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

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The importance of water resources to human society, the impact of humans on water resources, the relationship between humans and... A complex human-water relationship is gradually being established between water resources. And resulted in water utilization regime. This helps to identify and understand the traps in the development of river basins, thus providing a theoretical basis for integrated water resources management and development in a coordinated way.

Water resource management | Human-water relationship | Water scarcity | Sustainable development

Water, at the centre of the planetary drama of the Anthropocene, is not only essential for myriad Earth system processes, but also a key resource supporting development of human societies in various aspects (1). At the same time, however, human's modification has profoundly influenced water processes and related changes may lead to adverse transitions in functions of human-water systems, along with various development traps. Facing major challenges of the Anthropocene, many of the world's big river basins are also centres of economy and civilization and urgently in need for integrated water resources management toward sustainability. (2) Therefore, understanding the complex relationship between human societies and water resources utilization provides underlying supports to development in a coordinated way, at a basin scale.

Regime is a general term of systems structure and function and one of the most explanatory perspectives when analysis interactions within a coupling system, like human and water. Since widespread fluctuating disturbances in social development and natural water resources were out of consideration, water utilization regime only will be driven shifting when reorganizations occurred and the tipping points reached. As many large river basins had all experienced phases of accelerated water exploitation, over-exploitation of water resource, and integrated water management, it is a reasonable assumption that existence of a transitional water utilization regime corresponds to development of societies. Understanding the transitional nature of water resource regimes, therefore, can help to diagnosis and predict development traps, which is crucial for integrated management and coordinated development at a basin scale regard to sustainability. Despite pervasive and important as it is, there is lacking of effective method to detect the water utilization regimes and their shifts, with much fewer attempts to develop formal models of its transitions as well.

The key to analysis water utilization regimes is to understand the interactions between human societies and water resources, which have been depicted from different dimensions, as an ancient but evergreen topic. Firstly, the most widespread concern is the rising stresses on human societies with regard to water resources. Even though the stocks of water in increasing artificial reservoirs are helpful to water resources availability, highly stressed basins still characterized by high water consumption intensities and a major constraint to socio-economic development, driven by a significant increase in water extractions and a larger share of inflexible water utilization during the last century. (3–5) Secondly, as the need of industrial and ecological developments, tendentiousness of water utilization changed with. Despite a major water utilization of agricultural irrigation dominating most of the river basins, there are significant growths and preferential tendentiousness in the economy profits and water consumption regarding industry, leading a high potential for conflict between the industrial and agricultural sectors. (6, 7) Thirdly, since water availability and utilization are inherently regional concerns, patterns of also play an important role. Although only 10% of available water is withdrawn on global average, about 30% of population live in highly water-stressed areas, where dominated sections regarding water utilization are various. (8, 9) In addition, human activities are still changing this pattern, since positive impacts caused by human interventions mostly occur in upper regions whereas aggravated water resources downstream, in many basins around the world. (10) Although existing researches have evaluated the aspects of water resource utilization from these different dimensions, we still cannot obtain a coherent understanding of regime regard to social development and water utilization, without integrating them.

Here, by integrating three above mentioned dimensions of water utilization, we develop an Integrated Water Resources Utilization (IWRU) Index at a basin scale to give a sketch of

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Shuai Wang and Bojie Fu designed this research, Shuang Song performed the research and analysed data, Shuang Song, Xutong Wu wrote the paper.

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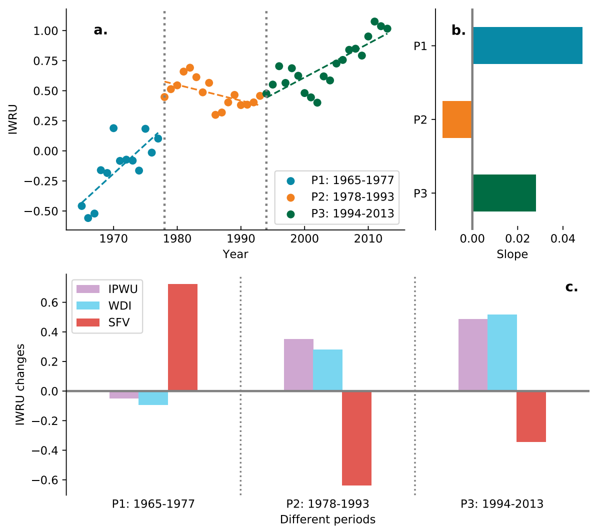

Fig. 1. Changes of the IWRU index. **A,** with two change points in 1978 and 1994, three periods were detected in trend of the IWRU. **B,** changes of IWRU in three periods have various slopes, while the second period have a negative growths rate. **C,** changes of the IWRU within three certain periods, which have different main contributors.

