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A novel integrated hydro-economic model based on the societal water cycle framework: application to water stress evaluation in China

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ABSTRACT

Economic activities are significant drivers for water quantity and quality related stress and understanding the impacts of those activities on water resources is a critical issue. There are still many gaps in recognizing the causes, impacts and mitigation solutions on water quantity and quality stress. In this study, we develop a hydro-economic model to track the physical and virtual water quantity and quality metabolism in China and study the impacts of economic activities on water quantity and quality stress. We also propose pathways to reduce the water stress for each province in China and identify the top five sectors that contribute to water quantity and quality stress. The results show that majority of the provinces in China suffer from water quantity and quality stress simultaneously. There is, however, a large potential to reduce water quantity stress by 41-80% with reducing water losses and return flows. Return flows especially from the agriculture (14-93%) and households (5-60%) contribute the most to water quality stress in China. For some stressed provinces, a lot of virtual return flows are exported, which aggravate local water stress. Return flow is therefore a crucial factor that influences both water quantity and quality related stress and should be considered in policy design. Top five sectors that contribute to the mitigation of water quantity and quality stress are identified for each province, which could reduce quantity and quality stress by 22-75% and 23-76%, respectively.

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Introduction

Water shortage and water pollution have become serious global issues[1–6]. It is reported that two billion people live in high water stressed countries[7], and four billion people experience high water quantity stress at least one month per year globally[8]. It is projected that over half of the global population will suffer from water stress by 2050[9]. Water pollution and water shortage may also trigger disease outbreaks in developing counties because of lack of sufficient sanitation and water supply facilities[10–12]. Addressing water shortage and water pollution induced stress is hence recognized as two important targets in the United Nations Sustainable Development Goals (SDGs)[13].

In recent years, there is an increasing number of studies on water stress assessment, especially on water quantity stress. But most of the research care about the impact of water withdrawal on water resources at regional level[14–17]. Several studies also focus on water consumption rather than water withdrawal[18–20]. These studies focus on identifying which areas are hotspots with high water stress but seldom clarify why those regions are stressed and how to reduce water stress. Water withdrawal and consumption are two specific water use processes under the societal water cycle[21], which includes the processes of water withdrawal, water consumption, return flows returning to environment directly, return flow discharging to wastewater treatment plants, wastewater reclamation and virtual water import and export. Therefore, studying the impacts of water withdrawal and consumption on water stress fail to reflect the comprehensive impacts of human water use activities on water resources. Some research also studies the drivers for water stress to figure out the factors that induce water stress[22–26]. But because only water withdrawal is considered in their research, the proposed drivers are just related to water withdrawal or water supply[24,27,28].

Water pollution induced stress (also water quality stress) has been paid an increasing attention, but research on water quality stress is still limited[4,16,29,30]. Recent water quality stress related research mainly addresses that water pollution exacerbates water stress and it is essential to include water quality for water stress assessment. For instance, Ma et al. evaluates water stress from the perspective of surface water at grid level for a case study in China and identify the hotspots of water quantity and quality stress, addressing that water pollution matters for water stress[31]. van Vliet et al chose indicators of temperature for thermoelectric power plants, electric conductivity for irrigation, and ammonia for drinking water to study seasonal changes of water quality stress, and suggest that water temperature, salinity, nutrient pollutants should be considered for water demand in water quality[32]. However, we need more insights into causes, impacts and solutions to mitigate water quality stress[32]. On the other hand, it is also essential to explore the relations between quantity and quality stress to reveal strategies to reduce shortage and pollution at the same time. But current studies examine quantity and quality stress problems separately.

Based on above identified research gaps, we propose the following research question: what are impacts of economic activities on water resources under the framework of societal water cycle? Under this main research question, we propose three sub-questions: (1) How do water quantity and water pollutants metabolize under the framework of societal water cycle. (2) Where are hotspots for quantity and quality stress. (3) What are pathways to reduce quantity and quality stress for a given socio-economic region. To address these research questions, we develop a hydro-economic model to track physical and virtual water quantity and water pollutants metabolism across different economic sectors and across multiple economic regions. We apply water stress assessment to figure out hotspots for quantity and quality stress, and to identify significant economic sectors and water use destinations in each region. Finally, we propose a pathway to reduce water quantity and quality stress for each region based on metabolism results and scenario analysis. In this study, we use China as a representative case study to achieve these research questions.

Materials and Methods

Framework of metabolism analysis

In this study, to trace physical and virtual water quantity and water pollutant metabolism of economic sectors is the first step. Economic sectors include agriculture, industry, service, construction, service sector (detailed economic sectors see Table S1). We also consider metabolism of urban household, urban household, and environmental flow augmentation. Fig. 1(b) is the metabolism framework based on societal water cycle. We map physical water quantity flows based on the processes of societal water cycle, which includes water withdrawal, water conveyance loss, water consumption, return flow, and wastewater reclamation in Fig. 1 (a). Regarding virtual water quantity flows, we trace virtual quantity flow of conveyance loss (agricultural conveyance loss and water leakage from industry, service, and household), water consumption, return flow (wastewater direct discharge and wastewater returning to WWTPs). Traditionally, virtual water withdrawal is quantified, but we disaggregate it to virtual water loss, virtual water consumption and virtual return flow in this research. For water pollutant metabolism, we mainly focus on the process that pollutants discharge from return flows. We ignore water quality of water use and assume that water quality is satisfied with water use standard for each economic sector. Water pollutants are TN (Total Nitrogen), TP (Total Phosphorus), COD (Chemical Oxygen Demand) and NH_3-N (Ammonia Nitrogen). For each economic sector or water use object, we map metabolism of these four pollutants, excluding environmental flow augmentation. Imported and exported TN, TP, COD and NH_3-N in each economic sector are quantified as virtual water pollutant metabolism.

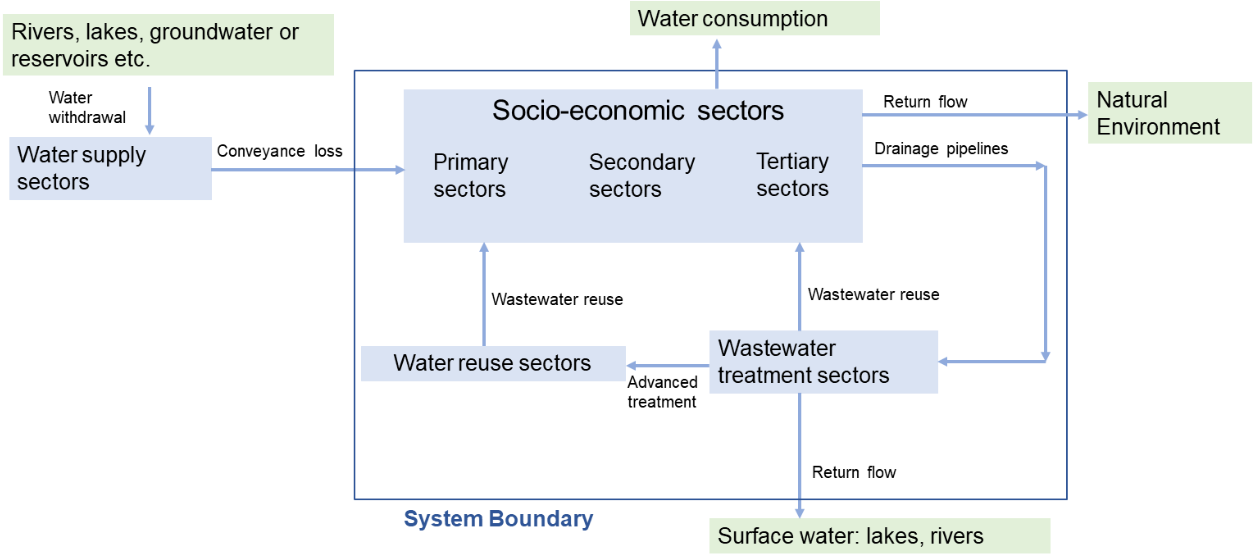

Fig. 1(a) Framework of societal water cycle

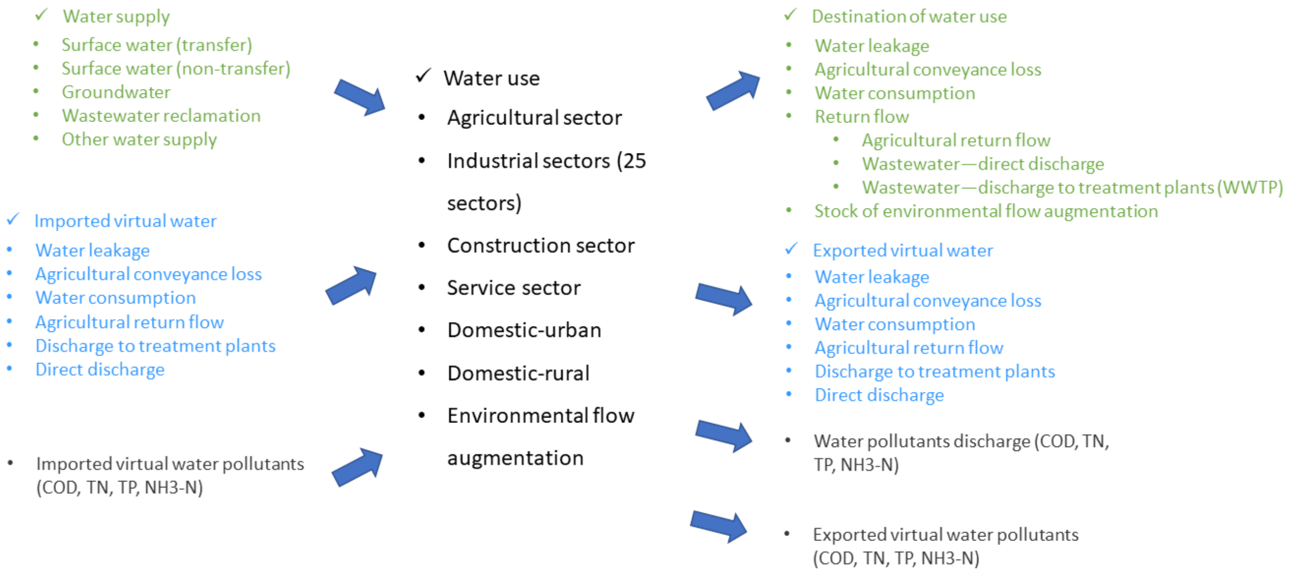

Fig. 1(b) Physical and virtual water quantity and water pollutant metabolism framework based on the societal water cycle

Physical water quantity metabolism

Agriculture

In this study, agriculture includes sectors of agriculture, forest, livestock, and fishing. We classify water quantity metabolism of agriculture into water quantity metabolism of irrigation and non-irrigation. Water quantity metabolism of non-irrigation denotes water quantity metabolism of forest, livestock, and fishing.

$$irrigation\ water\ loss_i = gross\ irrigation\ water\ use_i * (1 - effective\ utilization\ coefficient\ of\ irrigation_i)$$

$$irrigation\ water\ consumption_i = gross\ irrigation\ water\ use_i * irrigation\ water\ consumption\ rate_i$$

$$irrigation\ return\ flow_i = gross\ irrigation\ water\ use_i - irrigation\ water\ loss_i - irrigation\ water\ consumption_i$$

$$non\_irrigation\ return\ flow_i = gross\ non\_irrigation\ water\ use_i - non\_irrigation\ water\ consumption_i$$

where, $effective\ urilization\ coefficient\ of\ irrigation$ is measure by the ratio of water entering irrigation field to gross irrigation water use, which excludes water loss due to irrigation water conveyance. $irrigation\ water\ consumption\ rate$ is measured by the ratio of water consumption of irrigation field to gross irrigation water use. For forest, livestock, and fishing, we assumed that water loss of these sectors can be ignored. These two parameters are from China Water Resources Bulletin in 2017[33]

Industry

There are 26 industrial sectors for each region. The industry category is listed in Table S1. Industrial water use is derived from dataset of China Environmental Statistics Database (CESD) [34]. Firstly, we collect water use data for each firm from the CESD. Then, water use data for sector j in region i are aggregated.

$$water\ use_{ind_{i,j}} = \sum_{n=1}^{n=n} water\ use_{firm_{n,i,j}}$$

where, $water\ use_{ind_{i,j}}$ is water use that excludes water conveyance loss in sector j in region i. $water\ use_{firm_{n,i,j}}$ is water use excluding water loss of firm n of sector j in region i.

Gross water use that includes water conveyance loss for each sector j in region i is measured by:

$$gross\ water\ use_{ind_{i,j}} = water\ use_{ind_{i,j}} / water\ leakage\ rate_i$$

$gross\ water\ use_{ind_{i,j}}$ means gross water use including water leakage for industry j in region i. $water\ leakage\ rate_i$ is the water conveyance loss rate of water supply in each region.

Because the water use of industrial enterprises in CESD covers only 80-90% of total water use, rather than total industrial water use for all industrial firms. Thus, we use the following equations to adjust sectoral water use.

$$gross\ water\ use^*_{ind_{i,j}} = gross\ water\ use_{ind_{i,j}} * \frac{gross\ water\ use_{ind,WRB_i}}{\sum_{j=1}^{j=26} gross\ water\ use_{ind_{i,j}}}$$

$gross\ water\ use^*_{ind_{i,j}}$ is adjusted gross water use for industry j in region i. $gorss\ water\ use_{ind,WRB_j}$ is gross water use for industry from provincial water resources bulletin (WRB) in 2017. $\sum_{j=1}^{j=26} gross\ water\ use_{ind_{i,j}}$ is gross water use for industry which is obtained from CESD.

For each industry, CESD also contains industrial wastewater discharge$return\ flow_{ind_{i,j}}$, including wastewater returning to wastewater treatment plants $return\ flow\ entering\ WWTPs_{ind_{i,j}}$ and wastewater discharging to environment directly $return\ flow\ direct\ discharge_{ind_{i,j}}$.

$$water\ consumption_{ind_{i,j}} = water\ use_{ind_{i,j}} - return\ flow_{ind_{i,j}}$$

$$return\ flow_{ind_{i,j}} = return\ flow\ entering\ WWTPs_{ind_{i,j}} + return\ flow\ direct\ discharge_{ind_{i,j}}$$

$$Ratio_{RF,WWTP_{i,j}} = \frac{return\ flow\ entering\ WWTPs_{ind_{i,j}}}{return\ flow_{ind_{i,j}}}$$

$$Ratio_{RF,direct_{i,j}} = \frac{return\ flow\ direct\ discharge_{ind_{i,j}}}{return\ flow_{ind_{i,j}}}$$

We need to adjust the parameters of $water\ consumption_{ind_{i,j}}$, $return\ flow\ entering\ WWTPs_{ind_{i,j}}$ and $return\ flow\ direct\ discharge_{ind_{i,j}}$, because CESD does not contain all industrial enterprises, but containing firms that use 80-90% of total industrial water use and discharge 80-90% industrial water pollutants. We use the following equations to adjust industrial water consumption and return flow.

$$water\ consumption^*_{ind_{i,j}} = water\ consumption_{ind_{i,j}} * \frac{gross\ water\ use_{ind,WRB_i}}{\sum_{j=1}^{j=26} gross\ water\ use_{ind_{i,j}}}$$

$$return\ flow\ entering\ WWTPs^*_{ind_{i,j}} = (gross\ water\ use^*_{ind_{i,j}} - gross\ water\ use^*_{ind_{i,j}} * water\ leakage\ rate_i - water\ consumption^*_{ind_{i,j}}) * Ratio_{RF,WWTP_{i,j}}$$

$$\begin{aligned} return\ flow\ direct\ discharge^{*}_{ind_{i,j}} &= (gross\ water\ use^{*}_{ind_{i,j}} - gross\ water\ use^{*}_{ind_{i,j}} * water\ leakage\ rate_{i} \\ &- water\ consumption^{*}_{ind_{i,j}}) * Ratio_{RF,direct_{i,j}} \end{aligned}$$

Where, $water\ consumption^{*}_{ind_{i,j}}$, $return\ flow\ entering\ WWTPs^{*}_{ind_{i,j}}$ and $return\ flow\ direct\ discharge^{*}_{ind_{i,j}}$ are adjusted industrial water consumption and return flow of entering WWTPs and direct discharge.

Construction

$$gross\ water\ use_{con_i} = Floor\ areas\ of\ completed\ buildings_i * water\ use\ quota\ for\ constructure_i$$

$$return\ flow_{con_i} = gross\ water\ use_{con_i} - leakage_{con_i} - water\ consumption_{con_i}$$

$$leakage_{con_i} = gross\ water\ use_{con_i} * leakage\ rate_{urban_i}$$

$$water\ consumption_{con_i} = gross\ water\ use_{con_i} * water\ consumption\ rate_{con_i}$$

$$return\ flow\ entering\ WWTPs_{con_i} = return\ flow_{con_i} * wastewater\ treatment\ rate_{urban_i}$$

$$return\ flow\ direct\ discharge_{con_i} = return\ flow_{con_i} - return\ flow\ entering\ WWTPs_{con_i}$$

where, $gross\ water\ use_{con_i}$ indicate gross water use in the construction sector in province i. $water\ use\ quota\ for\ constructure_i$ refer to the standard or regulation of the amount of water use by per unit area, including water use for construction and building decoration. $leakage_{con_i}$ are water leakage in the construction sector because of the conveyance of water supply in province i. We apply water supply leakage rate $leakage\ rate_{urban_i}$ in urban regions in province i to estimate water leakage $leakage_{con_i}$. $leakage\ rate_{urban_i}$ is from Urban and Rural Construction Statistical Yearbook in 2017[35]. $water\ consumption\ rate_{con_i}$ is used to estimate $water\ consumption_{con_i}$. In this study, $water\ consumption\ rate_{con_i}$ is assumed to be 70%, if we cannot obtain the real water consumption of construction sector in province i. $wastewater\ treatment\ rate_{urban_i}$ is wastewater treatment rate[35] in urban area in province i. We assume that the same percentage of return flow from construction sector is treated by wastewater treatment plants.

Service

$$\begin{aligned} gross\ water\ use_{ser_i} &= gross\ water\ use_{dom_i} - gross\ water\ use_{con_i} - gross\ water\ use_{hou,urban_i} \\ &- gross\ water\ use_{hou,rural_i} \end{aligned}$$

$$return\ flow_{ser_i} = gross\ water\ use_{ser_i} - leakage_{ser_i} - water\ consumption_{ser_i}$$

$$leakage_{ser_i} = gross\ water\ use_{ser_i} * leakage\ rate_{urban_i}$$

$$water\ consumption_{ser_i} = gross\ water\ use_{ser_i} * water\ consumption\ rate_{ser_i}$$

$$return\ flow\ entering\ WWTPs_{ser_i} = return\ flow_{ser_i} * wastewater\ treatment\ rate_{urban_i}$$

$$return\ flow\ direct\ discharge_{ser_i} = return\ flow_{ser_i} - return\ flow\ entering\ WWTPs_{ser_i}$$

For some regions where gross service water use data is not available from provincial water resources bulletins, we use the first equation of this section to estimate $gross\ water\ use_{ser_i}$. Regarding $gross\ water\ use_{con_i}$,

$gross\ water\ use_{hou,urban_i}$ and $gross\ water\ use_{hou,rural_i}$, please refer to the section of physical water quantity metabolism of construction and household. $gross\ water\ use_{dom_i}$ refers to domestic gross water use, which includes gross water use of construction sector, service sector and household in each province. $gross\ water\ use_{dom}$ can be obtained from water resources bulletin of each region. $water\ consumption_{ser}$ is estimated by assuming $water\ consumption\ rate_{ser}$ is 30% if the water consumption of service sector is not available.

Household

$$gross\ water\ use_{hou,urban_i} = urban\ domestic\ water\ use\ per\ capita_i * urban\ popolation_i$$

$$gross\ water\ use_{hou,rural_i} = rural\ domestic\ water\ use\ per\ capita_i * rural\ popolation_i$$

$$return\ flow_{hou,urban_i} = gross\ water\ use_{hou,urban_i} - leakage_{hou,urban_i} - water\ consumption_{hou,urban_i}$$

$$return\ flow_{hou,rural_i} = gross\ water\ use_{hou,rural_i} - leakage_{hou,rural_i} - water\ consumption_{hou,rural_i}$$

$$leakage_{hou,urban_i} = \ gross\ water\ use_{hou,urban_i} * water\ supply\ penetration\ rate_{urban_i} * leakage\ rate_{urban_i}$$

$$leakage_{hou,rural_i} = \ gross\ water\ use_{hou,rural_i} * water\ supply\ penetration\ rate_{rural_i} * leakage\ rate_{rural_i}$$

$$return\ flow\ entering\ WWTPs_{hou,urban_i} = wastewater\ treatment\ rate_{hou,urban_i} * return\ flow_{hou,urban_i}$$

$$return\ flow\ entering\ WWTPs_{hou,rural_i} = wastewater\ treatment\ rate_{hou,rural_{i_i}} * return\ flow_{hou,rural_i}$$

$$return\ flow\ direct\ discharge_{hou,urban_i} = \ return\ flow_{hou,urban_i} - return\ flow\ entering\ WWTPs_{hou,urban_i}$$

$$return\ flow\ direct\ discharge_{hou,rural_i} = return\ flow_{hou,rural_i} - return\ flow\ entering\ WWTPs_{hou,rural_i}$$

where, $gross\ water\ use_{hou,urban_i}$and $gross\ water\ use_{hou,rural_i}$ refer to household water use in urban and rural regions in province i, including the water leakage because of the conveyance of water supply pipelines. $leakage_{hou,urban_i}$ and $leakage_{hou,rural_i}$ are water leakage because of the conveyance of water supply in urban and rural areas in province i[35]. $water\ supply\ penetration\ rate_{urban_i}$ and $water\ supply\ penetration\ rate_{rural_i}$ are the ratio of the water supply access population to the total population in urban and rural areas and are used to reflect the water supply penetration and convenience within the water supply coverage areas[35]. For regions where household water consumption data is not available from provincial water resources bulletins, we quantify household water consumption by multiplying urban or rural household gross water use by household water consumption rate, with urban and rural household water consumption rates of 30% and 85%. We also quantity return flow discharging to wastewater treatment plants (WWTPs) ($return\ flow\ entering\ WWTPs_{hou,urban_i}$ and $return\ flow\ entering\ WWTPs_{hou,rural_i}$) and return flow discharging directly to the environment ($return\ flow\ direct\ discharge_{hou,urban_i}$ and $return\ flow\ direct\ discharge_{hou,rural_i}$).

Environmental flow augmentation

$$\begin{aligned} &water\ consumption\ of\ environmental\ flow\ augmentation_i \\ &\qquad = gross\ water\ use\ of\ environmental\ flow\ augmentation_i \\ &\qquad * water\ consumption\ rate\ of\ environmental\ flow\ augmentation_i \end{aligned}$$

$$\begin{aligned} &water\ stock\ of\ environmental\ flow\ augmentation_i \\ &\qquad = \ gross\ water\ use\ of\ environmental\ flow\ augmentation_i \\ &\qquad - water\ consumption\ of\ environmental\ flow\ augmentation_i \end{aligned}$$

Environmental flow augmentation means flow augmentation for lakes, rivers, wetlands, and urban environment water use, which are supplied by man-made measures, rather than precipitation and runoff. $water\ consumption\ of\ environmental\ flow\ augmentation$ means evaporated water of environmental flow augmentation, $water\ consumption\ rate\ of\ environmental\ flow\ augmentation$ is obtained from water resources bulletin in each province. $water\ stock\ of\ environmental\ flow\ augmentation$ refers to the amount of environmental flow augmentation stored in surface water. i represent a province in China.

Virtual water quantity metabolism

We apply an Environmental Extended Multi-Regional Input-Output (EEMRIO) model to trace virtual water quantity (i.e., virtual water loss, virtual water consumption, virtual return flow including virtual returning flow to WWTP and virtual return flow discharging to environment) across each sector for each region in China. The MRIO table in 2017 is from CEADs (China Emission Accounts and Datasets)[36]. It contains 42 sectors, including 1 agricultural sector, 26 industrial sectors, 1 construction sector and 14 service sectors. But we merge 14 service sectors in MRIO table to 1 sector to match with water quantity data. Table S2 is the framework of MRIO table in China in 2017.

The technological coefficient submatrix $\boldsymbol{A^{rs}} = (a_{ij}^{rs})$ is given by $a_{ij}^{rs} = z_{ij}^{rs}/x_j^s$, in which z_{ij}^{rs} is the monetary flow from industry i in region r to industry j in region s; x_j^s is the total output of industry j in region s. f_j^{rs} reveals the final demand of region s for goods produced in region r. It is important to note that here the final demand $f_j^{rs}$of region s is the sum of household consumption, non-profit organizations serving households consumption, government expenditure, capital formation and changes in inventories. Vector $\boldsymbol{x}$ represent total output of all economic industries (x_i) in each region. Using matrix notation and dropping the subscripts, we have

$$\boldsymbol{A}=\begin{bmatrix} \boldsymbol{A^{11}} & \boldsymbol{A^{12}} & \cdots & \boldsymbol{A^{1n}} \\ \boldsymbol{A^{21}} & \boldsymbol{A^{22}} & & \boldsymbol{A^{2n}} \\ \vdots & & \ddots & \vdots \\ \boldsymbol{A^{n1}} & \boldsymbol{A^{n2}} & \cdots & \boldsymbol{A^{nn}} \end{bmatrix},$$

$$\boldsymbol{F}=\begin{bmatrix} \boldsymbol{F^{11}} & \boldsymbol{F^{12}} & \cdots & \boldsymbol{F^{1n}} \\ \boldsymbol{F^{21}} & \boldsymbol{F^{22}} & & \boldsymbol{F^{2n}} \\ \vdots & & \ddots & \vdots \\ \boldsymbol{F^{n1}} & \boldsymbol{F^{n1}} & \cdots & \boldsymbol{F^{nn}} \end{bmatrix},$$

$$\boldsymbol{x}=\begin{bmatrix} \boldsymbol{x^{1}} \\ \boldsymbol{x^{2}} \\ \vdots \\ \boldsymbol{x^{n}} \end{bmatrix}$$

For the multi-regional input-output table in this study, there are 31 regions, and for each region, there are 29 sectors. Therefore, $\boldsymbol{A}$ is a 899*899 matrix, $\boldsymbol{A^{rs}}$ is a 29*29 matrix, $\boldsymbol{F}$is a 899*145 matrix, $\boldsymbol{F^{rs}}$ is a 29*5 matrix, and $\boldsymbol{x^i}$is a 29*1 vector.

