 | Ministry of Water Resources of the PRC |
| 10. Measures for the Administration of Water Drawing Permits -revised 2 | 2017 | Ministry of Water Resources of the PRC |
| 11. Regulations on the Allocation of Water in the Yellow River | 2006 | State Council of the PRC |
| 12. Annual distribution of available water supply of the Yellow River and mainstream water dispatching scheme | 1998 | Ministry of Water Resources of the PRC |
| 13. The Yellow River water dispatching management measures | 1998 | Ministry of Water Resources |
| 14. Measures for the Implementation of the Yellow River Water Rights Conversion Management | 2004 | Ministry of Water Resources |
| 15. Regulations on the Administration of Water Drawing Licences and The Collection of water resource fees | 2006 | State Council of the PRC |
| 16. Measures for the implementation of the water drawing Permit system State Council of the PRC | 1993 | |
| 17. Measures for the demonstration and management of water resources in construction projects | 2002 | Ministry of Water Resources of the PRC |
| 18. Implementation Opinions on the Reform of Water Conservancy Project Management System | 2006 | State Council of the PRC |

[1]If a policy was proposed by multiple legacies, we only show the highest one.