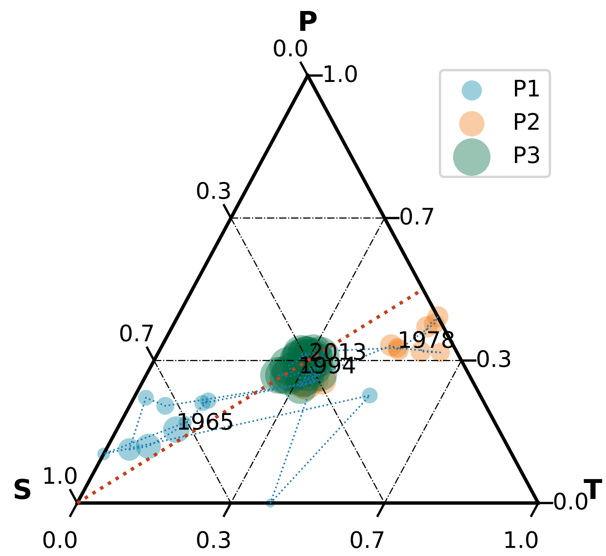

Fig. 2. Combination of three dimensions (S: stresses; T: tendentiousness; P: pattern) in different periods. Size of the points denoting values of the IWRU: the mean of the P1 phase is 0.10, while 0.14, 0.19 in P2 and P3. The red indicator line in this ternary plot denotes 1:1 contributions between tendentiousness (T) and patterns (P). Two key change points (1978, 1994), along with the beginning (1965) and the ending (2013) of research period, are labelled.

relationships between human societies and their water utilization. Then, by applying this index to the Yellow River Basin, China, we analysed water utilization regimes and their shifts in this typical basin of anthropogenic impacts, with change points detection and contribution decomposition methods following. In addition, combining model and data analysis, we further identify resource and development traps that have been exposed by regimes' shifting. Finally, refer to the existing theories, we summarized a general transition framework of water utilization regimes, which can be a useful guideline for basins to predict development traps and to develop in a coordinated way.

Results

Water utilization regimes. By the two significantly detected change points, the changes of IWRU index are split into three periods, whose slopes are various and mainly contributed by different factors (Figure 1). In the first period (P1, 1965-1978), the IWRU index had a rapidly increasing and the lightening of water stresses made the most striking contribution (124%), while tendentiousness and pattern of the water utilization had slight negative contribution. In the second period (P2, 1979-1994), the IWRU index experienced a slight drop, despite positive contributions of tendentiousness and pattern of water utilization, because of increasing stresses on water resource playing a larger negative role (-146%). However, as the further increasing of positive contributions of water utilization tendentiousness and pattern, and decelerations of water stresses in the third period (P3, 1995-2013), a positive growth of the IWRU returned. As a result, each period is various in the most striking positive contributors to IWRU, corresponding to different dimensions of water utilization.

Combining the three dimensions of water resources utilization, further more, sub-index regard to different water utilization dimensions were aggregative distinguishably in each same period, whose regimes show clear phase-characteristics (Figure 2). At the very beginning of research period (1965), high water stress domain the regime, while it experienced a large shift after entering P2 since 1978, with a change in the proportion of contributions between tendentiousness and pattern, too. In contrast, the three dimensions' contribution were similar from 1994 into P3 to 2013, making the points highly concentrated at the centre of the ternary diagram for that period. Taken all together, the three phases delineate distinct water resource utilization regimes, corresponding each period of.