We denote $\boldsymbol{f^r}$ as a column vector of total final demand of region $\boldsymbol{r}$. The basic equation of input-output table (Table S2) in matrix form can be shown as the following equation.

$$\begin{bmatrix} \boldsymbol{x^{1}} \\ \boldsymbol{x^{2}} \\ \vdots \\ \boldsymbol{x^{n}} \end{bmatrix} = \begin{bmatrix} \boldsymbol{A^{11}} & \boldsymbol{A^{12}} & \cdots & \boldsymbol{A^{1n}} \\ \boldsymbol{A^{21}} & \boldsymbol{A^{22}} & & \boldsymbol{A^{2n}} \\ \vdots & & \ddots & \vdots \\ \boldsymbol{A^{n1}} & \boldsymbol{A^{n2}} & \cdots & \boldsymbol{A^{nn}} \end{bmatrix} \begin{bmatrix} \boldsymbol{x^{1}} \\ \boldsymbol{x^{2}} \\ \vdots \\ \boldsymbol{x^{n}} \end{bmatrix} + \begin{bmatrix} \boldsymbol{f^{1}} \\ \boldsymbol{f^{2}} \\ \vdots \\ \boldsymbol{f^{n}} \end{bmatrix}$$

Here, we define Leontief inverse matrix as $\boldsymbol{L} = (\boldsymbol{I} - \boldsymbol{A})^{-1}$, so the framework of input-output table can also be written as:

$$\begin{bmatrix} \boldsymbol{x}^1 \\ \boldsymbol{x}^2 \\ \vdots \\ \boldsymbol{x}^n \end{bmatrix} = \begin{bmatrix} \boldsymbol{L}^{11} & \boldsymbol{L}^{12} & \cdots & \boldsymbol{L}^{1n} \\ \boldsymbol{L}^{21} & \boldsymbol{L}^{22} & & \boldsymbol{L}^{2n} \\ \vdots & & \ddots & \vdots \\ \boldsymbol{L}^{n1} & \boldsymbol{L}^{n2} & \cdots & \boldsymbol{L}^{nn} \end{bmatrix} \begin{bmatrix} \boldsymbol{f}^1 \\ \boldsymbol{f}^2 \\ \vdots \\ \boldsymbol{f}^n \end{bmatrix}$$

We use column vector of $\boldsymbol{E}^r$ represent coefficient of water loss, water consumption, return flow to WWTP and return flow discharging to environment of all industries, which are the ratio of water quantity to value added of each industry. We use matrix $\boldsymbol{V}^r$ represents virtual water loss, virtual water consumption, virtual return flow to WWTP and virtual return flow discharging to environment.

Therefore, $\boldsymbol{V}^r$ can be obtained by:

$$\boldsymbol{V}^r = diag\ ([\boldsymbol{E}^1 \quad \boldsymbol{E}^2 \quad \cdots \quad \boldsymbol{E}^{31}]) \begin{bmatrix} \boldsymbol{L}^{11} & \boldsymbol{L}^{12} & \cdots & \boldsymbol{L}^{1\,31} \\ \boldsymbol{L}^{21} & \boldsymbol{L}^{22} & & \boldsymbol{L}^{2\,31} \\ \vdots & & \ddots & \vdots \\ \boldsymbol{L}^{31\,1} & \boldsymbol{L}^{31\,2} & \cdots & \boldsymbol{L}^{31\,31} \end{bmatrix} \begin{bmatrix} \boldsymbol{f}^1 \\ \boldsymbol{f}^2 \\ \vdots \\ \boldsymbol{f}^{31} \end{bmatrix}$$

Finally, based on matrix $\boldsymbol{V}^r$ of different water quantity, we take appropriate sums to obtain virtual import and export of water loss, water consumption, return flow to WWTP and return flow discharging to environment for each sector and each region.

Physical water pollutants metabolism

Agriculture

Agricultural pollutants are mainly generated by farming and livestock. Total nitrogen and total phosphorus are two most important pollutants for farming, while livestock generates COD, NH_3-N, TN, and TP. In this study, we consider physical water pollutants metabolism of TN and TP generated by farming, and COD, NH_3-N, TN, and TP discharged by livestock (i.e., pig, cattle, sheep, and poultry).

For farming, loads of TN and TP that discharge to water bodies are calculated by:

$$Pollutant\ load_{farm_{TN,i}} = \left(F_{TN,i} + F_{COM,i} * 40\%\right) * a_{TN,i}$$

$$Pollutant\ load_{farm_{TP,i}} = \left(F_{TP,i} + F_{COM,i} * 32\%\right) * a_{TP,i}$$

Where, $Pollutant\ load_{farm_{TN,i}}$ and $Pollutant\ load_{farm_{TP,i}}$ are TN and TP loads discharged by farming in province i. $F_{TN,i}$ and $F_{TP,i}$ are amount of nitrogen and phosphate fertilizers in each region. $F_{COM,i}$ is the amount of compound fertilizer. 40% and 32% are percentages of TN and TP in compound fertilizer respectively. $a_{COD,i}$ and $a_{TP,i}$ are leaching-runoff fraction of TN and TP.

We use the following methods to quantify livestock COD, TN, and TP discharge to water bodies.

$$Pollutant\ load_{liv_{COD,i}} = \sum_j N_j * E_{liv_{COD,i,j}} * T_j * [R_{liv} * a_{COD,i} + (1 - R_{liv}) * b_{COD,i}]$$

$$Pollutant\ load_{liv_{TP,i}} = \sum_j N_j * E_{liv_{TP,i,j}} * T_j * [R_{liv} * a_{TP,i} + (1 - R_{liv}) * b_{TP,i}]$$

$$Pollutant\ load_{liv_{TN,i}} = \sum_j N_j * E_{liv_{TN,i,j}} * T_j * (1 - \beta_{TN}) * [R_{liv} * a_{TN,i} + (1 - R_{liv}) * b_{TN,i}]$$

$Pollutant\ load_{liv_{COD,i}}$, $Pollutant\ load_{liv_{TP,i}}$ and $Pollutant\ load_{liv_{TN,i}}$ are COD, TP and TN loads discharged by livestock in province i. N_j is the number of livestock j. $E_{liv_{COD,i,j}}$, $E_{liv_{TP,i,j}}$ and $E_{liv_{TN,i,j}}$ are COD, TP, and TN mass in per unit of manure generated by livestock j in province i. T_j are the feeding days per year of livestock j. Feeding cycle for pig, cattle, sheep, and poultry are 199, 365, 365 and 129 days. R_{liv} is recycle rate of livestock manure to farmlands, with the value of 69%[37]. $a_{COD,i}$, $a_{TP,i}$ and $a_{TN,i}$ are leaching-runoff fraction of COD, TN, and TP in province i, under the condition of being without recycling of manure [37]. $b_{COD,i}$, $b_{TP,i}$ and $b_{TN,i}$ are leaching-runoff fraction of COD, TN, and TP in the manure that are recycled [37]. β_{TN} is proportion of TN in manure that turns to gaseous NH_3-N and N_2O-N. β_{TN} is 45.5%, with 45% and 0.5% of TN emitting NH_3-N and N_2O-N respectively [38]. Numbers of four livestock are collected from China Rural Statistical Yearbook in 2017[39]. $a_{COD,i,j}$, $a_{TP,i,j}$, $a_{TN,j}$, $b_{COD,i,j}$, $b_{TP,i,j}$ and $b_{TN,j}$ are shown in Table S3. Parameters of $E_{liv_{COD,i,j}}$, $E_{liv_{TP,i,j}}$, $E_{liv_{TN,i,j}}$ are listed in Table S4.

The amount of NH_3-N that loss to water body is evaluated by:

$$Pollutant\ load_{liv_{NH3-N,i}} = \sum_j Pollutant\ load_{liv_{TN,i,j}} * \varphi_j$$

Where, φ_j is the ratio of the TN to NH_3-N of each livestock and poultry manure that go into the water body. The parameter of φ_j is derived from the report of National Large-Scale Livestock and Poultry Breeding Industry Pollution Investigation Report[40]. φ_j for cattle, pig, sheep, and poultry are 40.3%, 37.8%, 19.3% and 22.3%.

Industry

Discharged TN, TP, COD and NH_3-N from 26 industrial sectors are obtained from dataset of China Environmental Statistics Database (CESD)[34]. This dataset contains these four pollutants at firm level. We firstly aggregate firm level pollutants to sectoral level:

$$Pollutant\ load_{ind\ TN_{i,j}} = \sum_{n=1}^{n=n} pollutant\ load_{firm\ TN\ n,i,j}$$

$$Pollutant\ load_{ind\ TP_{i,j}} = \sum_{n=1}^{n=n} pollutant\ load_{firm\ TP\ n,i,j}$$

$$Pollutant\ load_{ind\ COD_{i,j}} = \sum_{n=1}^{n=n} pollutant\ load_{firm\ COD\ n,i,j}$$

$$Pollutant\ load_{ind\ NH3-N_{i,j}} = \sum_{n=1}^{n=n} pollutant\ load_{firm\ NH3-N\ n,i,j}$$

Where, $Pollutant\ load_{ind\ TN_{i,j}}$, $Pollutant\ load_{ind\ TP_{i,j}}$, $Pollutant\ load_{ind\ COD_{i,j}}$ and $Pollutant\ load_{ind\ NH3-N_{i,j}}$ indicate TN, TP, COD and NH3-N pollutant load of industry j in region i. $pollutant\ load_{firm\ TN\ n,i,j}$, $pollutant\ load_{firm\ TP\ n,i,j}$, $pollutant\ load_{firm\ COD\ n,i,j}$ and $pollutant\ load_{firm\ NH3-N\ n,i,j}$ mean TN, TP, COD and NH_3-N pollutant load of firm n in industry j in region i.

However, these water pollutants just cover 80-90% of pollutants from industry. Therefore, we adjust four pollutants data at industrial level for each region by using RAS method. We collect industrial TN, TP, NH_3-N and COD pollutants at national level and provincial TN, TP, NH_3-N and COD from industries from Annual Statistic Report on Environment in China[34] in 2017 to adjust $Pollutant\ load_{ind\ TN_{i,j}}$, $Pollutant\ load_{ind\ TP_{i,j}}$, $Pollutant\ load_{ind\ COD_{i,j}}$ and $Pollutant\ load_{ind\ NH3-N_{i,j}}$ through RAS method. For more information on RAS method, please refer to Miller and Blair[41].

Construction

Discharged TN, TP, COD and NH_3-N from construction sector are calculated as follows:

$$Pollutant\ load_{con_{TN,i}} = RF_{con,i}/\left(RF_{con,i} + RF_{ser,i} + RF_{urban,hh,i}\right) * Pollutant\ load_{urban,domestic_{TN,i}}$$

$$Pollutant\ load_{urban,domestic_{TN,i}} = E_{urban,domestic_{TN,i}} * P_{urban_i}$$

$$Pollutant\ load_{con_{TP,i}} = RF_{con,i}/\left(RF_{con,i} + RF_{ser,i} + RF_{urban,hh,i}\right) * Pollutant\ load_{urban,domestic_{TP,i}}$$

$$Pollutant\ load_{urban,domestic_{TP,i}} = E_{urban,domestic_{TP,i}} * P_{urban_i}$$

$$Pollutant\ load_{con_{COD,i}} = RF_{con,i}/\left(RF_{con,i} + RF_{ser,i} + RF_{urban,hh,i}\right) * Pollutant\ load_{urban,domestic_{COD,i}}$$

$$Pollutant\ load_{urban,domestic_{COD,i}} = E_{urban,domestic_{COD,i}} * P_{urban_i}$$

$$Pollutant\ load_{con_{NH3-N,i}} = RF_{con,i}/\left(RF_{con,i} + RF_{ser,i} + RF_{urban,hh,i}\right) * Pollutant\ load_{urban,domestic_{NH3-N,i}}$$

$$Pollutant\ load_{urban,domestic_{NH3-N,i}} = E_{urban,domestic_{NH3-N,i}} * P_{urban_i}$$

$Pollutant\ load_{con_{TN,i}}$, $Pollutant\ load_{con_{TP,i}}$, $Pollutant\ load_{con_{COD,i}}$ and $Pollutant\ load_{con_{NH3-N,i}}$ are pollutant loads of TN, TP, COD and NH_3-N generated from construction sector in region i. $RF_{con,i}$, $RF_{ser,i}$ and $RF_{urban,hh,i}$ are return flows from construction sector, service sector and urban household. $Pollutant\ load_{urban,domestic_{TN,i}}$, $Pollutant\ load_{urban,domestic_{TP,i}}$, $Pollutant\ load_{urban,domestic_{COD,i}}$ and $Pollutant\ load_{urban,domestic_{NH3-N,i}}$ are TN, TP, COD and NH_3-N loads from domestic water use related sectors[34]. Domestic water uses related sectors include service sector, construction sector and urban household.

Service

Pollutant loads of TN, TP, COD, NH_3-N from service sector are calculated by:

$$Pollutant\ load_{ser_{TN,i}} = RF_{ser,i}/\left(RF_{con,i} + RF_{ser,i} + RF_{urban,hh,i}\right) * Pollutant\ load_{urban,domestic_{TN,i}}$$

$$Pollutant\ load_{ser_{TP,i}} = RF_{ser,i}/\left(RF_{con,i} + RF_{ser,i} + RF_{urban,hh,i}\right) * Pollutant\ load_{urban,domestic_{TP,i}}$$

$$Pollutant\ load_{ser_{COD,i}} = RF_{ser,i}/\left(RF_{con,i} + RF_{ser,i} + RF_{urban,hh,i}\right) * Pollutant\ load_{urban,domestic_{COD,i}}$$

$$Pollutant\ load_{ser_{NH3-N,i}} = RF_{ser,i}/\left(RF_{con,i} + RF_{ser,i} + RF_{urban,hh,i}\right) * Pollutant\ load_{urban,domestic_{NH3-N,i}}$$

$Pollutant\ load_{ser_{TN,i}}$, $Pollutant\ load_{ser_{TP,i}}$, $Pollutant\ load_{ser_{COD,i}}$ and $Pollutant\ load_{ser_{NH3-N,i}}$ denote TN, TP, COD, NH_3-N loads from service sector. The meanings of parameters of $RF_{con,i}$, $RF_{ser,i}$, $RF_{urban,hh,i}$, $Pollutant\ load_{urban,domestic_{TP,i}}$, $Pollutant\ load_{urban,domestic_{COD,i}}$ and $Pollutant\ load_{urban,domestic_{NH3-N,i}}$ refer to the sub-section of Construction in the chapter of Physical water pollutants metabolism.

Household

Pollutants that discharged by urban household are measured by:

$$Pollutant\ load_{urban,hh_{TN,i}} = RF_{urban,hh,i}/\left(RF_{con,i} + RF_{ser,i} + RF_{urban,hh,i}\right) * Pollutant\ load_{urban,domestic_{TN,i}}$$

$$Pollutant\ load_{urban,hh_{TP,i}} = RF_{urban,hh,i}/\left(RF_{con,i} + RF_{ser,i} + RF_{urban,hh,i}\right) * Pollutant\ load_{urban,domestic_{TP,i}}$$

$$Pollutant\ load_{urban,hh_{COD,i}} = RF_{urban,hh,i}/\left(RF_{con,i} + RF_{ser,i} + RF_{urban,hh,i}\right) * Pollutant\ load_{urban,domestic_{COD,i}}$$

$$Pollutant\ load_{urban,hh_{NH3-N,i}} = RF_{urban,hh,i}/\left(RF_{con,i} + RF_{ser,i} + RF_{urban,hh,i}\right) * Pollutant\ load_{urban,domestic_{NH3-N,i}}$$

$Pollutant\ load_{urban,hh_{pollutants,i}}$ means pollutants loads of TN, TP, COD and NH_3-N from urban household in region i. The meanings of parameters of $RF_{con,i}$, $RF_{ser,i}$, $RF_{urban,hh,i}$, $Pollutant\ load_{urban,domestic_{TP,i}}$, $Pollutant\ load_{urban,domestic_{COD,i}}$ and $Pollutant\ load_{urban,domestic_{NH3-N,i}}$ refer to the sub-section of Construction in the chapter of Physical water pollutants metabolism.

Pollutants that discharged by rural household are calculated by

$$Pollutant\ load_{rural,hh_{TN,i}} = E_{rural,hh_{TN,i}} * P_{rural_i}$$

$$Pollutant\ load_{rural,hh_{TP,i}} = E_{rural,hh_{TP,i}} * P_{rural_i}$$

$$Pollutant\ load_{rural,hh_{COD,i}} = E_{rural,hh_{COD,i}} * P_{rural_i}$$

$$Pollutant\ load_{rural,hh_{NH3-N,i}} = E_{rural,hh_{NH3-N,i}} * P_{rural_i}$$

$Pollutant\ load_{rural,hh_{TN,i}}$, $Pollutant\ load_{rural,hh_{TP,i}}$, $Pollutant\ load_{rural,hh_{COD,i}}$, $Pollutant\ load_{rural,hh_{NH3-N,i}}$ are TN, TP, COD and NH_3-N loads from rural household. $E_{rural,hh_{TN,i}}$, $E_{rural,hh_{TP,i}}$, $E_{rural,hh_{COD,i}}$ and $E_{rural,hh_{NH3-N,i}}$ are discharged TN, TP, COD and NH_3-N per capita in rural area in region i, and they are obtained from Annual Statistic Report on Environment in China in 2020[42]. P_{rural_i} refers to rural population in each region.

Virtual water pollutants metabolism

The method of tracing virtual water pollutants flow is similar to that of virtual water quantity metabolism. The mainly difference is the environmental coefficient indicator. For virtual water pollutant metabolism, the environmental coefficient vector $\boldsymbol{E}^r$ represent coefficient of TN, TP, COD and NH_3-N, which are the ratio of pollutant mass of TN, TP, COD and NH_3-N to value added of each industry.

Water stress assessment

Water stress assessment in this study includes three parts: water quantity stress, water quality stress and total water stress. Water quantity stress is used to measure if a region suffers from water shortage or not. Water quality stress reflects water pollution degree induced by discharged polluted wastewater or return flows from agriculture, industry, service, and households. By evaluating water quantity and quality stress level, we can figure out the regions where suffer from water shortage and water pollution.

Water quantity stress

Water quantity stress is defined as the ratio of annual water withdrawal to water availability minus environmental flow requirement[43]

$$Water\ stress_{quantity_i} = \frac{WW_i}{WA_i - EFR_i}$$

$$WW_i = WU_i - WS_{uncon_i}$$

Where, $Water\ quantity\ stress_i$ is water quantity stress level. WW_i is annual water withdrawal in each region. Water withdrawal means withdrawn surface water and groundwater. Water withdrawal is calculated by total water use WU_i including water loss minus unconventional water supplies WS_{uncon_i}, which are rainwater utilization, wastewater reclamation, desalinated sea water and treated dewatering from mining sectors. WA_i is water availability from Water Resources Bulletin from each province in 2017. EFR_i is provincial level environmental flow requirement obtained from a newly published report by FAO and UN water[44].

Water quality stress

$$Water\ stress_{quality_i} = \frac{GWF_{total_i}}{WA_i - EFR_i}$$

$$GWF_{total_i} = GWF_{agr_i} + GWF_{ind_i} + GWF_{con_i} + GWF_{ser_i} + GWF_{urban,hh_i} + GWF_{rural,hh_i}$$

$Water\ stress_{quality_i}$ is water pollution induced stress in region i. GWF_{total_i} is regional total grey water footprint. GWF_{agr_i}, GWF_{ind_i}, GWF_{con_i}, GWF_{ser_i}, GWF_{urban,hh_i} and GWF_{rural,hh_i} are grey water footprint from agriculture, industry, construction, service, urban household and rural household.

$$GWF_{agr_i} = GWF_{farm_i} + GWF_{liv_i}$$

$$GWF_{farm_i} = \max\,(GWF_{farm,TN_i}, GWF_{farm,TP_i})$$

$$GWF_{liv_i} = \max\,(GWF_{liv,TN_i}, GWF_{liv,TP_i}, GWF_{liv,COD_i}, GWF_{liv,NH3-N_i})$$

$$GWF_{farm\ or\ liv_{i,j}} = \frac{Pollutant\ load_{i,j}}{C_{max\,j}}$$

GWF_{farm_i} and GWF_{liv_i} are grey water footprint from farming and livestock in region i. GWF_{farm,TN_i} and GWF_{farm,TP_i} are TN and TP grey water footprint of farming. GWF_{liv,TN_i}, GWF_{liv,TP_i}, GWF_{liv,COD_i} and $GWF_{liv,NH3-N_i}$ are TN, TP, COD, NH_3-N grey water footprint of livestock. $GWF_{farm\ or\ liv_{i,j}}$ is grey water footprint of pollutant j of farming and livestock in province i. $Pollutant\ load_{i,j}$ is pollutant load of pollutant j in region i. $C_{max\,j}$ is the maximum acceptable concentration of the ambient water quality of pollutant j. In this study, $C_{max\,j}$ is the third grade of China's Environmental Quality Standards for Surface Water[45]. The third grade indicates the water is suitable for fishing, swimming, and aquaculture. $C_{max_{TN}}$, $C_{max_{TP}}$, $C_{max_{COD}}$ and $C_{max_{NH3-N}}$ are 1, 0.2, 20 and 1 mg/L.

$$GWF_{ind_i} = \sum_{k=1}^{k=26} GWF_{ind_{k,i}}$$

$$GWF_{ind_{k,i}} = \max\,(GWF_{ind,TN_{k,i}}, GWF_{ind,TP_{k,i}}, GWF_{ind,COD_{k,i}}, GWF_{ind,NH3-N_{k,i}})$$

$GWF_{ind_{k,i,j}} = \frac{Load_{ind_{k,i,j}}}{C_{max\,j}} - RF_{ind_{k,i}}$ (If $\frac{Load_{ind_{k,i,j}}}{C_{max\,j}} - RF_{ind_{k,i}}$ is less than 0, $GWF_{ind_{k,i,j}}$ is 0, otherwise, $GWF_{ind_{k,i,j}} = \frac{Load_{ind_{k,i,j}}}{C_{max\,j}} - RF_{ind_{k,i}}$)

GWF_{ind_i} is grey water footprint of industry sector in region i. $GWF_{ind_{k,i}}$ is grey water footprint of industry k in in region i. $GWF_{ind_{k,i,j}}$ is grey water footprint of pollutant j in industry k in province i. $RF_{ind_{k,i}}$ is return flow of industry k in province i.

$GWF_{m_i} = max\,(GWF_{m_{i,j}})$

$GWF_{m_{i,j}} = \frac{Load_{m_{i,j}}}{C_{max\,j}} - RF_{m_i}$ (If $\frac{Load_{m_{i,j}}}{C_{max\,j}} - RF_{m_{i,j}}$ is less than 0, $GWF_{m_{i,j}}$ is 0, otherwise, $GWF_{m_{i,j}} = \frac{Load_{m_{i,j}}}{C_{max\,j}} - RF_{m_i}$)

$GWF_{m_{i,j}}$ is grey water footprint of pollutant j in sector m. m represents construction, service, urban and rural household. RF_{m_i} is return flow from sector m in region i.

Total water stress

Total water stress in this study is defined as the sum of water quantity and quality stress[15].

$Water\ stress_{total_i} = Water\ stress_{quantity_i} + Water\ stress_{quality_i}$

Scenario setting

We design scenarios to identify potential pathways to reduce water quantity and quality stress simultaneously. There are two assumptions for scenarios: (1) For each economic sector, we assume that value added is not changed (2) To produce the same value added, we assume water consumption remains the same. We design four scenarios to explore pathways to reduce water stress by adjusting parameters of water conveyance loss rate and the ratio of water consumption to sum of water consumption and return flow. The core for scenario setting is improving water use efficiency by reducing water conveyance loss and return flow. The scenario setting for this research is shown in Table 1. The parameter of the ratio of water consumption to sum of water consumption and return flow is important for scenario design. Therefore, we summarize the mean and maximum value of this parameter for scenario design in Table 2.

To reduce water loss and return flow is the way to reduce quantity stress. We set strict water loss rate and the ratio of water consumption to sum of water consumption and return flow for scenario analysis. For irrigation water loss rate, we design it as 20%, since this value is predicted to 25% in Beijing in 2025[46], which is the lowest among all regions. Therefore, we set a stricter irrigation water loss rate of 20% based on 25%. For water leakage rate, we set is as 8%, because it is expected to drop to 8% in 2025[47]. For return flow reduction, we use the designed ratio of water consumption to sum of water consumption and return flow to constrain (Table 1 and Table 2). Therefore, water loss, return flow and gross water use for different scenarios are measure by:

$$return\ flow_{sce_{i,j,n}} = \frac{water\ consumption_{i,j}}{ratio_{sce_{i,j,n}}}$$

$$water\ loss_{sce_{i,j,n}} = \frac{water\ loss\ rate_{\ sce_{i,j,n}} * \ (return\ flow_{sce_{i,j,n}} + water\ consumption_{i,j})}{1 - water\ loss\ rate_{\ sce_{i,j,n}}}$$

$$gross\ water\ use_{sce_{i,j,n}} = water\ consumption_{i,j} + return\ flow_{sce_{i,j,n}} + water\ loss_{sce_{i,j,n}}$$

$water\ consumption_{i,j}$ is real water consumption for industry j in region i. $ratio_{sce_{i,j,n}}$, $water\ loss_{sce_{i,j,n}}$ and $return\ flow_{sce_{i,j,n}}$ are ratio of water consumption to sum of water consumption, water loss rate and return flow for industry j in region i for scenario n.

Under different scenarios, water quantity stress is measured by

$$Water\ stress_{quantity,sce_{i,n}} = \frac{WW_{sce_{i,n}}}{WA_i - EFR_i}$$

$$WW_{sce_{i,n}} = \sum_j gross\ water\ use_{sce_{i,j,n}} - WS_{uncon_i}$$

$Water\ stress_{quantity,sce_{i,n}}$ is quantity stress of scenario n in region i. $\sum_j gross\ water\ use_{sce_{i,j,n}}$ is the sum of gross water use for all sectors in region i for different scenarios.

Then, comparing with water quantity stress of baseline in 2017, we calculate the reduction percentage of water quantity stress under different scenarios

$$Quantity\ stress_{reduce,sce_{i,n}} = \frac{Water\ stress_{quantity_i} - Water\ stress_{quantity,sce_{i,n}}}{Water\ stress_{quantity_i}}$$

$Water\ stress_{quantity_i}$ is the water quantity stress baseline in region i in 2017. $Water\ stress_{quantity,sce_{i,n}}$ is water quantity stress of scenario n for each region. $Quantity\ stress_{reduce,sce_{i,n}}$is quantity stress reduction percentage for different scenarios.

Water pollutant loads and grey water footprint of different sectors also change with the reduction of return flow. To estimate water quality stress of four scenarios, we have following assumptions: (1) for farming, the amount of return flows affects leaching-runoff fractions of TN, TP, COD and NH_3-N. Return flows and leaching-runoff fractions of different pollutants vary linearly. (2) for point-source pollution sources, we assume concentration of discharged pollutants remains the same. This assumption is reasonable because of advanced wastewater purification technologies and requirements for meeting discharge standard.

Baes on the above assumptions, grey water footprints of different industries are changed:

$$RF\ change\ ratio_{sce_{i,j,n}} = \frac{return\ flow_{sce_{i,j,n}}}{return\ flow_{i,j}}$$

$$GWF_{total_{i,n}} = \sum_j RF\ change\ ratio_{sce_{i,j,n}} * GWF_{i,j}$$

$return\ flow_{sce_{i,j,n}}$ is return flow for industry j in region i under different scenarios. $return\ flow_{i,j}$ is baseline return flow. $RF\ change\ ratio_{sce_{i,j,n}}$ is the ratio of return flow for industry j in region i in scenario n to baseline return flow. $GWF_{total_{i,n}}$is regional total grey water footprint in scenario n. $GWF_{i,j}$ is baseline grey water footprint for industry j in each region. Then, we apply water quality stress assessment to evaluate quality stress in different scenarios. Furthermore, we use the following equation to measure the reduction percentage of quality stress under different scenarios

$$Quality\ stress_{reduce,sce_{i,n}} = \frac{Water\ stress_{quality_i} - Water\ stress_{quality,sce_{i,n}}}{Water\ stress_{quality_i}}$$

$Water\ stress_{quality_i}$ is the water quality stress baseline in region i in 2017. $Water\ stress_{quality,sce_{i,n}}$ is water quality stress of scenario n for each region. $Quality\ stress_{reduce,sce_{i,n}}$is quality stress reduction percentage in different scenarios.

Table 1. Scenario setting

Scenarios	Scenario setting	Parameters setting	
		Water conveyance rate	Ratio of water consumption to sum of water consumption and return flow
Baseline (BL)	Original situation	-	-
Scenario 1	water loss and return flow of agricultural sectors are reduced	Irrigation: 20% Livestock: 0	Irrigation: 90% Livestock: 100%
Scenario 2	Water leakage and return flow of 26 industrial sectors and construction sectors are reduced	8%	See Table 2
Scenario 3	Water leakage and return flow of service sectors and urban households are reduced	8%	service sectors and urban households: 70%
Scenario 4	Water conveyance loss and return flow from agricultural, industrial, service and construction sectors and urban households are reduced	8%	Irrigation: 90% Livestock: 100% 26 industrial sectors and construction sectors: See Table 2 Service sectors and urban households: 70%

Table 2. Parameters design for scenario setting

	Ratio of water consumption to sum of water consumption and return flow		
Sectors	Average in 2017	Maximum in 2017	Parameter design for scenario
Agriculture, Forestry, Animal Husbandry and Fishery-irrigation	0.38	0.87	0.9
Agriculture, Forestry, Animal Husbandry and Fishery-non-irrigation	0.79	1	1
Mining and washing of coal	0.31	1.00	1.00
Extraction of petroleum and natural gas	0.61	1.00	1.00
Mining and processing of metal ores	0.51	1.00	1.00
Mining and processing of nonmetal and other ores	0.54	1.00	1.00
Food and tobacco processing	0.33	0.51	0.60
Textile industry	0.27	0.63	0.70
Manufacture of leather, fur, feather, and related products	0.26	0.57	0.70
Processing of timber and furniture	0.58	1.00	1.00
Manufacture of paper, printing and articles for culture, education, and sport activity	0.33	0.91	0.95
Processing of petroleum, coking, processing of nuclear fuel	0.67	0.98	1.00
Manufacture of chemical products	0.56	0.91	1.00
Manuf. of non -metallic mineral products	0.86	1.00	1.00
Smelting and processing of metals	0.75	1.00	1.00
Manufacture of metal products	0.48	0.98	1.00
Manufacture of general-purpose machinery	0.46	1.00	1.00
Manufacture of special purpose machinery	0.43	1.00	1.00
Manufacture of transport equipment	0.46	1.00	1.00
Manufacture of electrical machinery and equipment	0.47	0.97	1.00
Manufacture of communication equipment, computers and other electronic equipment	0.24	0.40	0.50
Manufacture of measuring instruments	0.39	1.00	1.00
Other manufacturing and waste resources	0.47	0.98	1.00
Waste resources	0.63	1.00	1.00
Repair of metal products, machinery, and equipment	0.40	1.00	1.00
Production and distribution of electric power and heat power	0.93	1.00	1.00
Production and distribution of gas	0.65	1.00	1.00
Production and distribution of tap water	0.00	0.00	0.00
Construction	0.71	0.95	0.95
Service	0.34	0.62	0.70
Urban household	0.32	0.50	0.60
Rural household	0.86	0.97	no change for each region

Results

Metabolism analysis

We mapped physical and virtual water quantity and pollutants metabolism for 31 provinces or municipalities (hereafter 31 regions) in China, excluding Hong Kong, Macau, and Taiwan because of data unavailability. Due to space limitations, we select four representative regions to analyse physical and virtual water quantity and pollutants metabolism, which are Beijing, Shanghai, Jiangsu, and Ningxia. The selected four regions cover majority of metabolism types in China, as Beijing represents regions where water use is dominated by domestic water (water use by construction, service sectors and household), Shanghai is dominated by industrial water use, and in Ningxia, agriculture is the largest water consumer. Because thermal power industry accounts for a large proportion of industrial water use in several regions in China, we also choose Jiangsu as a representative region as its thermal power industry uses the largest proportion of industrial water (30.4%) compared with other regions. For more information about metabolism of physical water quantity, virtual water quantity, physical water pollutants and virtual water pollutants for 31 regions in China, please refer to Fig. S1-Fig. S4.

Physical water quantity metabolism

Physical water quantity metabolisms of four regions are shown in Fig. 2. Water supply categories are diverse in Beijing, with its groundwater, wastewater reclamation and other sources (rainwater harvesting, mining wastewater utilization, etc.) accounting for 40%, 14.6% and 12% of the total water supply. In Shanghai surface water is the only source of water supply. While Jiangsu mainly uses surface water, with non-transferred and transferred surface water of 87.5% and 9.8% respectively (here water transfer means water transfer between different first level basins). Ningxia mostly uses 91.4% nonpreferred surface water and 8.3% groundwater.

Because economic structures, water use technologies and wastewater treatment processes are quite different in these regions, their physical water metabolism are different. We investigate physical water metabolism of 32 sectors in each region (industry list see Table S1), including urban households, rural household, and environmental flow augmentation. However, we merge them to 14 sectors (see Table S5) in the Sankey diagrams, in order to present metabolism clearly. In Beijing, its water uses for environmental flow augmentation rank the first (32.1%), followed by household (urban 24.4% and rural 3.1%), service sectors (17.4%) and then agriculture (12.9%). For industrial water use in Beijing, electric and heat power industry accounts for the largest proportion (3.1%). But in Shanghai, most water flows to industrial sectors (60%), among which petroleum, metal smelting, chemicals and electric and heat power rank in the top 4, accounting for 12.3%, 9.8%, 8.5% and 6.8%. Agricultural sector uses 15.9% of total water in Shanghai. While urban and rural household water use account for 13%. In Jiangsu, water use in agricultural sector and electric and heat power industry occupy 47.5% and 30.4%, but service sector and household just make up 2% and 7%. Ningxia is a developing region in China, its water use is dominated by agricultural sector, with its percentage of 86%. Water use in household and service sector just account for 2.5% and 0.9%. In Ningxia, its water use percentage (3.8%) for environmental flow augmentation is higher than that in Shanghai (0.8%) and Jiangsu (0.4%).

To map destination of water use of each sector is the key to understanding the metabolism of physical water. In Beijing and Shanghai, agricultural water conveyance loss accounts for only 2.2% and 3.8% of total water use, which are smaller than that in Jiangsu (16.4%) and Ningxia (36.5%). Agricultural return flow in these four regions also varies from 1.3% (Beijing) and 5.2% (Shanghai) to 9.6% (Jiangsu) and 34.6% (Ningxia). But regarding water leakage resulting from water conveyance of industrial and household water use, Beijing (8.9%) and Shanghai (14.0%) account for larger proportion than that in Jiangsu (6.6%) and Ningxia (1.0%). Because of high urbanization rate in Beijing and Shanghai, the proportion of wastewater return to wastewater treatment plants (WWTP) are also very high, with 27% and 29.3% of total water use discharging to WWTPs in Beijing and Shanghai. However, the values are just 7% in Jiangsu and 2.2% in Ningxia. For environmental flow augmentation, its stock occupies 6.2% of total water use in Beijing and most environmental flow augmentation is evaporated and become water consumption. This value is very small (less than 0.5%) in other three regions. Water consumption account for 52.9%, 38.1%, 57% and 36.5% of total water use in Beijing, Shanghai, Jiangsu, and Ningxia. This indicates that around 40.9% (Beijing), 61.9% (Shanghai), 43% (Jiangsu) and 76.1% (Ningxia) of total water use is returned to environment, in the form of water conveyance loss and polluted return flow which can be saved by improving water use efficiency.

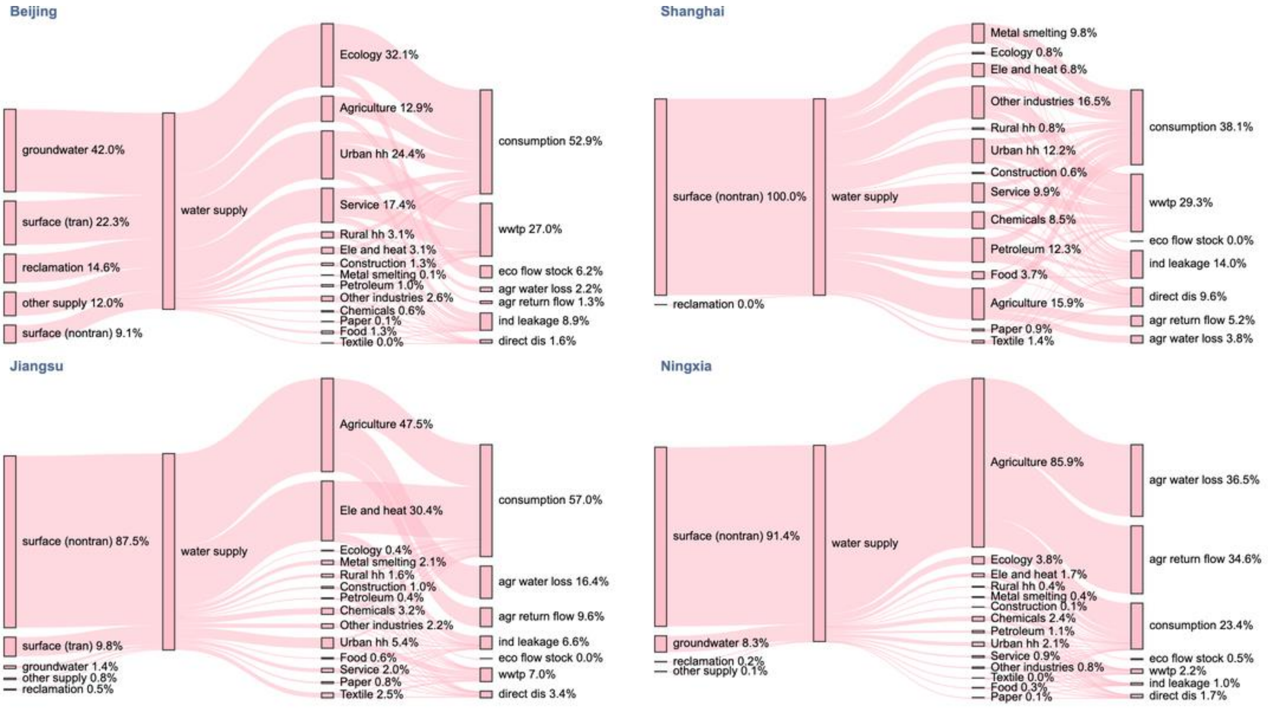

Fig. 2 Physical water quantity metabolism of four representative regions

Note: surface (tran): surface water supply with first order inter-basin transfer; surface (nontran): surface water supply without first order inter-basin transfer; Ecology: environmental flow augmentation; Urban hh: Urban household; Rural hh: Rural household; Ele and heat: Production and distribution of electric power and heat power; Metal smelting: Smelting and processing of metals; Petroleum: Processing of petroleum, coking, processing of nuclear fuel; Chemicals: Manufacture of chemical products; Paper: Manufacture of paper, printing and articles for culture, education, and sport activity; Textile: Textile industry; consumption: water consumption; agr water loss: agricultural water conveyance loss; agr return flow: agricultural return flow; ind leakage: industrial and household water conveyance leakage; eco flow stock: environmental flow augmentation that stored in rivers and lakes etc.; wwtp: wastewater treatment plant; direct dis: direct discharge

Virtual water quantity metabolism

Virtual water quantity metabolism in Beijing, Shanghai, Jiangsu, and Ningxia are presented in Fig. 3. There have been numerous studies on virtual water trade, especially on virtual water withdrawal or virtual water use trade, but our study classifies virtual water use into different categories based on the process of societal water cycle, which include virtual water consumption, virtual return flow and virtual water loss, because we want to clarify and quantify how much virtual water is really consumed and how much virtual water returns to environment. Virtual water return to environment has potential to be saved by using water saving technologies.

Imported water consumption account for 36% (Beijing), 36.3% (Shanghai), 32.4% (Jiangsu) and 38.7% (Ningxia) of total imported virtual water while the remaining is imported virtual water loss and return flow Four regions import large proportion of agricultural water loss and agricultural return flow, with percentage of imported agricultural water loss 27.3% in Beijing, 27.1% in Shanghai, 30% in Jiangsu, and 24.2% in Ningxia. Imported agricultural return flow account for 23.4% (Beijing), 23.2% (Shanghai), 26.5% (Jiangsu) and 31.0% (Ningxia). Water loss from industry and household, return flow of direct discharge and discharging to WWTPs occupy less than 7% of total virtual imported water in these four regions.

For virtual water export, exported water consumption account for 43.1% (Beijing), 41.7% (Shanghai), 60.6% (Jiangsu) and 24.2% (Ningxia) of total exported water, accompanying by 56.9% (Beijing), 58.3% (Shanghai), 39.4% (Jiangsu) and 75.8% (Ningxia) of virtual water export becoming water loss and return flow. It shows that water loss and return flow account for a high proportion of virtual water export in four regions. In Beijing and Shanghai, exported water loss and return flow from industries are higher than that from agriculture. Exported water leakage from industry and wastewater returning to WWTPs account for 13.4% and 35.6% in Beijing and they are 15.6% and 26.3% in Shanghai, 6.8% and 3.5% in Jiangsu, 1.6% and 1.0% in Ningxia. Regarding exported agricultural water loss, Ningxia accounts for the highest proportion (35.8%), followed by Jiangsu (16%), but this value is just 2.9% in Beijing and 1.7% in Shanghai. In terms of agricultural return flow, Ningxia also take up the highest proportion, with the value of 33.9%. But they are 1.7%, 2.4% and 9.4% in Beijing, Shanghai, and Jiangsu.

From the virtual water quantity metabolism diagram in Fig.3, it is evident to see that total virtual water import, and export are not equal for different sectors and different regions. Because numerous papers have studied virtual water trade inequalities across sectors and regions. Therefore, we would not pay much attention for this part in this paper.

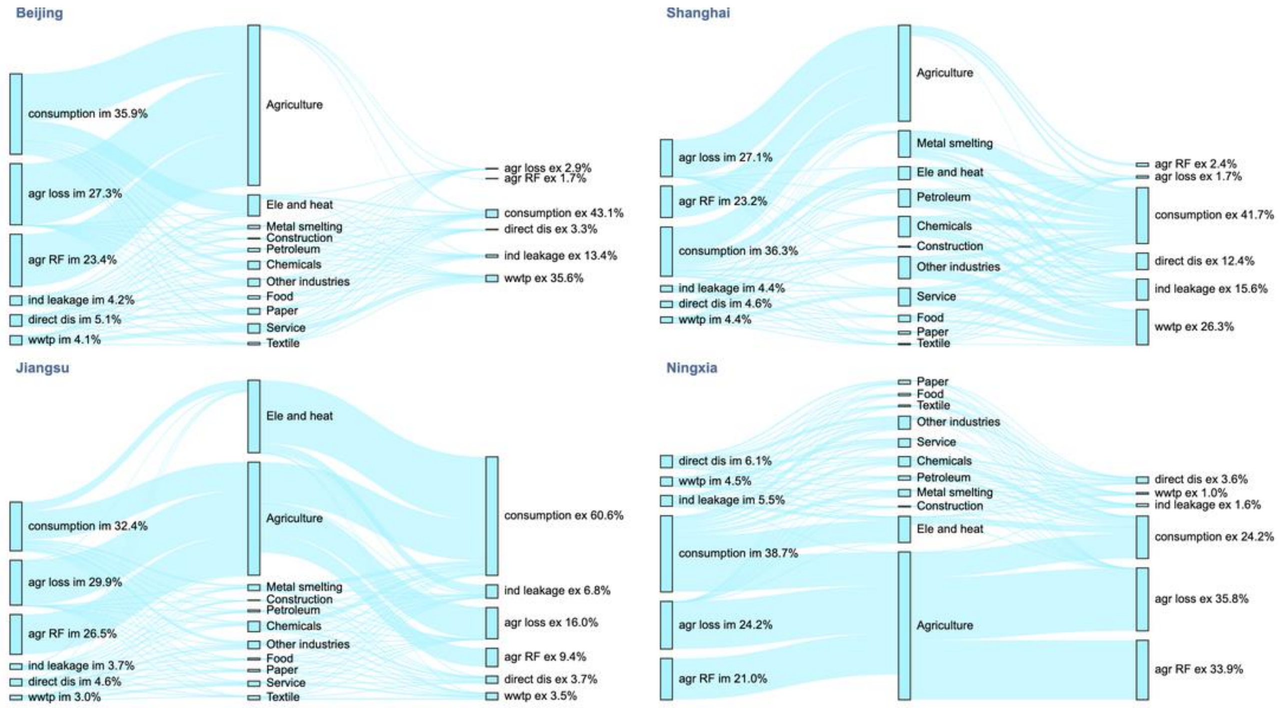

Fig. 3 Virtual water quantity metabolism of four representative regions

Note: im: imported virtual water; ex: exported virtual water; agr RF: agricultural return flow; other abbreviations refer to notes of Fig. 1.

Physical water pollutants metabolism

We examine COD, NH_3-N, TN, and TP metabolism across different sectors in 31 regions in China. Pollutants metabolism in this paper means quantifying amount of four different pollutants that discharge to environment. Due to data limitation, we do not consider pollutants generated in each industry or pollutants removal by internal (industry itself) or external (a WWTP) treatment facilities but consider pollutants discharging to environment across sectors.

We present COD, NH_3-N, TN, and TP metabolism across different sectors in Beijing, Shanghai, Jiangsu, and Ningxia in Fig. 4. For COD metabolism, agricultural livestock contribute to the highest proportion in four regions, with the percentages of 44.0% (Beijing), 33.4% (Shanghai), 53.8% (Jiangsu) and 64.1% (Ningxia). Rural household rank the second for COD discharge in Beijing (38%), Shanghai (21%), and Ningxia (12.5%), followed by urban household, with the number of 9.3% in Beijing, 20.3% in Shanghai and 9.3% in Ningxia. Service sectors are the fourth contributors for COD pollution in Beijing (6.6%), Shanghai (16.4%) and Jiangsu (6.4%). Industries generate small proportion of COD pollutants compared with livestock, household, and service sectors, with percentage of 2.1% in Beijing, 8.9% in Shanghai, 11.9% in Jiangsu and 10% in Ningxia.

For NH_3-N, TN and TP pollutants, urban household, rural household, agriculture, and service sectors are top four pollution sources in four regions. Industrial sectors contribute little to these four pollutants in each province. For NH_3-N, rural and urban household is the main pollution source in four regions, and agriculture and service sectors are the second and third pollution sources. Urban household generate the most of TN in Beijing (28.2%) and Shanghai (33.7%), but in Jiangsu (75.2%) and Ningxia (38.5%), farming and livestock are the main contributors for TN pollution. Agricultural is the second largest TN pollution source for Beijing (22.3%), but it is service sector for Shanghai (27.2%). While for Jiangsu (10.6%) and Ningxia (21.7%), urban household rank the second for TN emission. In terms of TP, agriculture is the primary pollution source in these four regions, and urban and rural household are the second or third TP emission sources, followed by service sector.

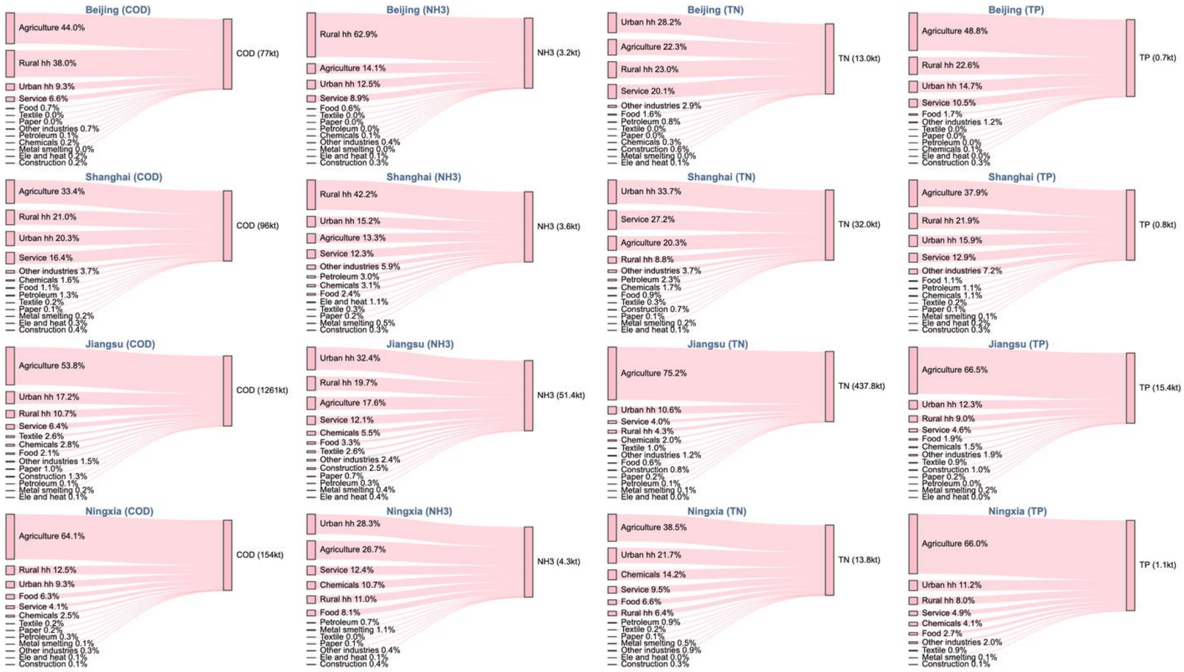

Fig. 4 Physical water pollutants metabolism of four representative regions

Virtual water pollutants metabolism

We map virtual water pollutants metabolism for each industry in 31 regions. Virtual water pollutants metabolism traces virtual import and export of discharged COD, NH_3-N, TN, and TP across sectors. Virtual water pollutants metabolism is beneficial for analysing how does the trade has an impact on water quality stress. Virtual water pollutants metabolism of four representative regions are shown in Fig.5. For all virtual water pollutants metabolism for 31 regions in China, please see Fig. S4.

From Fig.5, it is evident that Beijing, Shanghai, Jiangsu, and Ningxia have net import of different pollutants. It indicates that these four regions outsource four pollutants to other regions to reduce water pollution in local area. Compared with other sectors, agriculture outsources the most pollutants, because agriculture imports 83-95% of COD, 48-82% of NH_3-N, 84-95% of TN, and 84-95% of TP in each region. For Jiangsu and Ningxia, virtual TN, TP, COD and NH_3-N exports are dominated by agriculture. But for Beijing and Shanghai, their service sectors export the largest proportion of virtual NH_3-N and TN, and agriculture sectors import the most of TP.

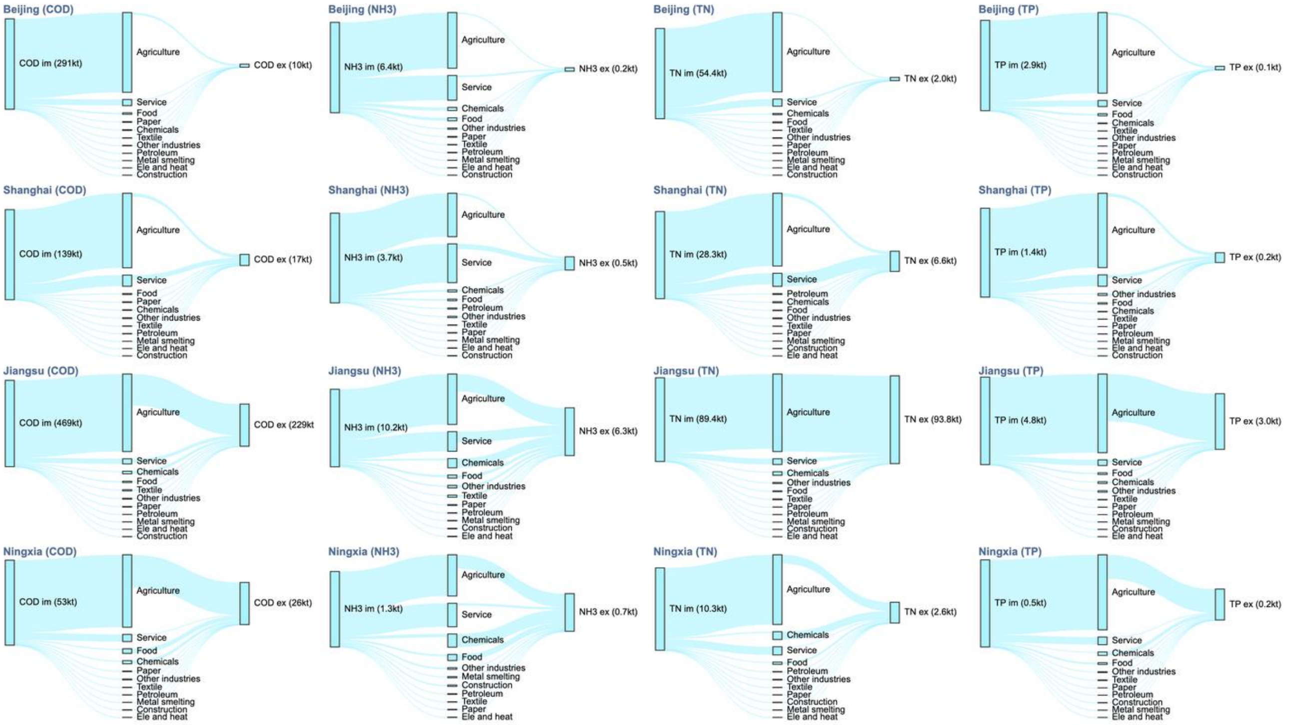

Fig. 5 Virtual water pollutants metabolism of four representative regions

Water stress assessment

Water stress level

Water stress results are shown in Fig 6 (a)-6 (c). In China, 25 out of 31 regions suffer from different level of water quantity stress. For water quantity stress, Ningxia is the most stressed region in China, with water quantity stress of 7.64, followed by Shanghai (5.84) and Jiangsu (2.6). The remaining regions that experience the critical water quantity stress are Tianjin (2.39), Hebei (1.88), Beijing (1.36), Shandong (1.25), Liaoning (1.2), Inner Mongolia (1.05), Xinjiang (1.04), and Heilongjiang (1.01). Gansu, Anhui, Henan, and Shanxi are high level water stress regions, with water quantity level ranging from 0.76 to 0.88. Jilin (0.68), Guangdong (0.64), and Fujian (0.56) are medium level stressed regions. For Hubei (0.47), Zhejiang (0.43), Jiangxi (0.41), Shaanxi (0.36), Hainan (0.35), Hunan (0.34) and Chongqing (0.26), these regions suffer from low level quantity stress. There are 6 regions that have no quantity stress in 2017, which are all in southeast: Guangxi, Guizhou, Sichuan, Yunnan, Qinghai, and Tibet. In Fig 6 (b), those regions with water quality stress higher than 1 suffer from water quality stress. In China, 28 out of 31 regions experience pollution induced stress. Only Xingjian, Qinghai, and Tibet have no water quality stress. Jiangsu (19.5), Tianjin (18.6), Hebei (18.1), Ningxia (17.7), and Shandong (16.6) are top 5 pollution induced stress.