Changes between different regimes. A comparison of the phases under different dimensions reveals notable differences between each water use regime (Figure 3). Moving from the regime in P1 to P2, the most striking change is the reversal of the trend in water stresses (Figure 3A). The P1, when water resources were the most abundant period, also had the least water consumption, while most of which were flexible water utilization. Despite the rapid rise in water use during that period, numerous reservoirs were also built during this period, which increased storage capacities in each water-demand region to relief water resource stresses (SI). However, entering P2, although water consumptions continued to increase, the number of new reservoirs was significantly reduced and the total storage capacity of each region was hardly increasing any more. Coupled with declining natural water resources, the water stress index of the basin was rapidly increasing. On the other hand, as the most positive contributors to the IWRU index in P2 and P3, separately, tendentiousness and patterns of water utilization were still enlarging their impacts (Figure 3B and C). Representing tendentiousness of water uti-

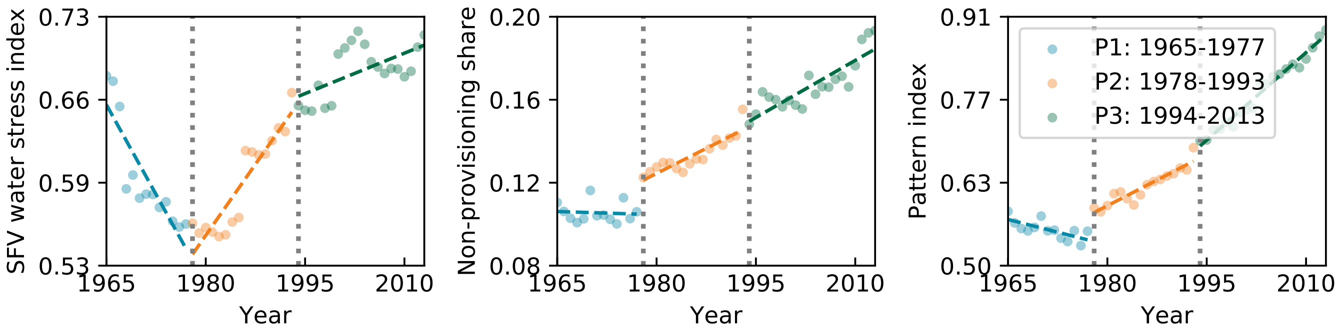

Fig. 3. Changes in different dimensions of water resources utilization regime. **A,** changes of scarcity-flexibility-variability water stresses index (SFV-index). **B,** changes of non-provisioning water share, indicating water utilization tendentiousness. **C,** changes of water utilization pattern index.

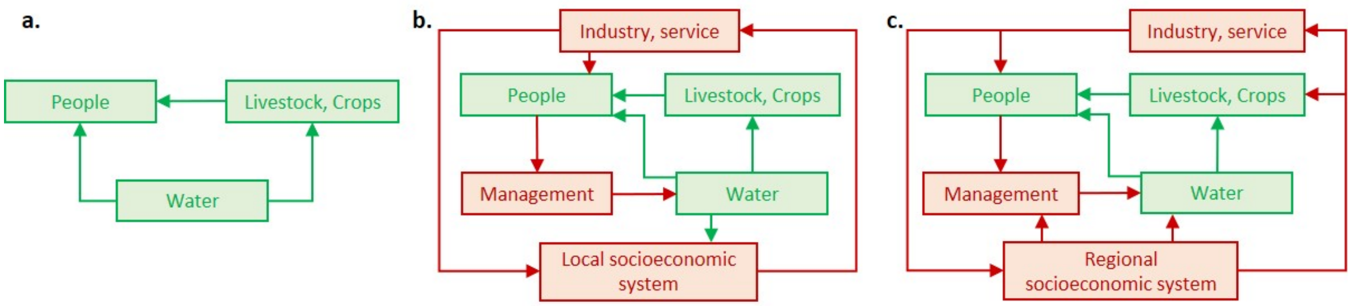

Fig. 4. Placeholder image of a frog with a long example legend to show justification setting.

lization, increasing non-provisioning share of water utilizations were mainly contributed by larger industrial water consumptions and minor total water uses, while the influence of both is waning. However, patterns of water utilization, with accelerating changes and larger contributions to the IWRU, were mainly benefited from the convergence of development paces between regions and the basin-wide intersectoral water balance. In summary, the changes in various aspects of the water use characteristics of the Yellow River Basin over the past 60 years are reflected in the changes in the corresponding indicators of the three dimensions.

Drivers of regime shifts. Two regime shifts had distinct main drivers.

Discussion

Transition Framework. Tables should be included in the main manuscript file and should not be uploaded separately.

Development Traps.

Materials and Methods

Please describe your materials and methods here. This can be more than one paragraph, and may contain subsections and equations as required. Authors should include a statement in the methods section describing how readers will be able to access the data in the paper.

Water utilization regime index. Example text for subsection.

Stresses. 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.

Lopsidedness.

Patterns.

Change points detection.

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