Total water stress, the sum of water quantity and quality stress is presented in Fig 6 (c). Currently, there is no uniform way to classify total water quantity to different levels. Tibet (0.07) and Qinghai (0.34) have the least total water stress. For other regions, their water stress change with the flow of Yangtze and Yellow River from west to east. The Yangtze River flows through Qinghai, Tibet, Sichuan, Yunnan, Chongqing, Hubei, Hunan, Jiangxi, Anhui, Jiangsu, and Shanghai. Water stress in lower regions of Yangtze River (Anhui (10.9), Jiangsu (22.1), and Shanghai (21.9)) are much higher than that in middle (Hubei (5.1), Hunan (3.4), Jiangxi (3.1)) and upper regions (Qinghai (0.34), Tibet (0.07), Sichuan (5.3), Yunnan (5.5), Chongqing (3.9), Hubei (5.1)). Yellow River flows from west to east through Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, and Shandong. The lower regions (Henan (10.7), and Shandong (17.8)) of Yellow River also have higher total water stress compared with middle (Inner Mongolia (2.8), Shaanxi (4.2), Shanxi (5.7)) and most upper provinces (Qinghai (0.34), Sichuan (5.3), Gansu (2.4), Ningxia (25.3), Inner Mongolia (2.8)).

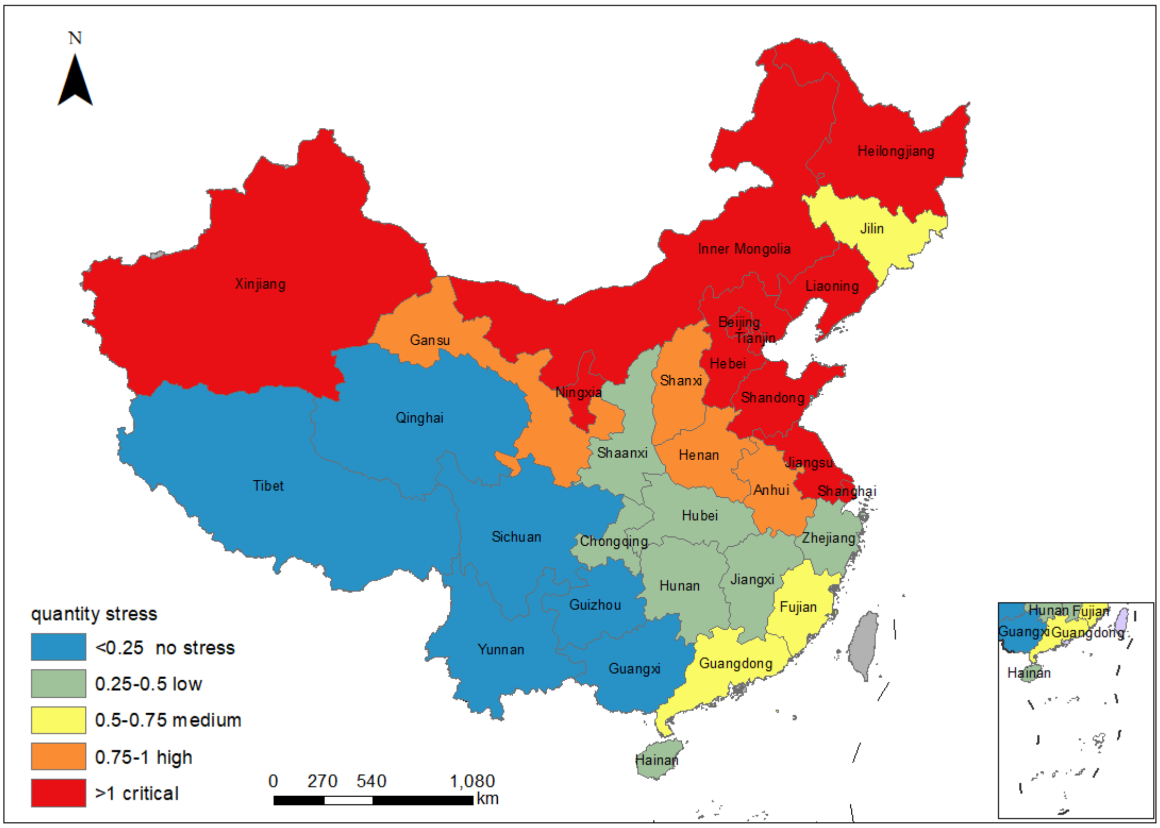

Fig. 6 (a) Water quantity stress

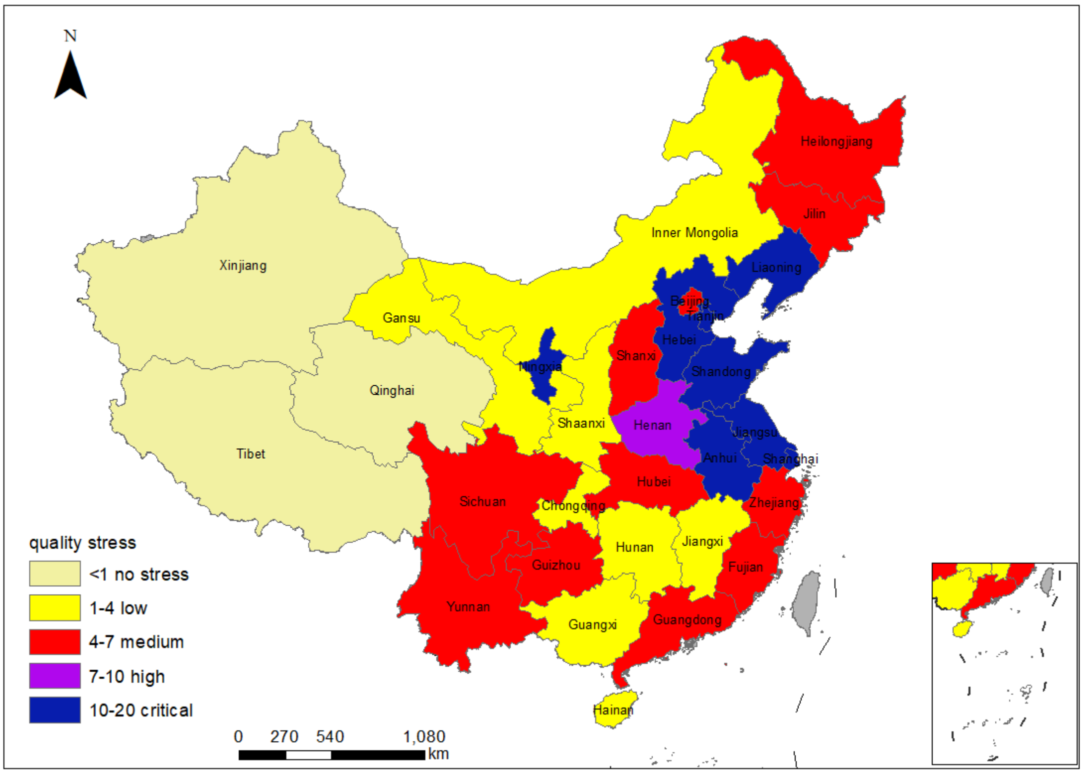

Fig. 6 (b) Water quality stress

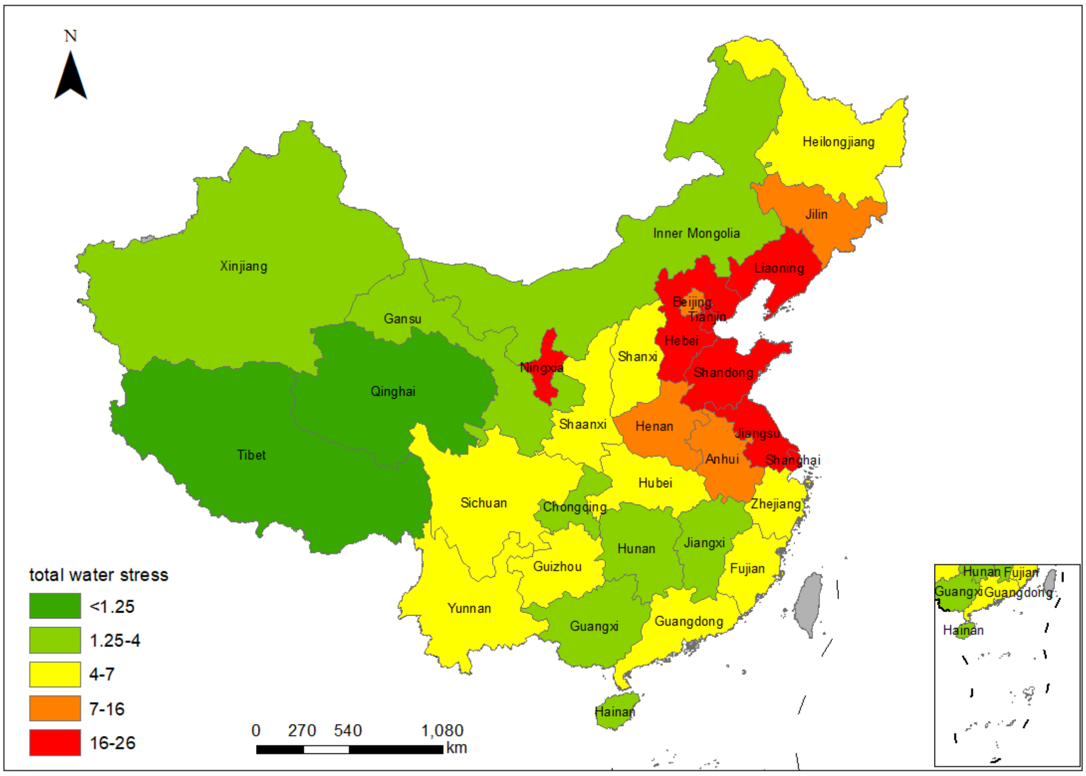

Fig. 6 (c) Total water stress

Water stress induced by different water use destinations

We compare the proportion of water use destination between physical and virtual water quantity metabolism to find out attribution of different water use destination to water stress, especially the attribution of water loss and different return flows to water stress. The result is shown in Fig. 7. For physical water quantity metabolism, water consumption attributes to 20-59% of water quantity stress in each region, with the lowest value of 20% in Hainan and the highest value of 59% in Tianjin. It means that water loss and return flow attributes to 41-80% of quantity stress. Except for Beijing and Shanghai, agricultural water loss and agricultural return flow cause high water stress (attribute more than 15%) for majority of provinces. For instance, in Ningxia, agricultural water loss and agricultural return flow attribute 37% and 35% of quantity stress respectively, and in Heilongjiang, these values are 35% and 29%. But in Shanghai and Beijing, water leakage from industries and household and return flow discharging to WWTPs also cause high water quantity stress, with both attribution of 43% in Shanghai and 36% in Beijing.

Regarding virtual water quantity metabolism, virtual export of water consumption account for 11-61% of total virtual water export induced stress, with the lowest percentage of 11% in Hainan and the largest proportion of 61% in Tianjin. At the same time, virtual export of return flow and water loss attribute to 39-89% of virtual water export caused stress. In Beijing and Shanghai, virtual water leakage and virtual water retuning to WWTPs contribute 42% and 49% of export induced quantity stress. For most of regions where water use structure is dominated by agricultural use, agricultural water loss and agricultural return flow attribute to 20-86% of quantity stress.

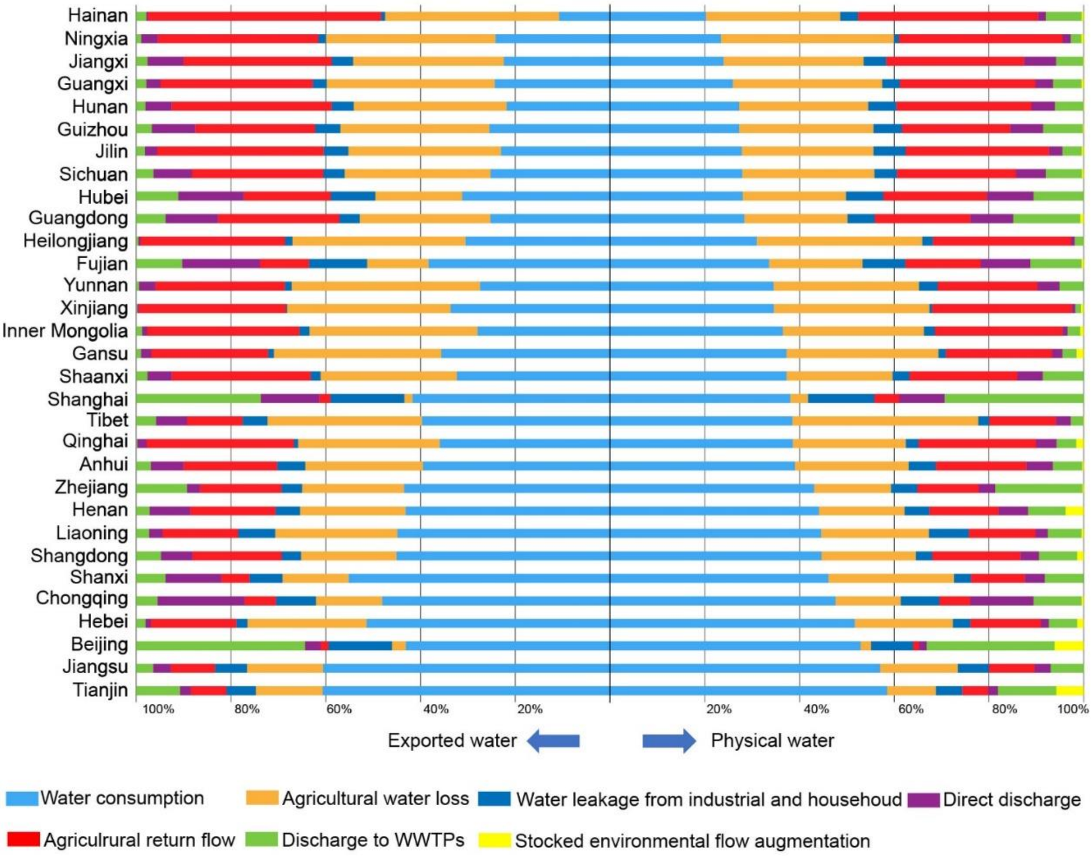

Fig. 7 Proportion comparison of water use destination between physical and virtual water quantity metabolism

Sectoral water stress

We also compare sectoral water quantity and quality stress to identify key sectors that induce water stress in each region. The sectoral water stress result is seen in Fig. 8. Agriculture is the main water use sector for most regions, as it attributes 33-93% of total water use, excluding Beijing and Shanghai. For Beijing, water use for environmental flow augmentation occupy the largest proportion of total water use (32%). Domestic water use (i.e., water use for household, service, and construction sectors) in Beijing is also very high, as water use for household and service sector account for 27% and 17.4% respectively, while agricultural water use just takes up 12.9%. In Shanghai, industrial water use contributes a lot to quantity stress, as its industrial water use accounts for 59% of total water use, followed by household (27%), service (17%) and agriculture (16%).

For a specific sector, high water use does not always equate to serious water pollution. In Shanghai, industries are largest water consumers (59%), but quality stress induced by industries is very small (2.7%). Attribution of agriculture to quality stress in Xinjiang is relatively lower (16.5%), even though agricultural water use accounts for a large proportion (93%) of water use. However, agriculture generates the most quality stress in most provinces (14-93%). Industrial water pollution induced stress contributes small percentage (0.2-10%) in China, except for Ningxia (21%) and Inner Mongolia (16%). Urban and rural household pollution attributes a certain percentage of water quality stress (6-60%) and household pollution in some regions is an important pollution source, such as Xingjian (60%), Beijing (50%), Qinghai (47%), Gansu (46%), Shanghai (45%) etc.

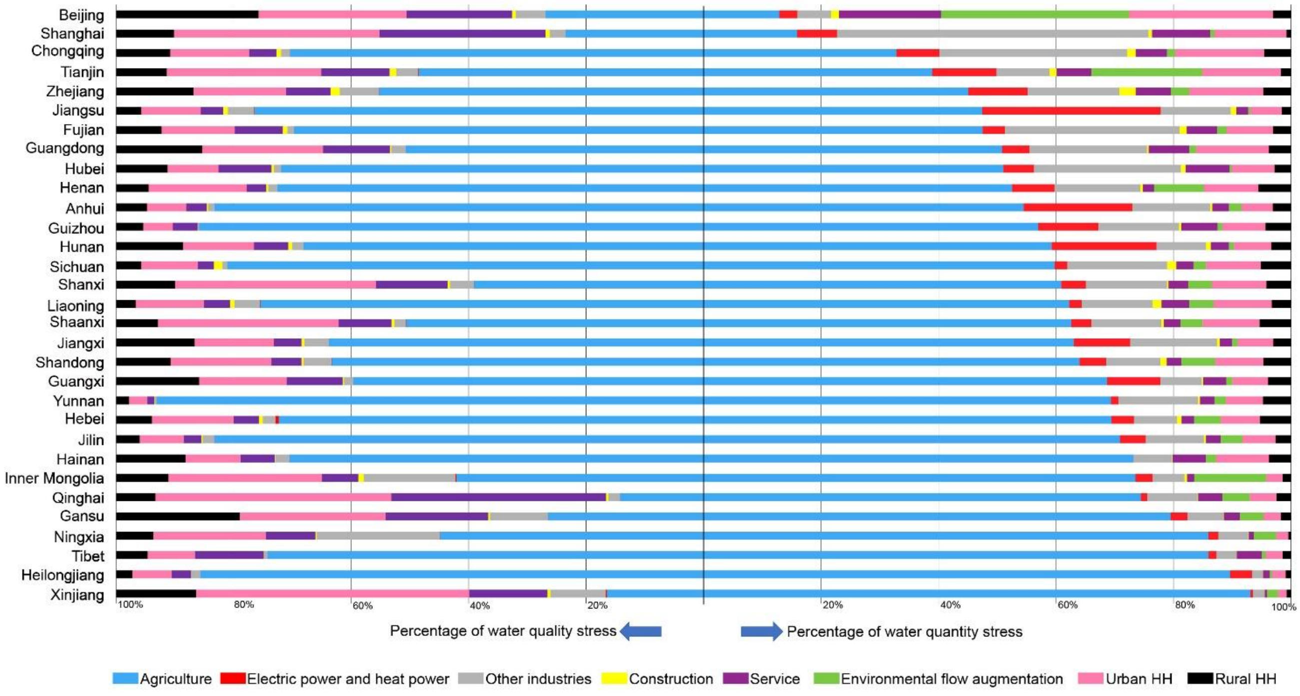

Fig. 8 Proportion comparison of sectoral water quantity and quality stress

Scenario analysis

Scenario results on water quantity stress, water quality stress and total water stress are presented in Fig. 9 (a)-9 (b). In this study, 2017 water stress level is considered as a baseline for scenario analysis. Scenario 4 shows the best water stress reduction results, as we set that every sector adopts the strictest water consumption ratio and water loss rate (see Table 1). Comparing scenarios 1,2,3 with scenario 4, we can judge which sector contributes the most to water quantity and quality stress reduction if sectors' consumption ratio and water loss rate are improved to the optimal state that we set in Table 1 and Table 2.

From Fig. 9 (a), it is evident to see that only reducing water loss and return from agriculture sector can achieve the mitigation of water stress to a large extend (more than 20%) for majority of regions, except for Beijing (2%), Shanghai (7%) and Tianjin (9%). For some regions, their water quantity stress is reduced by more than 50% in scenario 1, such as Yunnan (50%), Guizhou (52%), Sichuan (53%), Inner Mongolia (54%), Heilongjiang (55%), Jilin (55%), Xinjiang (56%), Hunan (56%), Guangxi (59%), Jiangxi (59%), Hainan (66%), and Ningxia (67%). While results of scenarios 2 and 3 of these regions indicate that only reducing water loss and return flow of industry sectors (scenarios 2) or service and household (scenarios 3) would not affect too much for water quantity stress reduction. For Beijing, scenario 3 shows that quantity stress can be reduced by 33% if household and service sector' consumption ratio increase to 70% and water conveyance rate decrease to 8%. Therefore, increasing water use efficiency of household and service sector in Beijing could largely mitigate quantity stress by 33%. In Shanghai, industries sectors have potential to reduce quantity stress by 32% in scenario 2.

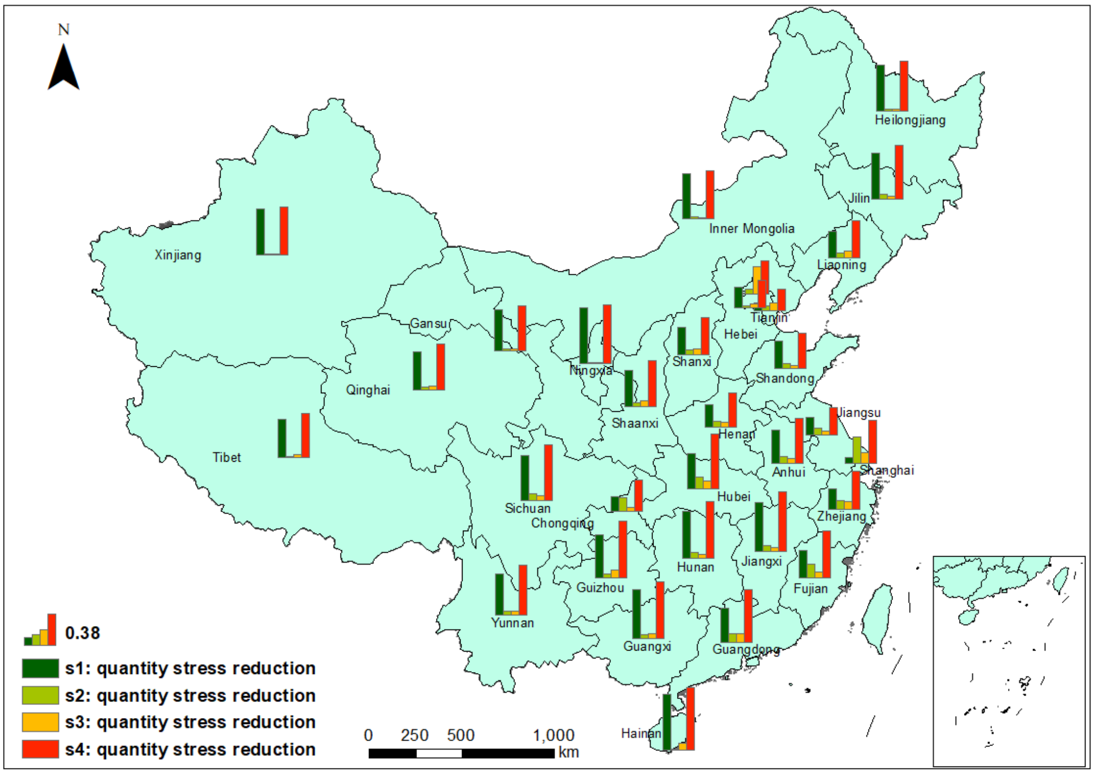

Fig. 9 (a) Water quantity stress scenario

In terms of water quality stress scenario in Fig. 9 (b), agriculture is a critical sector for alleviating pollution induced stress for 22 provinces, with mitigation potential ranging from 31% to 68%. Scenario 2 shows that reducing return flow of industries sectors would not decrease water quality stress too much for most of regions as their quality stress just reduce by less than 5%. But for Ningxia and Inner Mongolia, 21% and 15% of water quality stress can be decreased if strict industrial water saving measures are adopted in these two regions. For some regions, reducing return flow from domestic water use (water use for household and service sector) is the key to mitigate water quality stress, because their quality stress can be mitigated by more than 23%, such as Qinghai (59%), Shanghai (48%), Xinjiang (44%), Shanxi (34%), Beijing (33%), Shaanxi (29%), Gansu (24%), Guangdong (24%) and Tianjin (23%).

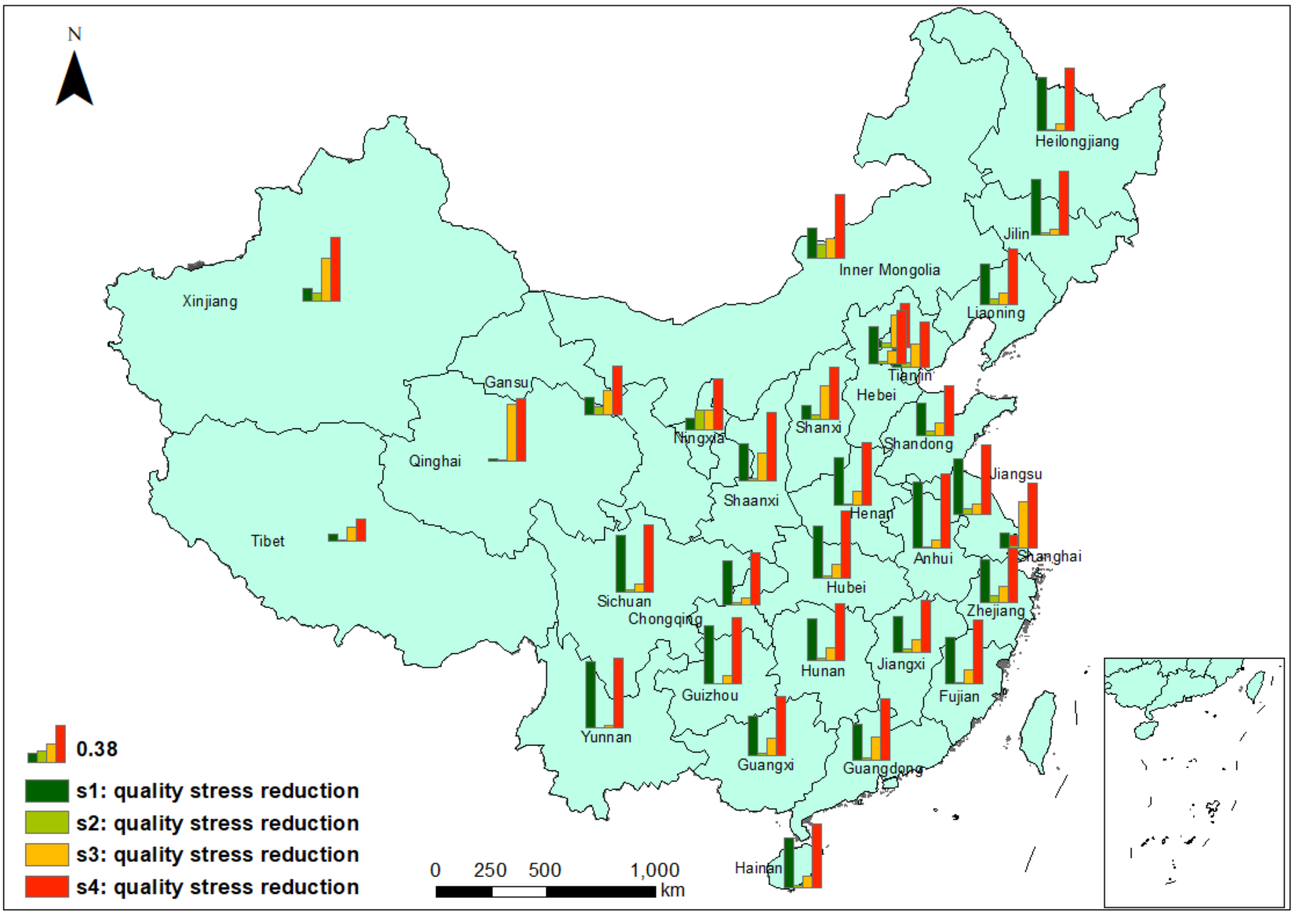

Fig. 9 (a) Water quality stress scenario

For both quantity and quality scenario results in Fig. 9 (c), agriculture is the most important sector for 23 provinces, as it has the largest potential to reduce total water stress by 34-67%. For Beijing and Qinghai, decreasing return flow and water loss of domestic water use could mitigate total water stress by 39% and 50%. However, for regions like Tianjin, Shanghai, Shaanxi, Guangdong, it is necessary to reduce return flow and water loss of several sectors simultaneously to achieve reducing water stress largely.

Based on scenario 4, we propose a pathway to mitigate water quantity and quality stress for each region by reducing water conveyance loss and return flow of top 5 industries with large potential to reduce water stress. In Table 3 and Table 4, we list top 5 industries that contribute to quantity and quality stress mitigation. For majority of regions, agriculture and urban household are top two sectors that mitigate both quantity and quality stress. Therefore, reducing water loss and return flow of agriculture and urban household by improving water use efficiency is the most efficient way to reduce water quantity and quality stress in China. Top 5 sectors could reduce water quantity stress by 22-75% and reduce water quality stress by 23-76%.

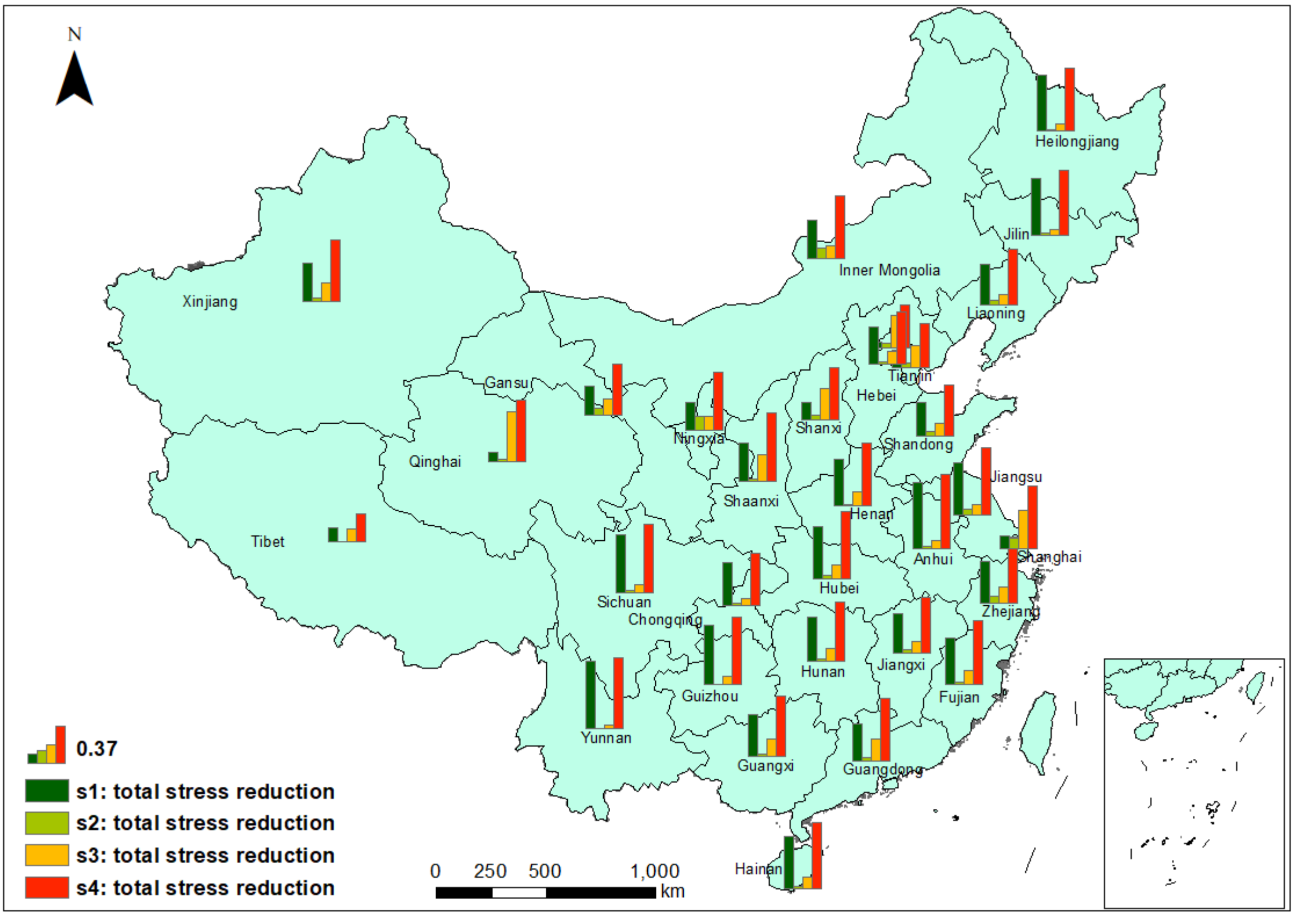

Fig. 9 (c) Total water stress scenario

Table 3. Top 5 sectors contributing to water quantity stress alleviation

Provinces	top 1		top 2		top 3		top 4		top 5		reduced quantity stress percentage of top 5 sectors
	sector	reduced water quantity stress	sector	reduced water quantity stress	sector	reduced water quantity stress	sector	reduced water quantity stress	sector	reduced water quantity stress	
Beijing	31	0.25	29	0.20	1	0.03	25	0.02	20	0.01	36%
Tianjin	1	0.22	31	0.14	29	0.08	25	0.04	12	0.03	22%
Hebei	1	0.48	31	0.07	29	0.02	14	0.01	12	0.01	31%
Shanxi	1	0.24	31	0.04	29	0.02	2	0.02	12	0.01	42%
Inner Mongolia	1	0.56	31	0.02	12	0.01	25	0.00	2	0.00	57%
Liaoning	1	0.36	31	0.07	11	0.03	29	0.03	28	0.01	42%
Jilin	1	0.37	12	0.02	31	0.02	29	0.01	25	0.01	63%
Heilongjiang	1	0.56	31	0.01	29	0.01	25	0.01	2	0.002	58%
Shanghai	11	0.42	1	0.40	31	0.39	29	0.35	12	0.32	32%
Jiangsu	1	0.52	31	0.07	7	0.05	25	0.04	12	0.04	28%
Zhejiang	1	0.11	31	0.03	7	0.02	29	0.02	12	0.01	41%
Anhui	1	0.32	31	0.02	12	0.01	29	0.01	25	0.01	48%
Fujian	1	0.18	31	0.02	29	0.02	10	0.02	12	0.02	46%
Jiangxi	1	0.24	31	0.01	12	0.01	4	0.01	29	0.01	66%
Shandong	1	0.41	31	0.04	12	0.02	29	0.01	10	0.01	40%
Henan	1	0.22	31	0.04	12	0.02	10	0.01	29	0.01	37%
Hubei	1	0.20	29	0.02	12	0.02	31	0.02	14	0.01	58%
Hunan	1	0.19	31	0.01	29	0.01	25	0.01	10	0.00	64%
Guangdong	1	0.26	31	0.04	29	0.03	7	0.02	10	0.02	57%
Guangxi	1	0.13	31	0.01	29	0.01	10	0.00	6	0.001	66%
Hainan	1	0.23	31	0.02	29	0.01	3	0.00	10	0.0002	75%
Chongqing	1	0.05	10	0.01	12	0.01	31	0.01	2	0.01	30%
Sichuan	1	0.11	31	0.01	12	0.00	10	0.00	29	0.003	62%
Guizhou	1	0.12	31	0.01	29	0.01	2	0.00	14	0.002	65%
Yunnan	1	0.08	31	0.01	29	0.00	6	0.00	4	0.002	57%
Tibet	1	0.01	29	0.00	31	0.00	25	0.00	13	0.000	52%
Shaanxi	1	0.16	31	0.02	29	0.01	2	0.01	12	0.004	53%
Gansu	1	0.43	31	0.01	12	0.01	14	0.01	29	0.01	52%
Qinghai	1	0.03	12	0.00	29	0.00	31	0.00	14	0.0002	54%
Ningxia	1	5.17	31	0.08	12	0.07	29	0.04	2	0.03	70%
Xinjiang	1	0.59	31	0.01	12	0.00	29	0.00	6	0.001	58%

Table 4. Top 5 sectors contributing to water quality stress alleviation

	top 2		top 2		top 3		top 4		top 5		reduced quality stress percentage of top 5 sectors
Provinces	sector	reduced water quality stress	sector	reduced water quality stress	sector	reduced water quality stress	sector	reduced water quality stress	sector	reduced water quality stress	
Beijing	31	1.03	29	0.84	1	0.41	27	0.09	6	0.06	42%
Tianjin	1	3.48	31	2.78	29	1.56	12	0.25	28	0.19	45%
Hebei	1	7.03	31	1.79	29	0.64	12	0.11	28	0.11	54%
Shanxi	31	1.19	1	0.69	29	0.49	12	0.10	11	0.03	51%
Inner Mongolia	1	0.55	31	0.33	6	0.11	12	0.10	29	0.03	63%
Liaoning	1	6.04	31	1.15	29	0.42	11	0.17	6	0.14	53%
Jilin	1	3.79	31	0.28	29	0.14	6	0.05	12	0.04	64%
Heilongjiang	1	2.92	31	0.25	29	0.14	12	0.02	6	0.01	64%
Shanghai	31	4.00	29	3.69	1	2.55	27	0.14	28	0.10	65%
Jiangsu	1	10.96	31	1.41	29	0.61	12	0.36	28	0.13	69%
Zhejiang	1	1.94	31	0.50	29	0.27	7	0.13	12	0.07	66%
Anhui	1	6.83	31	0.48	29	0.29	12	0.05	6	0.02	76%
Fujian	1	2.65	31	0.49	29	0.37	28	0.04	12	0.03	65%
Jiangxi	1	0.97	31	0.26	29	0.10	12	0.04	28	0.01	52%
Shandong	1	5.62	31	1.62	29	0.60	6	0.28	12	0.21	50%
Henan	1	4.80	31	1.18	29	0.27	12	0.07	6	0.04	64%
Hubei	1	2.42	29	0.34	31	0.29	12	0.05	28	0.02	68%
Hunan	1	1.28	31	0.26	29	0.14	12	0.03	28	0.02	57%
Guangdong	1	1.88	31	0.75	29	0.47	7	0.03	6	0.02	62%
Guangxi	1	0.83	31	0.22	29	0.16	6	0.01	12	0.01	59%
Hainan	1	1.84	31	0.24	29	0.17	6	0.04	12	0.01	64%
Chongqing	1	1.62	31	0.16	29	0.09	28	0.02	12	0.02	53%
Sichuan	1	2.96	31	0.30	29	0.10	28	0.07	12	0.02	68%
Guizhou	1	3.36	31	0.24	29	0.21	6	0.00	12	0.00	68%
Yunnan	1	3.61	31	0.12	29	0.05	12	0.01	6	0.01	71%
Tibet	29	0.01	1	0.00	31	0.00	6	0.00	27	0.00	23%
Shaanxi	1	1.47	31	0.84	29	0.28	12	0.03	28	0.02	69%
Gansu	1	0.25	31	0.22	29	0.14	14	0.06	6	0.04	47%
Qinghai	29	0.08	31	0.08	1	0.01	12	0.00	11	0.00	63%
Ningxia	31	2.42	12	2.22	1	2.15	29	1.22	6	0.94	51%
Xinjiang	31	0.24	1	0.09	29	0.08	6	0.03	12	0.02	64%

Discussion

Water loss and return flow matter for water stress

Normally, water withdrawal or total water use is used to measure water quantity stress [48,49], and water quantity stress has no relation with quality stress in previous studies [4,14,15,17]. Water stress assessment based on metabolism analysis in this study demonstrate that impact of water loss and return flow on water stress matters, and water quality stress is related to polluted return flow. Theoretically, water consumption is the water that really need for production and consumption. Water conveyance loss could be reduced or avoided by update or maintenance of supplied pipelines. Return flow can be reduced by advanced water saving technologies or restricting water use time. Furthermore, replacing traditional water-cooling technologies by air cooling processes can reduce water use drastically, not only for return flow, but also for water consumption[50–52]. Water stress assessment based on 2017 data reveals that most regions in China still have great potential to mitigate water stress by reducing return flow, agricultural water loss, water leakage from industry and household, because water loss and return flow attributes to 41-80% of quantity stress. Meanwhile, return flow attributes to 100% of water quality stress, because return flow is always polluted, even for returned cooling water with high temperature. Water quality stress can be decreased if return flow volume is reduced, under the condition by assuming that concentration of discharged pollutants remain the same because of sound treatment technologies. In scenario 4, we assume that all sectors adopt the strict consumption ratio, and water loss and return flow are lowest. In this case, total water stress decreases by 44-74% for each region, excluding Tibet (29%). This is a huge decrease for both water quantity and quality stress, since 20 out of 25 quantity stressed regions decease to a lower stress level, and water quality stress could be mitigated by 45-76% for all provinces, except for Tibet (23%).

Improving water use efficiency

Some studies mention that improving water use efficiency is an effective way to reduce water stress[27,53,54], but they do not clarify how to improve water use efficiency. Based on our physical and virtual metabolism analysis for each province in China, we identify that improve water use efficiency by increasing water consumption ratio and decreasing water loss rate could largely reduce water stress by 44-74% for each region. Irrigation water loss rate in China is still very high, ranging from 26 % to 57 %. It means 43% to 74% of irrigation water use is consumed or returned to environment, among which only 38% is consumed averagely (see Table 2). It indicates that 27-46% of irrigation water is return flow and is not used effectively. Water leakage rate of water supply is 10-29% in 2017, and it is expected to drop to 8% by 2025 in The Fourteenth Five-Year Plan. Therefore, a huge effort could be made to reduce water conveyance loss to improve water use efficiency.

Water consumption ratios (water consumption ratio means the ratio of water consumption to sum of water consumption and return flow) for many sectors in 31 regions still have great potential to be improved. Table 2 lists the average and maximum water consumption ratio of each sector for all provinces. For some industries, the average consumptive ratios are still very low. For instance, average of consumptive ratio for textile industry is 27%, for manufacture of leather, fur, feather, and related products is 26%, for mining and washing of coal is 31% and for urban household is 32%. Water consumption ratios for different sectors vary significantly due to different industry types. For some industries in some regions, their water consumption ratios could reach to 100%, such as industry of extraction of petroleum and natural gas and manufacture of transport equipment, but for industry of food and tobacco processing, its highest water consumption ratio is 51% in China, and the value is 63% for textile industry. It indicates that it is necessary to set a reasonable target for water consumption ratio for a specific sector, even though increasing water consumption ratio is an effective way to improve water use efficiency and to reduce return flow.

Metabolism analysis is useful for water stress assessment and reduction

Traditionally, water withdrawal is considered for water quantity stress assessment, and discharged water pollutants are used for quality stress evaluation. But it cannot highlight the inter connection between the quantity and the quality stress if we just look at water stress problems at the beginning (withdrawal) and at the end (discharge) of water use. It is also not conducive to identify the key factors that influence quantity and quality stress, and to propose a pathway to mitigate quantity and quality stress simultaneously. The hydro-economic model developed in this study provides a new insight for a coupled quantity and quality-based water stress assessment and mitigation. The hydro-economic model makes it possible to analyse both physical and virtual water metabolism for each process of societal water cycle, rather than only withdrawal and pollutants discharge. Based on the metabolism analysis, we identify key sectors for water use and water pollution in each region, and we quantify water quantity and quality stress induced by each sector and identify key sectors that should reduce return flow and water loss to save water. We also estimate the potential water quantity and quality stress reduction by decreasing water loss rate and improving water consumption rate. The proposed hydro-economic model based on physical and virtual metabolism can achieve water quantity and quality stress assessment and mitigation at the same time. Metabolism analysis for 31 regions in China shows that each region has its unique metabolic pathway. Therefore, it is undesirable to generate and implement a one-size-fits-all water stress mitigation strategy for all provinces in China. It is necessary to design a specific mitigation strategy for a certain region.

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Supplementary information

Table S1. List of water use industry or water use object

No.	Water use sectors or water use object
1	Agriculture, Forestry, Animal Husbandry and Fishery-irrigation Agriculture, Forestry, Animal Husbandry and Fishery-non-irrigation
2	Mining and washing of coal
3	Extraction of petroleum and natural gas
4	Mining and processing of metal ores
5	Mining and processing of nonmetal and other ores
6	Food and tobacco processing
7	Textile industry
8	Manufacture of leather, fur, feather, and related products
9	Processing of timber and furniture
10	Manufacture of paper, printing and articles for culture, education, and sport activity
11	Processing of petroleum, coking, processing of nuclear fuel
12	Manufacture of chemical products
13	Manuf. of non -metallic mineral products
14	Smelting and processing of metals
15	Manufacture of metal products
16	Manufacture of general-purpose machinery
17	Manufacture of special purpose machinery
18	Manufacture of transport equipment
19	Manufacture of electrical machinery and equipment
20	Manufacture of communication equipment, computers, and other electronic equipment
21	Manufacture of measuring instruments
22	Other manufacturing
23	Waste resources
24	Repair of metal products, machinery, and equipment
25	Production and distribution of electric power and heat power
26	Production and distribution of gas
27	Production and distribution of tap water
28	Construction
29	Service
30	Environmental flow augmentation
31	Urban household
32	Rural household

Table S2. Framework of Multi-Regional Input-Output Table in 2017 in China

			Intermediate Use			Final demand			Total output
			Region 1	…	Region n	Region 1	…	Region n	
			Industry 1 … Industry m		Industry 1 … Industry m				
Intermediate Use	Region 1	Industry 1 … Industry m	$\boldsymbol{Z}^{\boldsymbol{11}}$	…	$\boldsymbol{Z}^{\boldsymbol{1n}}$	$\boldsymbol{F}^{11}$	…	$\boldsymbol{F}^{1n}$	$\boldsymbol{x}^{\boldsymbol{1}}$
	…	…				…	…	…	…
	Region n	Industry 1 … Industry m	$\boldsymbol{Z}^{\boldsymbol{n2}}$	…	$\boldsymbol{Z}^{\boldsymbol{nn}}$	$\boldsymbol{F}^{n1}$	…	$\boldsymbol{F}^{nn}$	$\boldsymbol{x}^{\boldsymbol{n}}$
Value added			$(\boldsymbol{V}^1)'$	…	$(\boldsymbol{V}^n)'$				
Total output			$(\boldsymbol{x}^{\boldsymbol{1}})'$	…	$(\boldsymbol{x}^{\boldsymbol{n}})'$				
Environmental indicator			$(\boldsymbol{W}^{\boldsymbol{1}})'$	…	$(\boldsymbol{W}^{\boldsymbol{n}})'$				

Table S3. The leaching-runoff fraction of COD, NH_3-N, TN, and TP (%) under recycling and non-recycling condition.

	a_{COD}	$a_{\mathrm{NH3-N}}$	α_{TN}	α_{TP}	b_{COD}	$b_{\mathrm{NH3-N}}$	b_{TN}	b_{TP}
Beijing	1.2	0.6	3	0.2	20	20	20	20
Tianjin	2.4	1.2	6	0.5	20	20	20	20
Hebei	1.8	0.9	4.5	0.3	20	20	20	20
Shanxi	0.6	0.3	1.5	0.1	20	20	20	20
Inner Mongolia	0.32	0.16	0.8	0.1	0.8	0.16	0.8	0.1
Liaoning	3.6	1.8	9	0.8	20	20	20	20
Jilin	2.4	1.2	6	0.5	20	20	20	20
Heilongjiang	3.84	1.92	9.6	0.9	20	20	20	20
Shanghai	3.6	1.8	9	0.8	30	30	30	30
Jiangsu	6.32	3.16	15.8	1.3	30	30	30	30
Zhejiang	6.72	3.36	16.8	1.5	30	30	30	30
Anhui	6.32	3.16	15.8	1.3	30	30	30	30
Fujian	6.72	3.36	16.8	1.5	30	30	30	30
Jiangxi	3.84	1.92	9.6	0.9	30	30	30	30
Shandong	1.8	0.9	4.5	0.3	20	20	20	20
Henan	1.8	0.9	4.5	0.3	20	20	20	20
Hubei	3.6	1.8	9	0.7	30	30	30	30
Hunan	3.84	1.92	9.6	0.9	30	30	30	30
Guangdong	3.84	1.92	9.6	0.9	30	30	30	30
Guangxi	3.84	1.92	9.6	0.9	30	30	30	30
Hainan	3.84	1.92	9.6	0.9	30	30	30	30
Chongqing	3.84	1.92	9.6	0.9	30	30	30	30
Sichuan	10.8	5.4	27	2.7	30	30	30	30
Guizhou	10.8	5.4	27	2.7	30	30	30	30
Yunnan	10.8	5.4	27	2.7	30	30	30	30
Tibet	1.52	0.76	3.8	0.7	3.8	0.76	3.8	0.7
Shaanxi	1.2	0.6	3	0.2	20	20	20	20
Gansu	0.32	0.16	0.8	0.1	0.8	0.16	0.8	0.1
Qinghai	0.32	0.16	0.8	0.1	0.8	0.16	0.8	0.1
Ningxia	0.32	0.16	0.8	0.1	20	20	20	20
Xinjiang	0.16	0.08	0.4	0.05	0.4	0.08	0.4	0.05

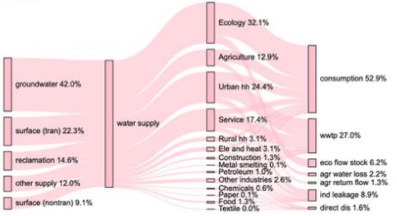
Table S4. COD, TP, and TN mass in per unit of manure generated by livestock

	Pig (g capita^{-1} day^{-1})			Cattle (g capita^{-1} day^{-1})			Sheep (g capita^{-1} day^{-1})			Poultry (g capita^{-1} day^{-1})		
	COD	TN	TP	COD	TN	TP	COD	TN	TP	COD	TN	TP
Beijing	420	33.23	6.06	3758	135.35	19.99	168	13.29	2.42	21	1.16	0.3
Tianjin	420	33.23	6.06	3758	135.35	19.99	168	13.29	2.42	21	1.16	0.3
Hebei	420	33.23	6.06	3758	135.35	19.99	168	13.29	2.42	21	1.16	0.3
Shanxi	420	33.23	6.06	3758	135.35	19.99	168	13.29	2.42	21	1.16	0.3
Inner Mongolia	420	33.23	6.06	3758	135.35	19.99	168	13.29	2.42	21	1.16	0.3
Liaoning	430	57.7	6.16	3881	167.57	28.18	172	23.08	2.46	26	1.37	0.33
Jilin	430	57.7	6.16	3881	167.57	28.18	172	23.08	2.46	26	1.37	0.33
Heilongjiang	430	57.7	6.16	3881	167.57	28.18	172	23.08	2.46	26	1.37	0.33
Shanghai	338	25.4	3.21	3698	157.31	22.66	135	10.16	1.28	29	0.99	0.47
Jiangsu	338	25.4	3.21	3698	157.31	22.66	135	10.16	1.28	29	0.99	0.47
Zhejiang	338	25.4	3.21	3698	157.31	22.66	135	10.16	1.28	29	0.99	0.47
Anhui	338	25.4	3.21	3698	157.31	22.66	135	10.16	1.28	29	0.99	0.47
Fujian	338	25.4	3.21	3698	157.31	22.66	135	10.16	1.28	29	0.99	0.47
Jiangxi	338	25.4	3.21	3698	157.31	22.66	135	10.16	1.28	29	0.99	0.47
Shandong	338	25.4	3.21	3698	157.31	22.66	135	10.16	1.28	29	0.99	0.47
Henan	359	44.73	5.99	3735	156.26	27.37	144	17.89	2.4	17	0.89	0.13
Hubei	359	44.73	5.99	3735	156.26	27.37	144	17.89	2.4	17	0.89	0.13
Hunan	359	44.73	5.99	3735	156.26	27.37	144	17.89	2.4	17	0.89	0.13
Guangdong	359	44.73	5.99	3735	156.26	27.37	144	17.89	2.4	17	0.89	0.13
Guangxi	359	44.73	5.99	3735	156.26	27.37	144	17.89	2.4	17	0.89	0.13
Hainan	359	44.73	5.99	3735	156.26	27.37	144	17.89	2.4	17	0.89	0.13
Chongqing	404	19.74	4.84	3259	132.62	17.82	161	7.9	1.94	17	0.89	0.13
Sichuan	404	19.74	4.84	3259	132.62	17.82	161	7.9	1.94	17	0.89	0.13
Guizhou	404	19.74	4.84	3259	132.62	17.82	161	7.9	1.94	17	0.89	0.13
Yunnan	404	19.74	4.84	3259	132.62	17.82	161	7.9	1.94	17	0.89	0.13
Tibet	404	19.74	4.84	3259	132.62	17.82	161	7.9	1.94	17	0.89	0.13
Shaanxi	397	36.77	4.88	2521	125.53	11.95	159	14.71	1.95	26	1.37	0.33
Gansu	397	36.77	4.88	2521	125.53	11.95	159	14.71	1.95	26	1.37	0.33
Qinghai	397	36.77	4.88	2521	125.53	11.95	159	14.71	1.95	26	1.37	0.33
Ningxia	397	36.77	4.88	2521	125.53	11.95	159	14.71	1.95	26	1.37	0.33
Xinjiang	397	36.77	4.88	2521	125.53	11.95	159	14.71	1.95	26	1.37	0.33

Table S5. Aggregated water use industry for Sankey diagrams

No.	Sectors presented in Sankey diagrams	Abbreviation
1	Agriculture, Forestry, Animal Husbandry and Fishery	Agriculture
2	Food and tobacco processing	Food
3	Textile industry	Textile
4	Manufacture of paper, printing and articles for culture, education, and sport activity	Paper
5	Processing of petroleum, coking, processing of nuclear fuel	Petroleum
6	Manufacture of chemical products	Chemicals
7	Smelting and processing of metals	Metal smelting
8	Production and distribution of electric power and heat power	Ele and heat
9	Other industries	Other industries
10	Construction	Construction
11	Service	Service
12	Environmental flow augmentation	Ecology
13	Urban household	Urban hh
14	Rural household	Rural hh

Beijing



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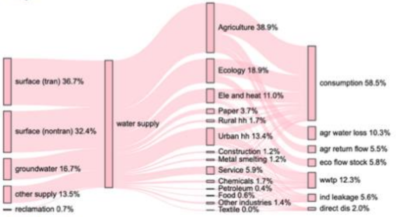
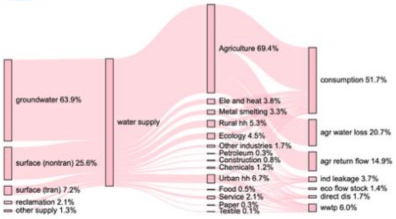


Hebei



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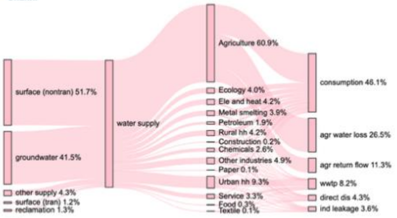
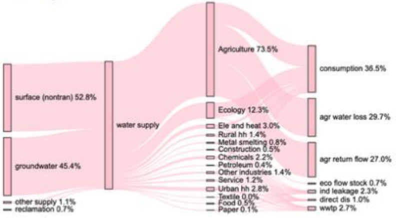
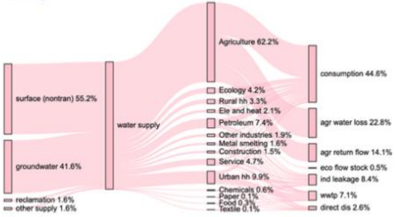


Inner Mongolia



Liaoning



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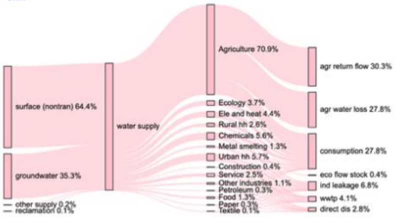
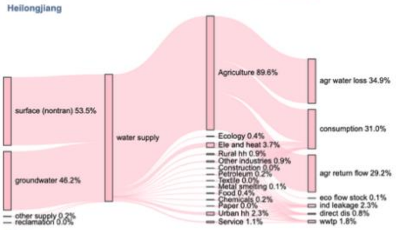
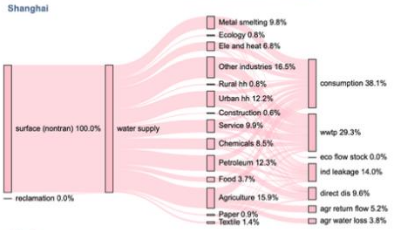


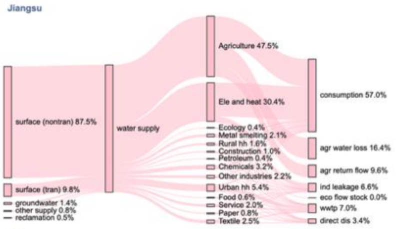
Heilongjiang



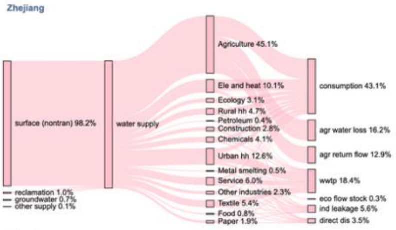
Shanghai



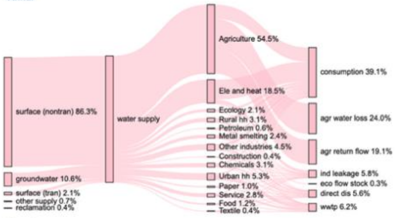
Jiangsu



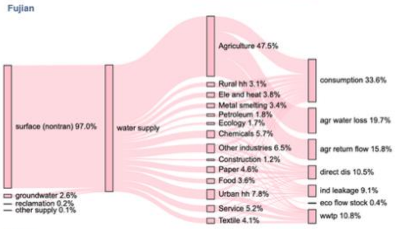
Zhejiang



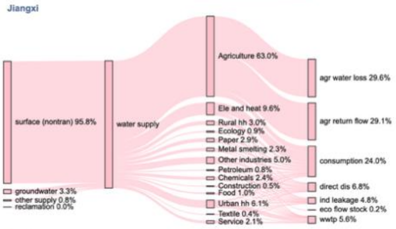
Anhui



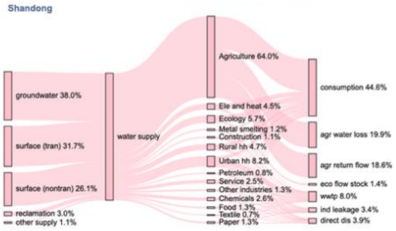
Fujian



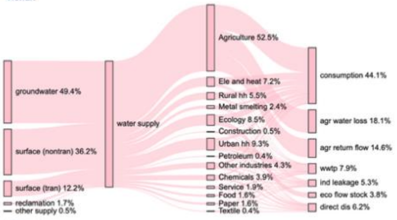
Jiangxi



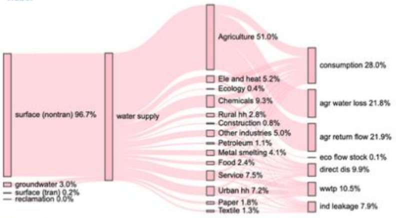
Shandong



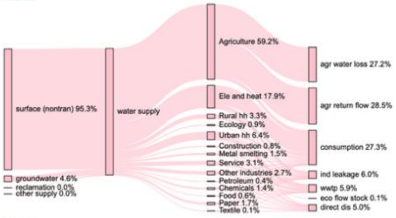
Henan



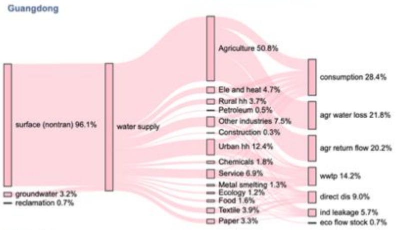
Hubei



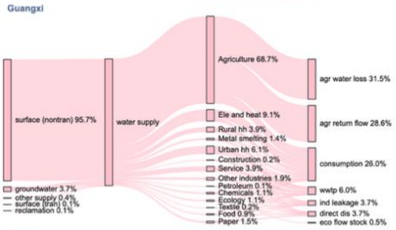
Hunan



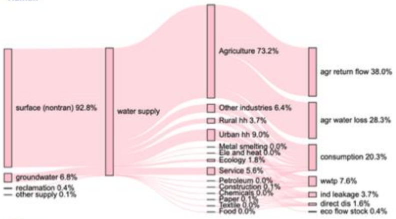
Guangdong



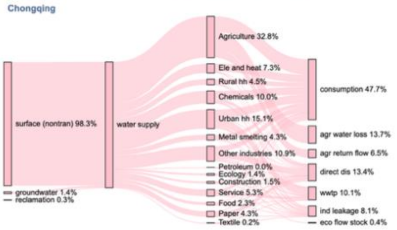
Guangxi



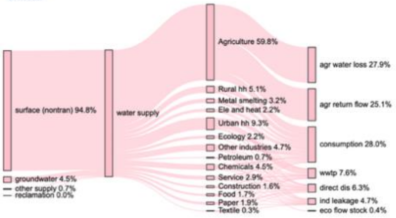
Hainan



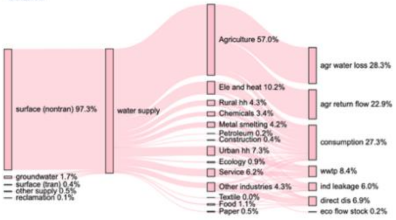
Chongqing



Sichuan



Guizhou



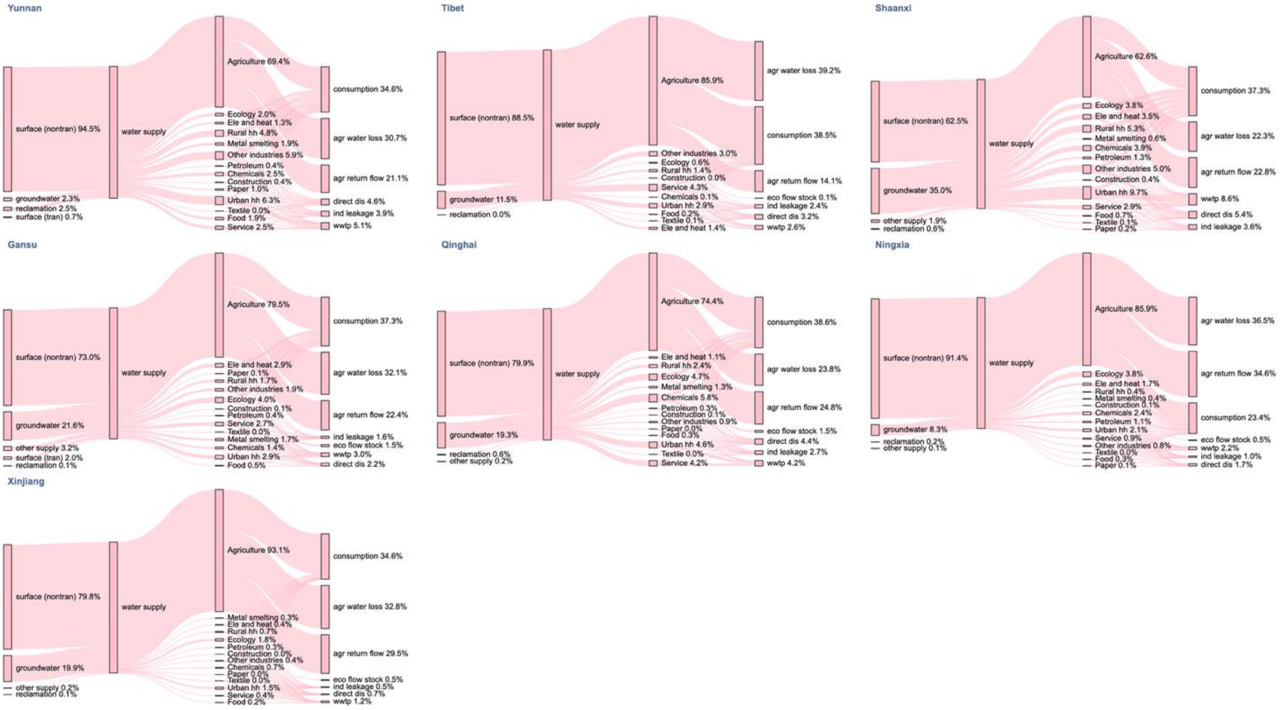


Fig. S1 Physical water quantity metabolism of 31 regions in China


Beijing
consumption im 35.9%
agr loss im 27.3%
agr RF im 23.4%
ind leakage im 4.2%
direct dis im 5.1%
wwtp im 4.1%
Agriculture
Ele and heat
Metal smelting
Construction
Petroleum
Chemicals
Other industries
Food
Paper
Service
Textile
agr loss ex 2.9%
agr RF ex 1.7%
consumption ex 43.1%
direct dis ex 3.3%
ind leakage ex 13.4%
wwtp ex 35.6%
Tianjin
consumption im 35.7%
agr loss im 30.2%
agr RF im 25.0%
ind leakage im 3.1%
direct dis im 3.5%
wwtp im 2.6%
Agriculture
Ele and heat
Metal smelting
Construction
Petroleum
Chemicals
Other industries
Paper
Food
Service
Textile
agr loss ex 14.1%
consumption ex 60.7%
agr RF ex 7.5%
ind leakage ex 6.2%
direct dis ex 2.3%
wwtp ex 9.2%
Hebei
consumption im 33.7%
agr loss im 29.1%
agr RF im 25.6%
ind leakage im 4.0%
direct dis im 4.8%
wwtp im 2.8%
Agriculture
Ele and heat
Metal smelting
Petroleum
Construction
Chemicals
Other industries
Food
Service
Paper
Textile
consumption ex 51.4%
agr loss ex 25.1%
agr RF ex 18.1%
ind leakage ex 2.4%
direct dis ex 1.1%
wwtp ex 2.0%
Shanxi
agr loss im 33.3%
agr RF im 28.9%
consumption im 31.0%
ind leakage im 2.1%
direct dis im 2.9%
wwtp im 1.8%
Agriculture
Ele and heat
Metal smelting
Petroleum
Chemicals
Construction
Other industries
Paper
Food
Textile
Service
agr loss ex 13.9%
agr RF ex 6.0%
consumption ex 55.2%
ind leakage ex 7.0%
direct dis ex 11.7%
wwtp ex 6.2%
Inner Mongolia
wwtp im 3.6%
direct dis im 4.3%
ind leakage im 3.6%
consumption im 34.0%
agr loss im 29.1%
agr RF im 25.4%
Textile
Paper
Service
Food
Agriculture
Other industries
Chemicals
Petroleum
Construction
Metal smelting
Ele and heat
wwtp ex 1.2%
direct dis ex 1.1%
consumption ex 28.0%
agr loss ex 35.4%
ind leakage ex 2.1%
agr RF ex 32.2%
Liaoning
agr loss im 29.3%
agr RF im 25.8%
consumption im 33.0%
ind leakage im 3.6%
direct dis im 4.5%
wwtp im 3.7%
Agriculture
Ele and heat
Petroleum
Metal smelting
Construction
Other industries
Chemicals
Paper
Food
Service
Textile
agr loss ex 25.8%
agr RF ex 16.0%
consumption ex 44.9%
ind leakage ex 7.8%
direct dis ex 2.8%
wwtp ex 2.7%
Jilin
direct dis im 3.3%
wwtp im 2.2%
ind leakage im 3.2%
consumption im 34.9%
agr loss im 30.7%
agr RF im 25.6%
Textile
Paper
Food
Service
Other industries
Chemicals
Petroleum
Construction
Metal smelting
Ele and heat
Agriculture
direct dis ex 2.6%
wwtp ex 1.8%
ind leakage ex 5.2%
consumption ex 23.0%
agr RF ex 35.2%
agr loss ex 32.2%
Heilongjiang
agr loss im 23.2%
agr RF im 18.9%
consumption im 41.1%
ind leakage im 5.9%
direct dis im 6.1%
wwtp im 4.7%
Agriculture
Ele and heat
Petroleum
Metal smelting
Construction
Other industries
Chemicals
Food
Paper
Textile
Service
agr loss ex 36.5%
agr RF ex 30.5%
consumption ex 30.6%
ind leakage ex 1.5%
direct dis ex 0.4%
wwtp ex 0.4%
Shanghai
agr loss im 27.1%
agr RF im 23.2%
consumption im 36.3%
ind leakage im 4.4%
direct dis im 4.6%
wwtp im 4.4%
Agriculture
Metal smelting
Ele and heat
Petroleum
Chemicals
Construction
Other industries
Service
Food
Paper
Textile
agr RF ex 2.4%
agr loss ex 1.7%
consumption ex 41.7%
direct dis ex 12.4%
ind leakage ex 15.6%
wwtp ex 26.3%
Jiangsu
consumption im 32.4%
agr loss im 29.9%
agr RF im 26.5%
ind leakage im 3.7%
direct dis im 4.6%
wwtp im 3.0%
Ele and heat
Agriculture
Metal smelting
Construction
Petroleum
Chemicals
Other industries
Food
Paper
Service
Textile
consumption ex 60.6%
ind leakage ex 6.8%
agr loss ex 16.0%
agr RF ex 9.4%
direct dis ex 3.7%
wwtp ex 3.5%
Zhejiang
consumption im 34.8%
agr loss im 28.7%
agr RF im 24.8%
ind leakage im 4.0%
direct dis im 4.9%
wwtp im 2.9%
Agriculture
Ele and heat
Metal smelting
Petroleum
Construction
Chemicals
Other industries
Food
Paper
Service
Textile
consumption ex 43.5%
agr loss ex 21.5%
agr RF ex 17.2%
ind leakage ex 4.4%
direct dis ex 2.8%
wwtp ex 10.7%
Anhui
ind leakage im 3.6%
direct dis im 4.1%
wwtp im 3.0%
consumption im 34.1%
agr loss im 29.5%
agr RF im 25.7%
Ele and heat
Other industries
Chemicals
Petroleum
Paper
Food
Metal smelting
Textile
Service
Construction
Agriculture
consumption ex 39.5%
direct dis ex 6.9%
ind leakage ex 5.9%
wwtp ex 3.0%
agr loss ex 24.8%
agr RF ex 19.8%
Fujian
agr loss im 34.8%
agr RF im 30.6%
consumption im 29.7%
ind leakage im 1.5%
direct dis im 1.9%
wwtp im 1.4%
Agriculture
Ele and heat
Metal smelting
Petroleum
Construction
Chemicals
Other industries
Paper
Food
Service
Textile
agr loss ex 12.9%
agr RF ex 10.4%
consumption ex 38.3%
ind leakage ex 12.3%
direct dis ex 16.4%
wwtp ex 9.6%
Jiangxi
direct dis im 4.2%
wwtp im 2.6%
ind leakage im 3.7%
consumption im 34.3%
agr loss im 29.3%
agr RF im 25.8%
Textile
Paper
Other industries
Food
Service
Chemicals
Petroleum
Metal smelting
Construction
Ele and heat
Agriculture
direct dis ex 7.6%
wwtp ex 2.4%
ind leakage ex 4.5%
consumption ex 22.4%
agr loss ex 31.8%
agr RF ex 31.3%
Shandong
consumption im 37.0%
agr loss im 28.3%
agr RF im 23.9%
ind leakage im 3.7%
direct dis im 3.9%
wwtp im 3.2%
Agriculture
Ele and heat
Metal smelting
Construction
Petroleum
Chemicals
Other industries
Food
Service
Paper
Textile
consumption ex 45.1%
agr loss ex 20.1%
agr RF ex 18.8%
ind leakage ex 4.1%
direct dis ex 6.7%
wwtp ex 5.2%
Henan
consumption im 38.9%
agr loss im 24.3%
agr RF im 21.6%
ind leakage im 5.5%
direct dis im 5.5%
wwtp im 4.2%
Agriculture
Ele and heat
Metal smelting
Petroleum
Construction
Chemicals
Other industries
Food
Service
Paper
Textile
consumption ex 43.2%
agr loss ex 22.2%
agr RF ex 18.0%
ind leakage ex 5.1%
direct dis ex 8.6%
wwtp ex 2.8%
Hubei
agr loss im 32.4%
agr RF im 28.6%
consumption im 30.7%
ind leakage im 2.7%
direct dis im 3.1%
wwtp im 2.4%
Agriculture
Ele and heat
Metal smelting
Chemicals
Construction
Petroleum
Other industries
Food
Paper
Service
Textile
agr loss ex 18.3%
agr RF ex 18.4%
consumption ex 31.2%
ind leakage ex 9.4%
direct dis ex 13.8%
wwtp ex 8.8%
Hunan
direct dis im 4.9%
wwtp im 3.0%
ind leakage im 4.6%
consumption im 34.3%
agr loss im 28.2%
agr RF im 25.0%
Paper
Textile
Food
Service
Chemicals
Other industries
Petroleum
Metal smelting
Ele and heat
Construction
Agriculture
direct dis ex 5.6%
wwtp ex 1.9%
ind leakage ex 4.7%
consumption ex 21.8%
agr RF ex 33.8%
agr loss ex 32.3%
Guangdong
direct dis im 4.2%
wwtp im 2.7%
ind leakage im 3.9%
consumption im 30.5%
agr loss im 30.8%
agr RF im 27.9%
Paper
Textile
Food
Other industries
Service
Chemicals
Petroleum
Metal smelting
Ele and heat
Construction
Agriculture
direct dis ex 11.1%
wwtp ex 6.2%
ind leakage ex 4.3%
consumption ex 25.3%
agr loss ex 27.5%
agr RF ex 25.6%
Guangxi
wwtp im 4.3%
direct dis im 6.1%
ind leakage im 5.3%
consumption im 35.2%
agr loss im 25.1%
agr RF im 24.0%
Service
Textile
Paper
Food
Other industries
Chemicals
Agriculture
Construction
Petroleum
Ele and heat
Metal smelting
wwtp ex 2.1%
direct dis ex 3.0%
ind leakage ex 2.9%
consumption ex 24.4%
agr loss ex 35.4%
agr RF ex 32.2%
Hainan
agr loss im 30.8%
agr RF im 26.8%
consumption im 32.7%
ind leakage im 2.9%
direct dis im 3.4%
wwtp im 3.4%
Agriculture
Ele and heat
Metal smelting
Petroleum
Construction
Other industries
Chemicals
Service
Paper
Food
Textile
agr RF ex 49.2%
agr loss ex 36.7%
consumption ex 10.8%
ind leakage ex 0.8%
wwtp ex 2.1%
direct dis ex 0.4%
Chongqing
consumption im 35.0%
agr loss im 29.3%
agr RF im 25.6%
ind leakage im 3.5%
direct dis im 4.0%
wwtp im 2.5%
Agriculture
Ele and heat
Metal smelting
Petroleum
Construction
Chemicals
Other industries
Food
Service
Paper
Textile
agr loss ex 14.0%
agr RF ex 6.6%
consumption ex 48.1%
ind leakage ex 8.4%
direct dis ex 18.4%
wwtp ex 4.5%
Sichuan
direct dis im 4.3%
wwtp im 2.6%
ind leakage im 3.3%
consumption im 34.7%
agr loss im 30.0%
agr RF im 25.1%
Textile
Paper
Food
Service
Other industries
Chemicals
Petroleum
Construction
Ele and heat
Metal smelting
Agriculture
direct dis ex 8.1%
wwtp ex 3.6%
ind leakage ex 4.5%
consumption ex 25.2%
agr loss ex 30.8%
agr RF ex 27.8%
Guizhou
wwtp im 3.6%
direct dis im 5.5%
ind leakage im 4.6%
consumption im 35.6%
agr loss im 28.1%
agr RF im 22.6%
Service
Other industries
Textile
Paper
Food
Chemicals
Metal smelting
Ele and heat
Construction
Petroleum
Agriculture
wwtp ex 3.3%
direct dis ex 9.2%
ind leakage ex 5.3%
consumption ex 25.5%
agr loss ex 31.4%
agr RF ex 25.3%

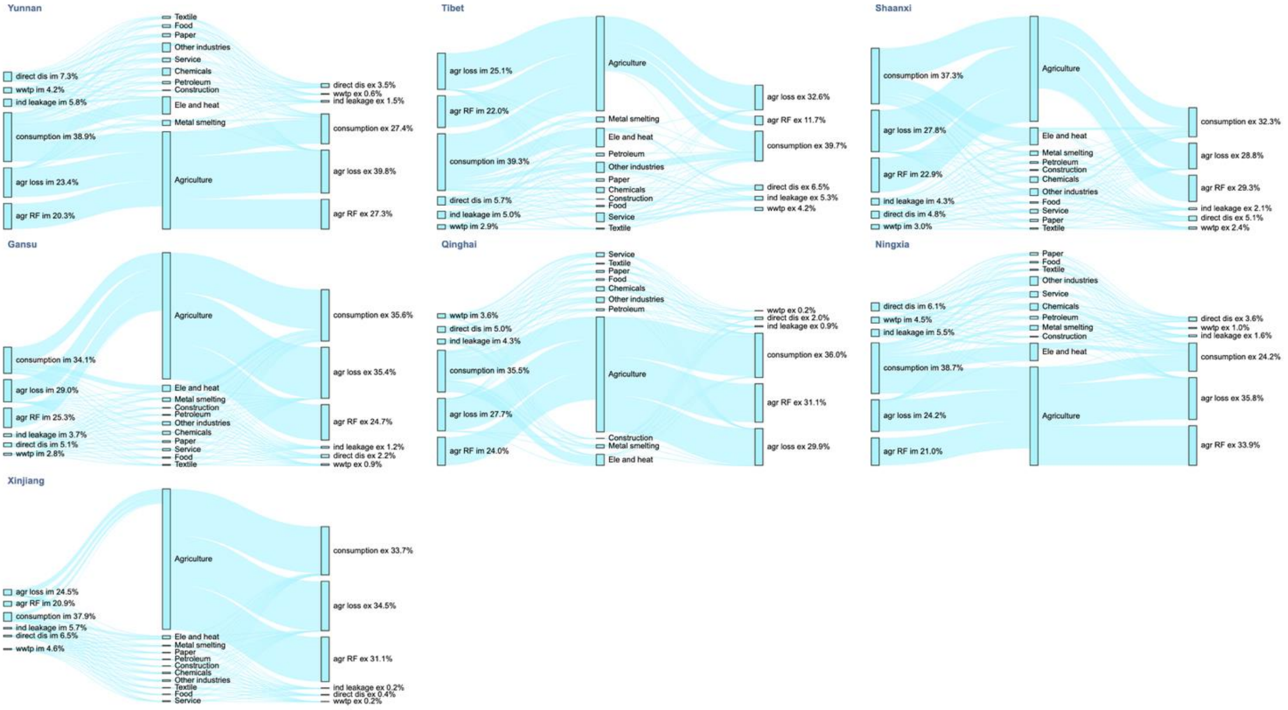
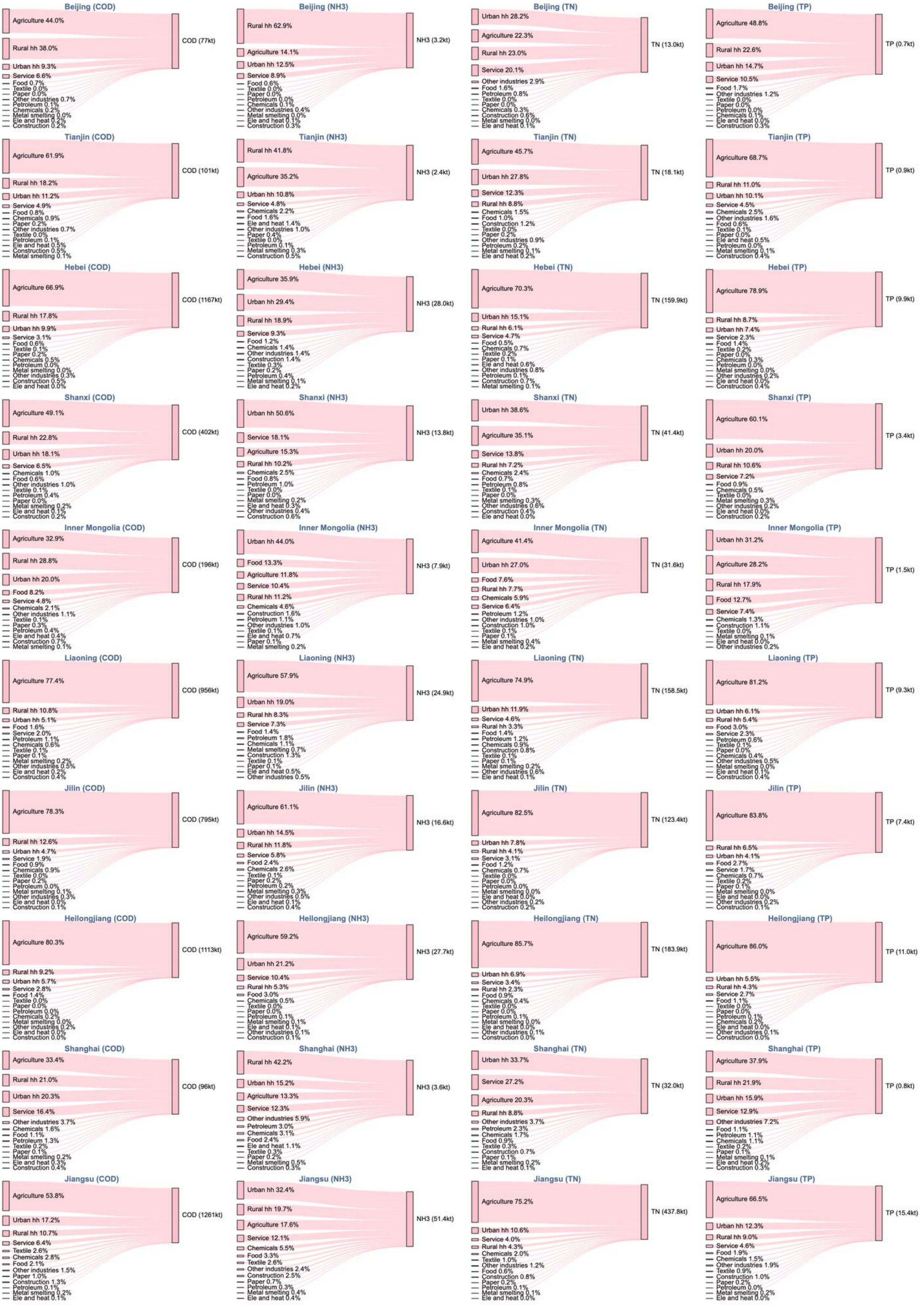
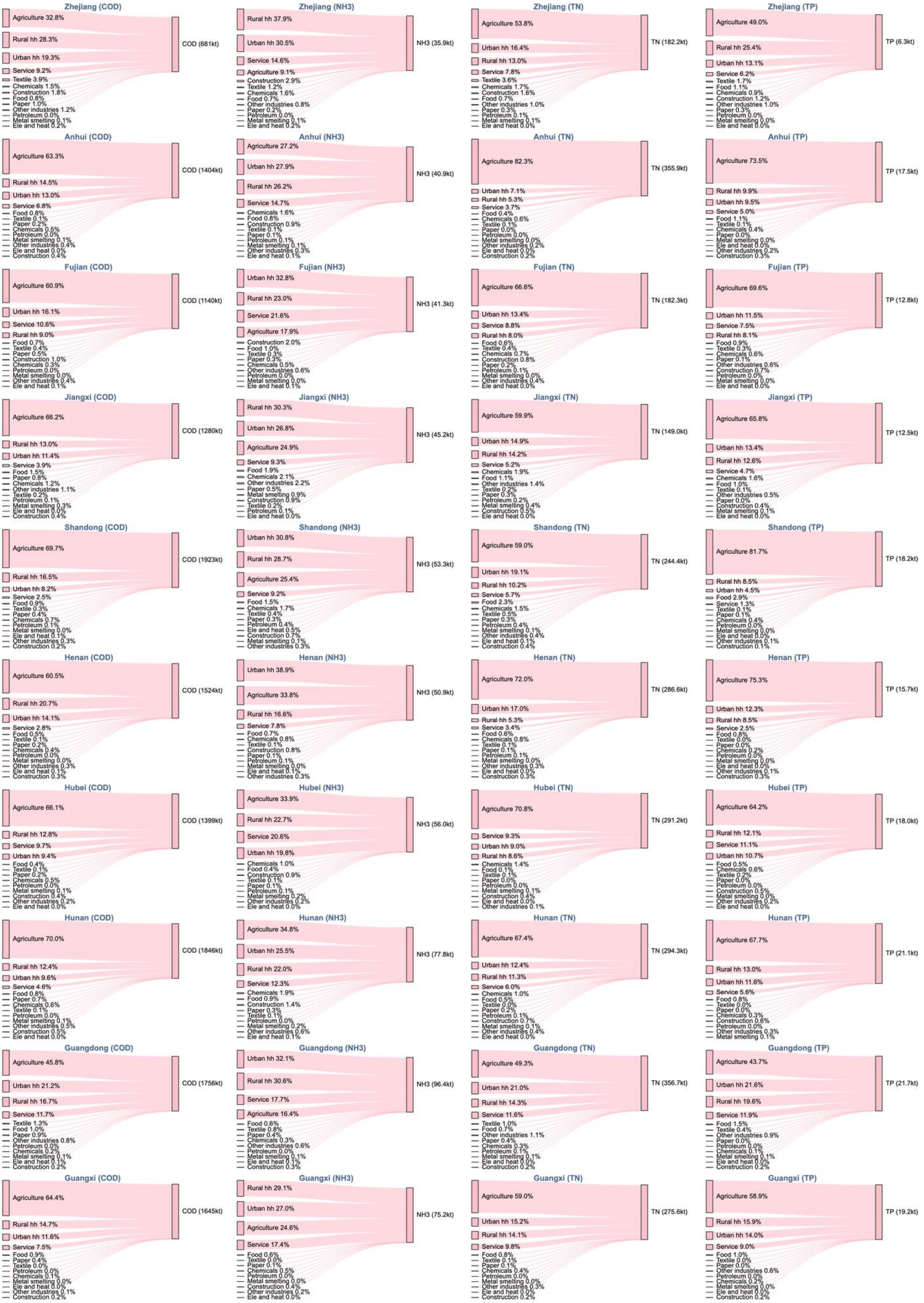
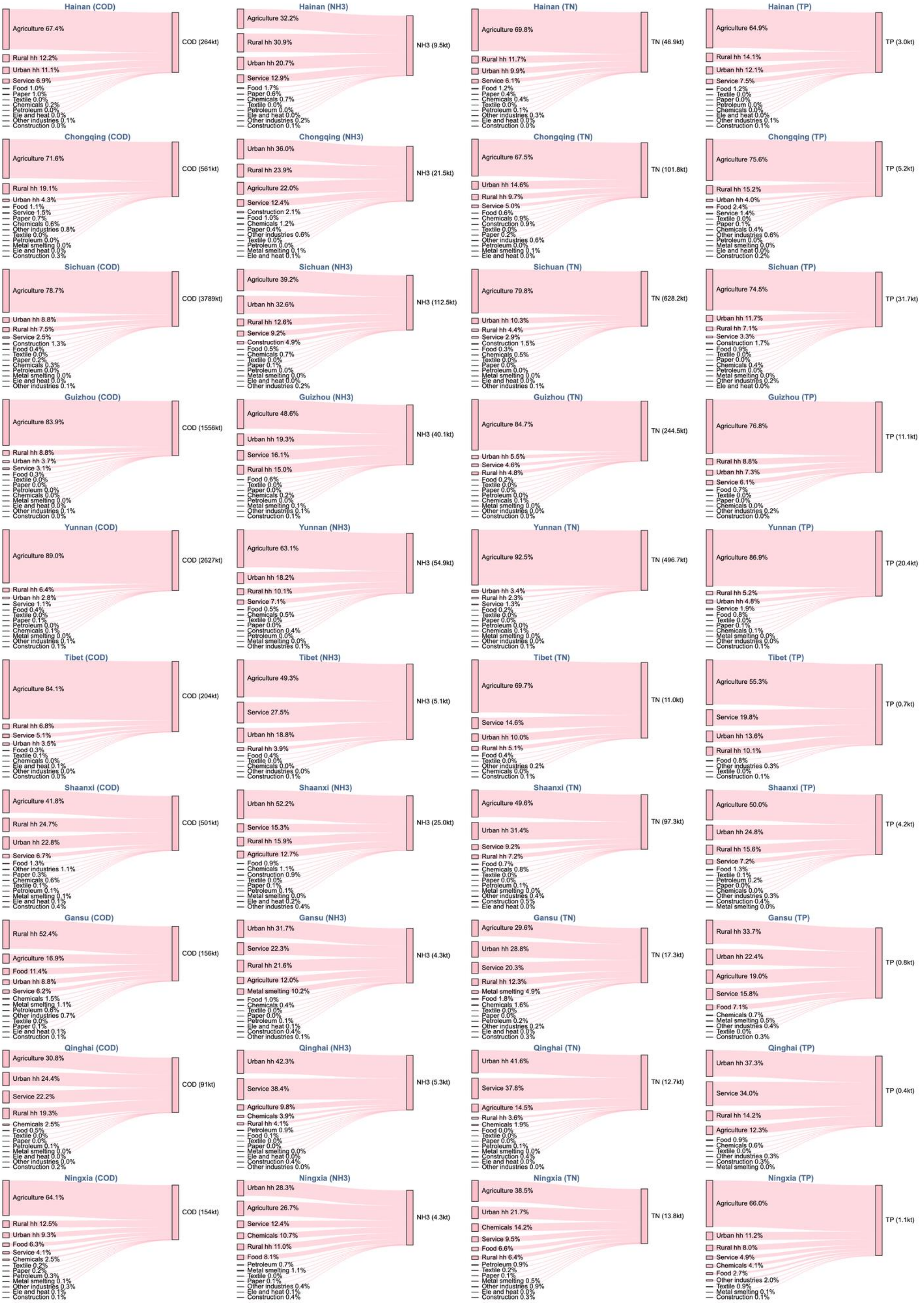


Fig. S2 Virtual water quantity metabolism of 31 regions in China


Beijing (COD)
Agriculture 44.0%
Rural hh 38.0%
Urban hh 9.3%
Service 6.6%
Food 0.7%
Textile 0.0%
Paper 0.0%
Other industries 0.7%
Petroleum 0.1%
Chemicals 0.2%
Metal smelting 0.0%
Ele and heat 0.2%
Construction 0.2%
COD (77kt)
Beijing (NH3)
Rural hh 62.9%
Agriculture 14.1%
Urban hh 12.5%
Service 8.9%
Food 0.6%
Textile 0.0%
Paper 0.0%
Petroleum 0.0%
Chemicals 0.1%
Other industries 0.4%
Metal smelting 0.0%
Ele and heat 0.1%
Construction 0.3%
NH3 (3.2kt)
Beijing (TN)
Urban hh 28.2%
Agriculture 22.3%
Rural hh 23.0%
Service 20.1%
Other industries 2.9%
Food 1.6%
Petroleum 0.8%
Textile 0.0%
Paper 0.0%
Chemicals 0.3%
Construction 0.6%
Metal smelting 0.0%
Ele and heat 0.1%
TN (13.0kt)
Beijing (TP)
Agriculture 48.8%
Rural hh 22.6%
Urban hh 14.7%
Service 10.5%
Food 1.7%
Other industries 1.2%
Textile 0.0%
Paper 0.0%
Petroleum 0.0%
Chemicals 0.1%
Ele and heat 0.0%
Construction 0.3%
TP (0.7kt)
Tianjin (COD)
Agriculture 61.9%
Rural hh 18.2%
Urban hh 11.2%
Service 4.9%
Food 0.8%
Chemicals 0.9%
Paper 0.2%
Other industries 0.7%
Textile 0.0%
Petroleum 0.1%
Ele and heat 0.5%
Construction 0.5%
Metal smelting 0.1%
COD (101kt)
Tianjin (NH3)
Rural hh 41.8%
Agriculture 35.2%
Urban hh 10.8%
Service 4.8%
Chemicals 2.2%
Food 1.6%
Ele and heat 1.4%
Other industries 1.0%
Paper 0.4%
Textile 0.0%
Petroleum 0.1%
Metal smelting 0.3%
Construction 0.5%
NH3 (2.4kt)
Tianjin (TN)
Agriculture 45.7%
Urban hh 27.8%
Service 12.3%
Rural hh 8.8%
Chemicals 1.5%
Food 1.0%
Construction 1.2%
Textile 0.0%
Paper 0.2%
Other industries 0.9%
Petroleum 0.2%
Metal smelting 0.1%
Ele and heat 0.2%
TN (18.1kt)
Tianjin (TP)
Agriculture 68.7%
Rural hh 11.0%
Urban hh 10.1%
Service 4.5%
Chemicals 2.5%
Other industries 1.6%
Food 0.6%
Textile 0.1%
Paper 0.0%
Ele and heat 0.5%
Petroleum 0.0%
Metal smelting 0.1%
Construction 0.4%
TP (0.9kt)
Hebei (COD)
Agriculture 66.9%
Rural hh 17.8%
Urban hh 9.9%
Service 3.1%
Food 0.6%
Textile 0.1%
Paper 0.2%
Chemicals 0.5%
Petroleum 0.0%
Metal smelting 0.0%
Other industries 0.3%
Construction 0.5%
Ele and heat 0.0%
COD (1167kt)
Hebei (NH3)
Agriculture 35.9%
Urban hh 29.4%
Rural hh 18.9%
Service 9.3%
Food 1.2%
Chemicals 1.4%
Other industries 1.4%
Construction 1.4%
Textile 0.3%
Paper 0.2%
Petroleum 0.4%
Metal smelting 0.1%
Ele and heat 0.2%
NH3 (28.0kt)
Hebei (TN)
Agriculture 70.3%
Urban hh 15.1%
Rural hh 6.1%
Service 4.7%
Food 0.5%
Chemicals 0.7%
Textile 0.2%
Paper 0.1%
Ele and heat 0.6%
Other industries 0.8%
Petroleum 0.1%
Construction 0.7%
Metal smelting 0.1%
TN (159.9kt)
Hebei (TP)
Agriculture 78.9%
Rural hh 8.7%
Urban hh 7.4%
Service 2.3%
Food 1.4%
Textile 0.2%
Paper 0.0%
Chemicals 0.3%
Petroleum 0.0%
Metal smelting 0.0%
Other industries 0.2%
Ele and heat 0.0%
Construction 0.4%
TP (9.9kt)
Shanxi (COD)
Agriculture 49.1%
Rural hh 22.8%
Urban hh 18.1%
Service 6.5%
Chemicals 1.0%
Food 0.6%
Other industries 1.0%
Textile 0.1%
Petroleum 0.4%
Paper 0.0%
Metal smelting 0.2%
Ele and heat 0.1%
Construction 0.2%
COD (402kt)
Shanxi (NH3)
Urban hh 50.6%
Service 18.1%
Agriculture 15.3%
Rural hh 10.2%
Chemicals 2.5%
Food 0.8%
Petroleum 1.0%
Textile 0.0%
Paper 0.0%
Metal smelting 0.2%
Ele and heat 0.3%
Other industries 0.4%
Construction 0.6%
NH3 (13.8kt)
Shanxi (TN)
Urban hh 38.6%
Agriculture 35.1%
Service 13.8%
Rural hh 7.2%
Chemicals 2.4%
Food 0.7%
Petroleum 0.8%
Textile 0.1%
Paper 0.0%
Metal smelting 0.3%
Other industries 0.6%
Construction 0.4%
Ele and heat 0.0%
TN (41.4kt)
Shanxi (TP)
Agriculture 60.1%
Urban hh 20.0%
Rural hh 10.6%
Service 7.2%
Food 0.9%
Chemicals 0.5%
Textile 0.0%
Metal smelting 0.3%
Other industries 0.2%
Ele and heat 0.0%
Construction 0.2%
TP (3.4kt)
Inner Mongolia (COD)
Agriculture 32.9%
Rural hh 28.8%
Urban hh 20.0%
Food 8.2%
Service 4.8%
Chemicals 2.1%
Other industries 1.1%
Textile 0.1%
Paper 0.3%
Petroleum 0.4%
Ele and heat 0.4%
Construction 0.7%
Metal smelting 0.1%
COD (196kt)
Inner Mongolia (NH3)
Urban hh 44.0%
Food 13.3%
Agriculture 11.8%
Service 10.4%
Rural hh 11.2%
Chemicals 4.6%
Construction 1.6%
Petroleum 1.1%
Other industries 1.0%
Textile 0.1%
Ele and heat 0.7%
Paper 0.1%
Metal smelting 0.2%
NH3 (7.9kt)
Inner Mongolia (TN)
Agriculture 41.4%
Urban hh 27.0%
Food 7.6%
Rural hh 7.7%
Chemicals 5.9%
Service 6.4%
Petroleum 1.2%
Other industries 1.0%
Construction 1.0%
Textile 0.1%
Paper 0.1%
Metal smelting 0.4%
Ele and heat 0.2%
TN (31.6kt)
Inner Mongolia (TP)
Urban hh 31.2%
Agriculture 28.2%
Rural hh 17.9%
Food 12.7%
Service 7.4%
Chemicals 1.3%
Construction 1.1%
Textile 0.0%
Metal smelting 0.1%
Ele and heat 0.0%
Other industries 0.2%
TP (1.5kt)
Liaoning (COD)
Agriculture 77.4%
Rural hh 10.8%
Urban hh 5.1%
Food 1.6%
Service 2.0%
Petroleum 1.1%
Chemicals 0.6%
Textile 0.1%
Paper 0.1%
Metal smelting 0.2%
Other industries 0.5%
Ele and heat 0.2%
Construction 0.4%
COD (956kt)
Liaoning (NH3)
Agriculture 57.9%
Urban hh 19.0%
Rural hh 8.3%
Service 7.3%
Food 1.4%
Petroleum 1.8%
Chemicals 1.1%
Metal smelting 0.7%
Construction 1.3%
Textile 0.1%
Paper 0.1%
Ele and heat 0.5%
Other industries 0.5%
NH3 (24.9kt)
Liaoning (TN)
Agriculture 74.9%
Urban hh 11.9%
Service 4.6%
Rural hh 3.3%
Food 1.4%
Petroleum 1.2%
Chemicals 0.9%
Construction 0.8%
Textile 0.1%
Paper 0.1%
Metal smelting 0.2%
Other industries 0.6%
Ele and heat 0.1%
TN (158.5kt)
Liaoning (TP)
Agriculture 81.2%
Urban hh 6.1%
Rural hh 5.4%
Food 3.0%
Service 2.3%
Petroleum 0.6%
Textile 0.1%
Paper 0.0%
Chemicals 0.4%
Other industries 0.5%
Metal smelting 0.0%
Ele and heat 0.1%
Construction 0.4%
TP (9.3kt)
Jilin (COD)
Agriculture 78.3%
Rural hh 12.6%
Urban hh 4.7%
Service 1.9%
Food 0.9%
Chemicals 0.9%
Textile 0.0%
Paper 0.2%
Petroleum 0.0%
Metal smelting 0.1%
Other industries 0.3%
Ele and heat 0.0%
Construction 0.1%
COD (795kt)
Jilin (NH3)
Agriculture 61.1%
Urban hh 14.5%
Rural hh 11.8%
Service 5.8%
Food 2.4%
Chemicals 2.6%
Textile 0.1%
Paper 0.2%
Petroleum 0.2%
Metal smelting 0.3%
Other industries 0.5%
Ele and heat 0.1%
Construction 0.4%
NH3 (16.6kt)
Jilin (TN)
Agriculture 82.5%
Urban hh 7.8%
Rural hh 4.1%
Service 3.1%
Food 1.2%
Chemicals 0.7%
Textile 0.0%
Paper 0.0%
Petroleum 0.0%
Metal smelting 0.0%
Ele and heat 0.0%
Other industries 0.2%
Construction 0.2%
TN (123.4kt)
Jilin (TP)
Agriculture 83.8%
Rural hh 6.5%
Urban hh 4.1%
Food 2.7%
Service 1.7%
Chemicals 0.7%
Textile 0.2%
Paper 0.1%
Metal smelting 0.0%
Ele and heat 0.0%
Other industries 0.2%
Construction 0.1%
TP (7.4kt)
Heilongjiang (COD)
Agriculture 80.3%
Rural hh 9.2%
Urban hh 5.7%
Service 2.8%
Food 1.4%
Textile 0.0%
Paper 0.0%
Petroleum 0.0%
Chemicals 0.2%
Metal smelting 0.0%
Other industries 0.2%
Ele and heat 0.0%
Construction 0.0%
COD (1113kt)
Heilongjiang (NH3)
Agriculture 59.2%
Urban hh 21.2%
Service 10.4%
Rural hh 5.3%
Food 3.0%
Chemicals 0.5%
Textile 0.0%
Paper 0.0%
Petroleum 0.1%
Metal smelting 0.1%
Ele and heat 0.1%
Other industries 0.1%
Construction 0.1%
NH3 (27.7kt)
Heilongjiang (TN)
Agriculture 85.7%
Urban hh 6.9%
Service 3.4%
Rural hh 2.3%
Food 0.9%
Chemicals 0.4%
Textile 0.0%
Paper 0.0%
Petroleum 0.1%
Metal smelting 0.0%
Ele and heat 0.0%
Other industries 0.1%
Construction 0.0%
TN (183.9kt)
Heilongjiang (TP)
Agriculture 86.0%
Urban hh 5.5%
Rural hh 4.3%
Service 2.7%
Food 1.1%
Textile 0.0%
Paper 0.0%
Petroleum 0.1%
Chemicals 0.2%
Ele and heat 0.0%
Other industries 0.1%
Construction 0.0%
TP (11.0kt)
Shanghai (COD)
Agriculture 33.4%
Rural hh 21.0%
Urban hh 20.3%
Service 16.4%
Other industries 3.7%
Chemicals 1.6%
Food 1.1%
Petroleum 1.3%
Textile 0.2%
Paper 0.1%
Metal smelting 0.2%
Ele and heat 0.3%
Construction 0.4%
COD (96kt)
Shanghai (NH3)
Rural hh 42.2%
Urban hh 15.2%
Agriculture 13.3%
Service 12.3%
Other industries 5.9%
Petroleum 3.0%
Chemicals 3.1%
Food 2.4%
Ele and heat 1.1%
Textile 0.3%
Paper 0.2%
Metal smelting 0.5%
Construction 0.3%
NH3 (3.6kt)
Shanghai (TN)
Urban hh 33.7%
Service 27.2%
Agriculture 20.3%
Rural hh 8.8%
Other industries 3.7%
Petroleum 2.3%
Chemicals 1.7%
Food 0.9%
Textile 0.3%
Construction 0.7%
Paper 0.1%
Metal smelting 0.2%
Ele and heat 0.1%
TN (32.0kt)
Shanghai (TP)
Agriculture 37.9%
Rural hh 21.9%
Urban hh 15.9%
Service 12.9%
Other industries 7.2%
Food 1.1%
Petroleum 1.1%
Chemicals 1.1%
Textile 0.2%
Paper 0.1%
Metal smelting 0.1%
Ele and heat 0.2%
Construction 0.3%
TP (0.8kt)
Jiangsu (COD)
Agriculture 53.8%
Urban hh 17.2%
Rural hh 10.7%
Service 6.4%
Textile 2.6%
Chemicals 2.8%
Food 2.1%
Other industries 1.5%
Paper 1.0%
Construction 1.3%
Petroleum 0.1%
Metal smelting 0.2%
Ele and heat 0.1%
COD (1261kt)
Jiangsu (NH3)
Urban hh 32.4%
Rural hh 19.7%
Agriculture 17.6%
Service 12.1%
Chemicals 5.5%
Food 3.3%
Textile 2.6%
Other industries 2.4%
Construction 2.5%
Paper 0.7%
Petroleum 0.3%
Metal smelting 0.4%
Ele and heat 0.4%
NH3 (51.4kt)
Jiangsu (TN)
Agriculture 75.2%
Urban hh 10.6%
Service 4.0%
Rural hh 4.3%
Chemicals 2.0%
Textile 1.0%
Other industries 1.2%
Food 0.6%
Construction 0.8%
Paper 0.2%
Petroleum 0.1%
Metal smelting 0.1%
Ele and heat 0.0%
TN (437.8kt)
Jiangsu (TP)
Agriculture 66.5%
Urban hh 12.3%
Rural hh 9.0%
Service 4.6%
Food 1.9%
Chemicals 1.5%
Other industries 1.9%
Textile 0.9%
Construction 1.0%
Paper 0.2%
Petroleum 0.0%
Metal smelting 0.2%
Ele and heat 0.0%
TP (15.4kt)


Zhejiang (COD)
Agriculture 32.8%
Rural hh 28.3%
Urban hh 19.3%
Service 9.2%
Textile 3.9%
Chemicals 1.5%
Construction 1.8%
Food 0.8%
Paper 1.0%
Other industries 1.2%
Petroleum 0.0%
Metal smelting 0.1%
Ele and heat 0.2%
COD (681kt)
Zhejiang (NH3)
Rural hh 37.9%
Urban hh 30.5%
Service 14.6%
Agriculture 9.1%
Construction 2.9%
Textile 1.2%
Chemicals 1.6%
Food 0.7%
Other industries 0.8%
Paper 0.2%
Petroleum 0.0%
Metal smelting 0.1%
Ele and heat 0.2%
NH3 (35.9kt)
Zhejiang (TN)
Agriculture 53.8%
Urban hh 16.4%
Rural hh 13.0%
Service 7.8%
Textile 3.6%
Chemicals 1.7%
Construction 1.6%
Food 0.7%
Other industries 1.0%
Paper 0.3%
Petroleum 0.1%
Metal smelting 0.1%
Ele and heat 0.0%
TN (182.2kt)
Zhejiang (TP)
Agriculture 49.0%
Rural hh 25.4%
Urban hh 13.1%
Service 6.2%
Textile 1.7%
Food 1.1%
Chemicals 0.9%
Construction 1.2%
Other industries 1.0%
Paper 0.3%
Petroleum 0.0%
Metal smelting 0.0%
Ele and heat 0.0%
TP (6.3kt)
Anhui (COD)
Agriculture 63.3%
Rural hh 14.5%
Urban hh 13.0%
Service 6.8%
Food 0.8%
Textile 0.1%
Paper 0.2%
Chemicals 0.5%
Petroleum 0.0%
Metal smelting 0.1%
Other industries 0.4%
Ele and heat 0.0%
Construction 0.4%
COD (1404kt)
Anhui (NH3)
Agriculture 27.2%
Urban hh 27.9%
Rural hh 26.2%
Service 14.7%
Chemicals 1.6%
Food 0.8%
Construction 0.9%
Textile 0.1%
Paper 0.1%
Petroleum 0.1%
Metal smelting 0.1%
Other industries 0.3%
Ele and heat 0.1%
NH3 (40.9kt)
Anhui (TN)
Agriculture 82.3%
Urban hh 7.1%
Rural hh 5.3%
Service 3.7%
Food 0.4%
Chemicals 0.6%
Textile 0.1%
Paper 0.0%
Petroleum 0.0%
Metal smelting 0.0%
Other industries 0.2%
Ele and heat 0.0%
Construction 0.2%
TN (355.9kt)
Anhui (TP)
Agriculture 73.5%
Rural hh 9.9%
Urban hh 9.5%
Service 5.0%
Food 1.1%
Textile 0.1%
Chemicals 0.4%
Paper 0.0%
Metal smelting 0.0%
Ele and heat 0.0%
Other industries 0.2%
Construction 0.3%
TP (17.5kt)
Fujian (COD)
Agriculture 60.9%
Urban hh 16.1%
Service 10.6%
Rural hh 9.0%
Food 0.7%
Textile 0.4%
Paper 0.5%
Construction 1.0%
Chemicals 0.3%
Petroleum 0.0%
Metal smelting 0.0%
Other industries 0.4%
Ele and heat 0.1%
COD (1140kt)
Fujian (NH3)
Urban hh 32.8%
Rural hh 23.0%
Service 21.6%
Agriculture 17.9%
Construction 2.0%
Food 1.0%
Textile 0.3%
Paper 0.3%
Chemicals 0.5%
Other industries 0.6%
Petroleum 0.0%
Metal smelting 0.0%
Ele and heat 0.1%
NH3 (41.3kt)
Fujian (TN)
Agriculture 66.6%
Urban hh 13.4%
Service 8.8%
Rural hh 8.0%
Food 0.6%
Textile 0.4%
Chemicals 0.7%
Construction 0.8%
Paper 0.2%
Petroleum 0.1%
Metal smelting 0.0%
Other industries 0.4%
Ele and heat 0.0%
TN (182.3kt)
Fujian (TP)
Agriculture 69.6%
Urban hh 11.5%
Service 7.5%
Rural hh 8.1%
Food 0.9%
Textile 0.3%
Chemicals 0.6%
Paper 0.1%
Other industries 0.6%
Construction 0.7%
Petroleum 0.0%
Metal smelting 0.0%
Ele and heat 0.0%
TP (12.8kt)
Jiangxi (COD)
Agriculture 66.2%
Rural hh 13.0%
Urban hh 11.4%
Service 3.9%
Food 1.5%
Paper 0.8%
Chemicals 1.2%
Other industries 1.1%
Textile 0.2%
Petroleum 0.1%
Metal smelting 0.3%
Ele and heat 0.0%
Construction 0.4%
COD (1280kt)
Jiangxi (NH3)
Rural hh 30.3%
Urban hh 26.8%
Agriculture 24.9%
Service 9.3%
Food 1.9%
Chemicals 2.1%
Other industries 2.2%
Paper 0.5%
Metal smelting 0.9%
Construction 0.9%
Textile 0.2%
Petroleum 0.1%
Ele and heat 0.0%
NH3 (45.2kt)
Jiangxi (TN)
Agriculture 59.9%
Urban hh 14.9%
Rural hh 14.2%
Service 5.2%
Chemicals 1.9%
Food 1.1%
Other industries 1.4%
Textile 0.2%
Paper 0.3%
Petroleum 0.2%
Metal smelting 0.4%
Construction 0.5%
Ele and heat 0.0%
TN (149.0kt)
Jiangxi (TP)
Agriculture 65.8%
Urban hh 13.4%
Rural hh 12.6%
Service 4.7%
Chemicals 1.6%
Food 1.0%
Textile 0.1%
Other industries 0.5%
Paper 0.0%
Construction 0.4%
Metal smelting 0.1%
Ele and heat 0.0%
TP (12.5kt)
Shandong (COD)
Agriculture 69.7%
Rural hh 16.5%
Urban hh 8.2%
Service 2.5%
Food 0.9%
Textile 0.3%
Paper 0.4%
Chemicals 0.7%
Petroleum 0.1%
Metal smelting 0.0%
Ele and heat 0.1%
Other industries 0.3%
Construction 0.2%
COD (1923kt)
Shandong (NH3)
Urban hh 30.8%
Rural hh 28.7%
Agriculture 25.4%
Service 9.2%
Food 1.5%
Chemicals 1.7%
Textile 0.4%
Paper 0.3%
Petroleum 0.4%
Ele and heat 0.5%
Construction 0.7%
Metal smelting 0.1%
Other industries 0.3%
NH3 (53.3kt)
Shandong (TN)
Agriculture 59.0%
Urban hh 19.1%
Rural hh 10.2%
Service 5.7%
Food 2.3%
Chemicals 1.5%
Textile 0.5%
Paper 0.3%
Petroleum 0.4%
Metal smelting 0.1%
Other industries 0.4%
Ele and heat 0.1%
Construction 0.4%
TN (244.4kt)
Shandong (TP)
Agriculture 81.7%
Rural hh 8.5%
Urban hh 4.5%
Food 2.9%
Service 1.3%
Textile 0.1%
Paper 0.1%
Chemicals 0.4%
Petroleum 0.0%
Metal smelting 0.0%
Ele and heat 0.0%
Other industries 0.1%
Construction 0.1%
TP (18.2kt)
Henan (COD)
Agriculture 60.5%
Rural hh 20.7%
Urban hh 14.1%
Service 2.8%
Food 0.5%
Textile 0.1%
Paper 0.2%
Chemicals 0.4%
Petroleum 0.0%
Metal smelting 0.0%
Other industries 0.3%
Ele and heat 0.1%
Construction 0.3%
COD (1524kt)
Henan (NH3)
Urban hh 38.9%
Agriculture 33.8%
Rural hh 16.6%
Service 7.8%
Food 0.7%
Chemicals 0.8%
Textile 0.1%
Construction 0.8%
Paper 0.1%
Petroleum 0.1%
Metal smelting 0.0%
Ele and heat 0.1%
Other industries 0.3%
NH3 (50.9kt)
Henan (TN)
Agriculture 72.0%
Urban hh 17.0%
Rural hh 5.3%
Service 3.4%
Food 0.6%
Chemicals 0.8%
Textile 0.1%
Paper 0.1%
Petroleum 0.1%
Metal smelting 0.0%
Other industries 0.3%
Ele and heat 0.0%
Construction 0.3%
TN (286.6kt)
Henan (TP)
Agriculture 75.3%
Urban hh 12.3%
Rural hh 8.5%
Service 2.5%
Food 0.8%
Textile 0.0%
Paper 0.0%
Chemicals 0.2%
Petroleum 0.0%
Metal smelting 0.0%
Ele and heat 0.0%
Other industries 0.1%
Construction 0.3%
TP (15.7kt)
Hubei (COD)
Agriculture 66.1%
Rural hh 12.8%
Service 9.7%
Urban hh 9.4%
Food 0.4%
Textile 0.1%
Paper 0.2%
Chemicals 0.5%
Petroleum 0.0%
Metal smelting 0.1%
Construction 0.4%
Other industries 0.2%
Ele and heat 0.0%
COD (1399kt)
Hubei (NH3)
Agriculture 33.9%
Rural hh 22.7%
Service 20.6%
Urban hh 19.8%
Chemicals 1.0%
Food 0.4%
Construction 0.9%
Textile 0.1%
Paper 0.1%
Petroleum 0.1%
Metal smelting 0.2%
Other industries 0.2%
Ele and heat 0.0%
NH3 (56.0kt)
Hubei (TN)
Agriculture 70.8%
Service 9.3%
Urban hh 9.0%
Rural hh 8.6%
Chemicals 1.4%
Food 0.1%
Textile 0.1%
Paper 0.0%
Petroleum 0.0%
Metal smelting 0.1%
Construction 0.4%
Ele and heat 0.0%
Other industries 0.1%
TN (291.2kt)
Hubei (TP)
Agriculture 64.2%
Rural hh 12.1%
Service 11.1%
Urban hh 10.7%
Food 0.5%
Chemicals 0.6%
Textile 0.2%
Paper 0.0%
Petroleum 0.0%
Construction 0.5%
Metal smelting 0.0%
Other industries 0.2%
Ele and heat 0.0%
TP (18.0kt)
Hunan (COD)
Agriculture 70.0%
Rural hh 12.4%
Urban hh 9.6%
Service 4.6%
Food 0.8%
Paper 0.7%
Chemicals 0.6%
Textile 0.1%
Petroleum 0.0%
Metal smelting 0.1%
Other industries 0.5%
Construction 0.5%
Ele and heat 0.0%
COD (1846kt)
Hunan (NH3)
Agriculture 34.8%
Urban hh 25.5%
Rural hh 22.0%
Service 12.3%
Chemicals 1.9%
Food 0.9%
Construction 1.4%
Paper 0.3%
Textile 0.1%
Petroleum 0.0%
Metal smelting 0.2%
Other industries 0.6%
Ele and heat 0.1%
NH3 (77.8kt)
Hunan (TN)
Agriculture 67.4%
Urban hh 12.4%
Rural hh 11.3%
Service 6.0%
Chemicals 1.0%
Food 0.5%
Textile 0.0%
Paper 0.2%
Petroleum 0.1%
Construction 0.7%
Metal smelting 0.1%
Other industries 0.4%
Ele and heat 0.0%
TN (294.3kt)
Hunan (TP)
Agriculture 67.7%
Rural hh 13.0%
Urban hh 11.6%
Service 5.6%
Food 0.8%
Textile 0.0%
Paper 0.0%
Chemicals 0.3%
Construction 0.6%
Petroleum 0.0%
Other industries 0.3%
Metal smelting 0.1%
TP (21.1kt)
Guangdong (COD)
Agriculture 45.8%
Urban hh 21.2%
Rural hh 16.7%
Service 11.7%
Textile 1.3%
Food 1.0%
Paper 0.9%
Other industries 0.8%
Petroleum 0.0%
Chemicals 0.2%
Metal smelting 0.1%
Ele and heat 0.1%
Construction 0.2%
COD (1756kt)
Guangdong (NH3)
Urban hh 32.1%
Rural hh 30.6%
Service 17.7%
Agriculture 16.4%
Food 0.6%
Textile 0.8%
Paper 0.4%
Chemicals 0.3%
Other industries 0.6%
Petroleum 0.0%
Metal smelting 0.1%
Ele and heat 0.1%
Construction 0.3%
NH3 (96.4kt)
Guangdong (TN)
Agriculture 49.3%
Urban hh 21.0%
Rural hh 14.3%
Service 11.6%
Textile 1.0%
Food 0.7%
Other industries 1.1%
Paper 0.4%
Chemicals 0.3%
Petroleum 0.1%
Metal smelting 0.1%
Ele and heat 0.0%
Construction 0.2%
TN (356.7kt)
Guangdong (TP)
Agriculture 43.7%
Urban hh 21.6%
Rural hh 19.6%
Service 11.9%
Food 1.5%
Textile 0.4%
Other industries 0.9%
Paper 0.0%
Petroleum 0.0%
Chemicals 0.1%
Metal smelting 0.1%
Ele and heat 0.0%
Construction 0.2%
TP (21.7kt)
Guangxi (COD)
Agriculture 64.4%
Rural hh 14.7%
Urban hh 11.6%
Service 7.5%
Food 0.9%
Paper 0.4%
Textile 0.0%
Petroleum 0.0%
Chemicals 0.1%
Metal smelting 0.0%
Ele and heat 0.0%
Other industries 0.1%
Construction 0.2%
COD (1645kt)
Guangxi (NH3)
Rural hh 29.1%
Urban hh 27.0%
Agriculture 24.6%
Service 17.4%
Food 0.6%
Textile 0.0%
Paper 0.1%
Chemicals 0.5%
Petroleum 0.0%
Metal smelting 0.0%
Construction 0.4%
Other industries 0.2%
Ele and heat 0.0%
NH3 (75.2kt)
Guangxi (TN)
Agriculture 59.0%
Urban hh 15.2%
Rural hh 14.1%
Service 9.8%
Food 0.8%
Textile 0.1%
Paper 0.1%
Chemicals 0.4%
Petroleum 0.0%
Metal smelting 0.0%
Other industries 0.3%
Ele and heat 0.0%
Construction 0.2%
TN (275.6kt)
Guangxi (TP)
Agriculture 58.9%
Rural hh 15.9%
Urban hh 14.0%
Service 9.0%
Food 1.0%
Textile 0.0%
Paper 0.0%
Other industries 0.6%
Petroleum 0.0%
Chemicals 0.2%
Metal smelting 0.0%
Ele and heat 0.0%
Construction 0.2%
TP (19.2kt)


Hainan (COD)
Agriculture 67.4%
Rural hh 12.2%
Urban hh 11.1%
Service 6.9%
Food 1.0%
Paper 1.0%
Textile 0.0%
Chemicals 0.2%
Petroleum 0.0%
Ele and heat 0.0%
Other industries 0.1%
Construction 0.0%
COD (264kt)
Hainan (NH3)
Agriculture 32.2%
Rural hh 30.9%
Urban hh 20.7%
Service 12.9%
Food 1.7%
Paper 0.6%
Chemicals 0.7%
Textile 0.0%
Petroleum 0.0%
Ele and heat 0.0%
Other industries 0.2%
Construction 0.1%
NH3 (9.5kt)
Hainan (TN)
Agriculture 69.8%
Rural hh 11.7%
Urban hh 9.9%
Service 6.1%
Food 1.2%
Paper 0.4%
Chemicals 0.4%
Textile 0.0%
Petroleum 0.1%
Other industries 0.3%
Ele and heat 0.0%
Construction 0.0%
TN (46.9kt)
Hainan (TP)
Agriculture 64.9%
Rural hh 14.1%
Urban hh 12.1%
Service 7.5%
Food 1.2%
Textile 0.0%
Paper 0.0%
Petroleum 0.0%
Chemicals 0.0%
Ele and heat 0.0%
Other industries 0.1%
Construction 0.1%
TP (3.0kt)
Chongqing (COD)
Agriculture 71.6%
Rural hh 19.1%
Urban hh 4.3%
Food 1.1%
Service 1.5%
Paper 0.7%
Chemicals 0.6%
Other industries 0.8%
Textile 0.0%
Petroleum 0.0%
Metal smelting 0.0%
Ele and heat 0.0%
Construction 0.3%
COD (561kt)
Chongqing (NH3)
Urban hh 36.0%
Rural hh 23.9%
Agriculture 22.0%
Service 12.4%
Construction 2.1%
Food 1.0%
Chemicals 1.2%
Paper 0.4%
Other industries 0.6%
Textile 0.0%
Petroleum 0.0%
Metal smelting 0.1%
Ele and heat 0.1%
NH3 (21.5kt)
Chongqing (TN)
Agriculture 67.5%
Urban hh 14.6%
Rural hh 9.7%
Service 5.0%
Food 0.6%
Chemicals 0.9%
Construction 0.9%
Textile 0.0%
Paper 0.2%
Other industries 0.6%
Petroleum 0.0%
Metal smelting 0.1%
Ele and heat 0.0%
TN (101.8kt)
Chongqing (TP)
Agriculture 75.6%
Rural hh 15.2%
Urban hh 4.0%
Food 2.4%
Service 1.4%
Textile 0.0%
Paper 0.1%
Chemicals 0.4%
Other industries 0.6%
Petroleum 0.0%
Metal smelting 0.0%
Ele and heat 0.0%
Construction 0.2%
TP (5.2kt)
Sichuan (COD)
Agriculture 78.7%
Urban hh 8.8%
Rural hh 7.5%
Service 2.5%
Construction 1.3%
Food 0.4%
Textile 0.0%
Paper 0.2%
Chemicals 0.3%
Petroleum 0.0%
Metal smelting 0.0%
Ele and heat 0.0%
Other industries 0.1%
COD (3789kt)
Sichuan (NH3)
Agriculture 39.2%
Urban hh 32.6%
Rural hh 12.6%
Service 9.2%
Construction 4.9%
Food 0.5%
Chemicals 0.7%
Textile 0.0%
Paper 0.1%
Petroleum 0.0%
Metal smelting 0.0%
Ele and heat 0.0%
Other industries 0.2%
NH3 (112.5kt)
Sichuan (TN)
Agriculture 79.8%
Urban hh 10.3%
Rural hh 4.4%
Service 2.9%
Construction 1.5%
Food 0.3%
Chemicals 0.5%
Textile 0.0%
Paper 0.0%
Petroleum 0.0%
Metal smelting 0.0%
Ele and heat 0.0%
Other industries 0.1%
TN (628.2kt)
Sichuan (TP)
Agriculture 74.5%
Urban hh 11.7%
Rural hh 7.1%
Service 3.3%
Construction 1.7%
Food 0.9%
Textile 0.0%
Paper 0.0%
Chemicals 0.4%
Petroleum 0.0%
Metal smelting 0.0%
Other industries 0.2%
Ele and heat 0.0%
TP (31.7kt)
Guizhou (COD)
Agriculture 83.9%
Rural hh 8.8%
Urban hh 3.7%
Service 3.1%
Food 0.3%
Textile 0.0%
Paper 0.0%
Petroleum 0.0%
Chemicals 0.0%
Metal smelting 0.0%
Ele and heat 0.0%
Other industries 0.1%
Construction 0.0%
COD (1556kt)
Guizhou (NH3)
Agriculture 48.6%
Urban hh 19.3%
Service 16.1%
Rural hh 15.0%
Food 0.6%
Textile 0.0%
Paper 0.0%
Chemicals 0.2%
Petroleum 0.0%
Metal smelting 0.1%
Other industries 0.1%
Construction 0.1%
NH3 (40.1kt)
Guizhou (TN)
Agriculture 84.7%
Urban hh 5.5%
Service 4.6%
Rural hh 4.8%
Food 0.2%
Textile 0.0%
Paper 0.0%
Petroleum 0.0%
Chemicals 0.1%
Metal smelting 0.0%
Other industries 0.0%
Construction 0.0%
TN (244.5kt)
Guizhou (TP)
Agriculture 76.8%
Rural hh 8.8%
Urban hh 7.3%
Service 6.1%
Food 0.7%
Textile 0.0%
Paper 0.0%
Chemicals 0.0%
Other industries 0.2%
Construction 0.0%
TP (11.1kt)
Yunnan (COD)
Agriculture 89.0%
Rural hh 6.4%
Urban hh 2.8%
Service 1.1%
Food 0.4%
Textile 0.0%
Paper 0.1%
Petroleum 0.0%
Chemicals 0.1%
Metal smelting 0.0%
Other industries 0.1%
Construction 0.1%
COD (2627kt)
Yunnan (NH3)
Agriculture 63.1%
Urban hh 18.2%
Rural hh 10.1%
Service 7.1%
Food 0.5%
Chemicals 0.5%
Textile 0.0%
Paper 0.0%
Construction 0.4%
Petroleum 0.0%
Metal smelting 0.0%
Other industries 0.1%
NH3 (54.9kt)
Yunnan (TN)
Agriculture 92.5%
Urban hh 3.4%
Rural hh 2.3%
Service 1.3%
Food 0.2%
Textile 0.0%
Paper 0.0%
Petroleum 0.0%
Chemicals 0.1%
Metal smelting 0.0%
Other industries 0.0%
Construction 0.1%
TN (496.7kt)
Yunnan (TP)
Agriculture 86.9%
Rural hh 5.2%
Urban hh 4.8%
Service 1.9%
Food 0.8%
Textile 0.0%
Paper 0.1%
Chemicals 0.1%
Metal smelting 0.0%
Other industries 0.0%
Construction 0.1%
TP (20.4kt)
Tibet (COD)
Agriculture 84.1%
Rural hh 6.8%
Service 5.1%
Urban hh 3.5%
Food 0.3%
Textile 0.1%
Chemicals 0.0%
Ele and heat 0.1%
Other industries 0.0%
Construction 0.0%
COD (204kt)
Tibet (NH3)
Agriculture 49.3%
Service 27.5%
Urban hh 18.8%
Rural hh 3.9%
Food 0.4%
Textile 0.0%
Chemicals 0.0%
Other industries 0.0%
Construction 0.1%
NH3 (5.1kt)
Tibet (TN)
Agriculture 69.7%
Service 14.6%
Urban hh 10.0%
Rural hh 5.1%
Food 0.4%
Textile 0.0%
Other industries 0.2%
Chemicals 0.0%
Construction 0.1%
TN (11.0kt)
Tibet (TP)
Agriculture 55.3%
Service 19.8%
Urban hh 13.6%
Rural hh 10.1%
Food 0.8%
Other industries 0.3%
Textile 0.0%
Construction 0.1%
TP (0.7kt)
Shaanxi (COD)
Agriculture 41.8%
Rural hh 24.7%
Urban hh 22.8%
Service 6.7%
Food 1.3%
Other industries 1.1%
Paper 0.3%
Chemicals 0.6%
Textile 0.1%
Petroleum 0.1%
Metal smelting 0.1%
Ele and heat 0.1%
Construction 0.4%
COD (501kt)
Shaanxi (NH3)
Urban hh 52.2%
Service 15.3%
Rural hh 15.9%
Agriculture 12.7%
Food 0.9%
Chemicals 1.1%
Construction 0.9%
Textile 0.0%
Paper 0.1%
Petroleum 0.1%
Metal smelting 0.0%
Ele and heat 0.2%
Other industries 0.4%
NH3 (25.0kt)
Shaanxi (TN)
Agriculture 49.6%
Urban hh 31.4%
Service 9.2%
Rural hh 7.2%
Food 0.7%
Chemicals 0.8%
Textile 0.0%
Paper 0.0%
Petroleum 0.1%
Metal smelting 0.0%
Other industries 0.4%
Construction 0.5%
Ele and heat 0.0%
TN (97.3kt)
Shaanxi (TP)
Agriculture 50.0%
Urban hh 24.8%
Rural hh 15.6%
Service 7.2%
Food 1.3%
Textile 0.1%
Petroleum 0.2%
Paper 0.0%
Chemicals 0.0%
Other industries 0.3%
Construction 0.4%
Metal smelting 0.0%
TP (4.2kt)
Gansu (COD)
Rural hh 52.4%
Agriculture 16.9%
Food 11.4%
Urban hh 8.8%
Service 6.2%
Chemicals 1.5%
Metal smelting 1.1%
Petroleum 0.6%
Other industries 0.7%
Textile 0.0%
Paper 0.1%
Ele and heat 0.1%
Construction 0.1%
COD (156kt)
Gansu (NH3)
Urban hh 31.7%
Service 22.3%
Rural hh 21.6%
Agriculture 12.0%
Metal smelting 10.2%
Food 1.0%
Chemicals 0.4%
Textile 0.0%
Paper 0.0%
Petroleum 0.1%
Ele and heat 0.1%
Construction 0.4%
Other industries 0.1%
NH3 (4.3kt)
Gansu (TN)
Agriculture 29.6%
Urban hh 28.8%
Service 20.3%
Rural hh 12.3%
Metal smelting 4.9%
Food 1.8%
Chemicals 1.6%
Textile 0.0%
Paper 0.0%
Petroleum 0.2%
Other industries 0.2%
Ele and heat 0.0%
Construction 0.3%
TN (17.3kt)
Gansu (TP)
Rural hh 33.7%
Urban hh 22.4%
Agriculture 19.0%
Service 15.8%
Food 7.1%
Chemicals 0.7%
Metal smelting 0.5%
Other industries 0.4%
Textile 0.0%
Construction 0.3%
TP (0.8kt)
Qinghai (COD)
Agriculture 30.8%
Urban hh 24.4%
Service 22.2%
Rural hh 19.3%
Chemicals 2.5%
Food 0.5%
Textile 0.0%
Paper 0.0%
Petroleum 0.1%
Metal smelting 0.0%
Ele and heat 0.0%
Other industries 0.0%
Construction 0.2%
COD (91kt)
Qinghai (NH3)
Urban hh 42.3%
Service 38.4%
Agriculture 9.8%
Chemicals 3.9%
Rural hh 4.1%
Petroleum 0.9%
Food 0.1%
Textile 0.0%
Paper 0.0%
Metal smelting 0.0%
Ele and heat 0.0%
Construction 0.4%
Other industries 0.0%
NH3 (5.3kt)
Qinghai (TN)
Urban hh 41.6%
Service 37.8%
Agriculture 14.5%
Rural hh 3.6%
Chemicals 1.9%
Food 0.0%
Textile 0.0%
Paper 0.0%
Petroleum 0.1%
Metal smelting 0.0%
Construction 0.4%
Ele and heat 0.0%
Other industries 0.0%
TN (12.7kt)
Qinghai (TP)
Urban hh 37.3%
Service 34.0%
Rural hh 14.2%
Agriculture 12.3%
Food 0.9%
Chemicals 0.6%
Textile 0.0%
Other industries 0.3%
Construction 0.3%
Metal smelting 0.0%
TP (0.4kt)
Ningxia (COD)
Agriculture 64.1%
Rural hh 12.5%
Urban hh 9.3%
Food 6.3%
Service 4.1%
Chemicals 2.5%
Textile 0.2%
Paper 0.2%
Petroleum 0.3%
Metal smelting 0.1%
Other industries 0.3%
Ele and heat 0.1%
Construction 0.1%
COD (154kt)
Ningxia (NH3)
Urban hh 28.3%
Agriculture 26.7%
Service 12.4%
Chemicals 10.7%
Rural hh 11.0%
Food 8.1%
Petroleum 0.7%
Metal smelting 1.1%
Textile 0.0%
Paper 0.1%
Other industries 0.4%
Ele and heat 0.1%
Construction 0.4%
NH3 (4.3kt)
Ningxia (TN)
Agriculture 38.5%
Urban hh 21.7%
Chemicals 14.2%
Service 9.5%
Food 6.6%
Rural hh 6.4%
Petroleum 0.9%
Textile 0.2%
Paper 0.1%
Metal smelting 0.5%
Other industries 0.9%
Ele and heat 0.0%
Construction 0.3%
TN (13.8kt)
Ningxia (TP)
Agriculture 66.0%
Urban hh 11.2%
Rural hh 8.0%
Service 4.9%
Chemicals 4.1%
Food 2.7%
Other industries 2.0%
Textile 0.9%
Metal smelting 0.1%
Construction 0.1%
TP (1.1kt)

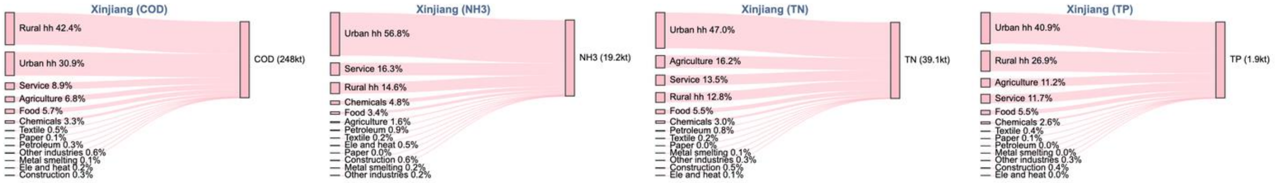
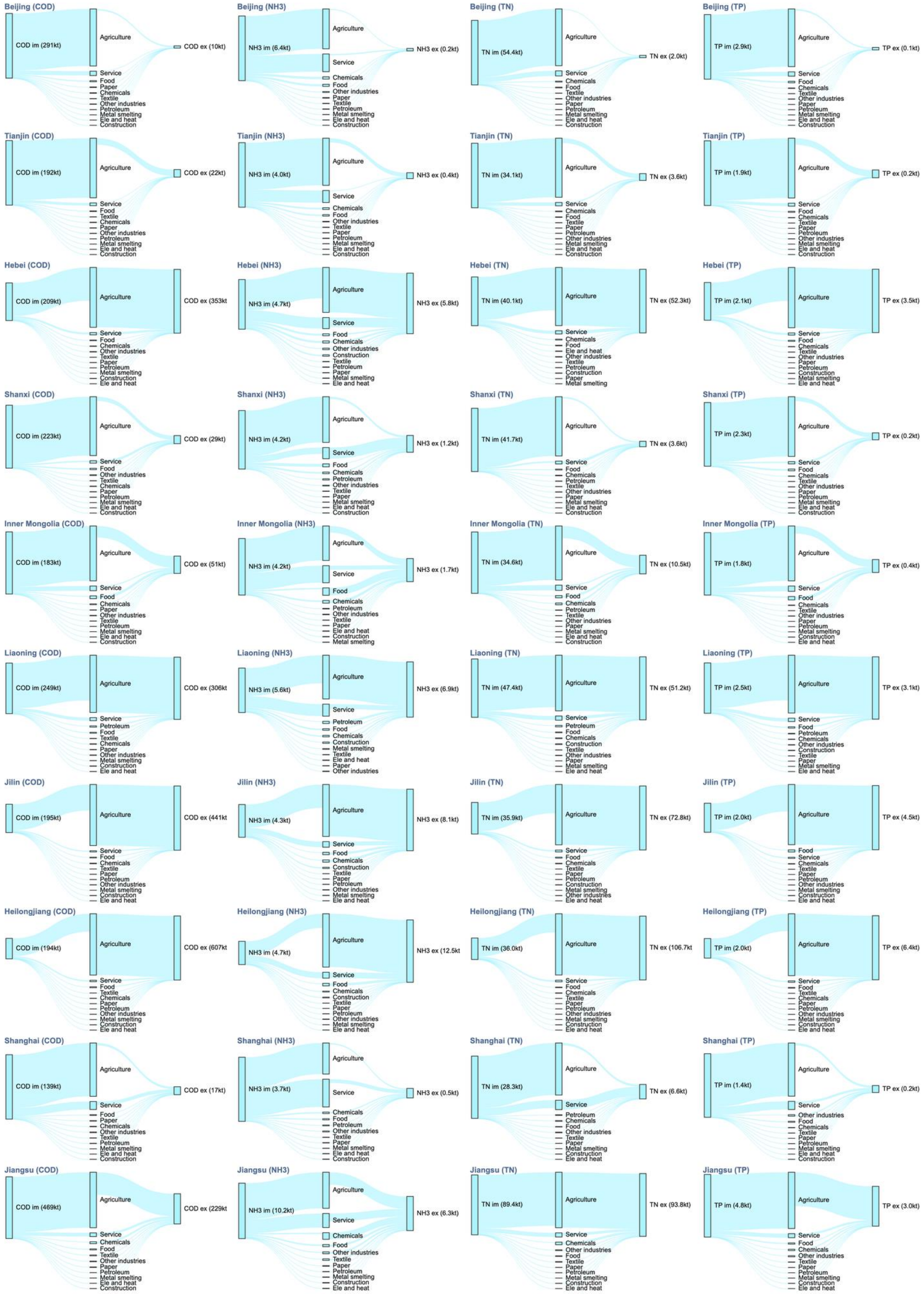
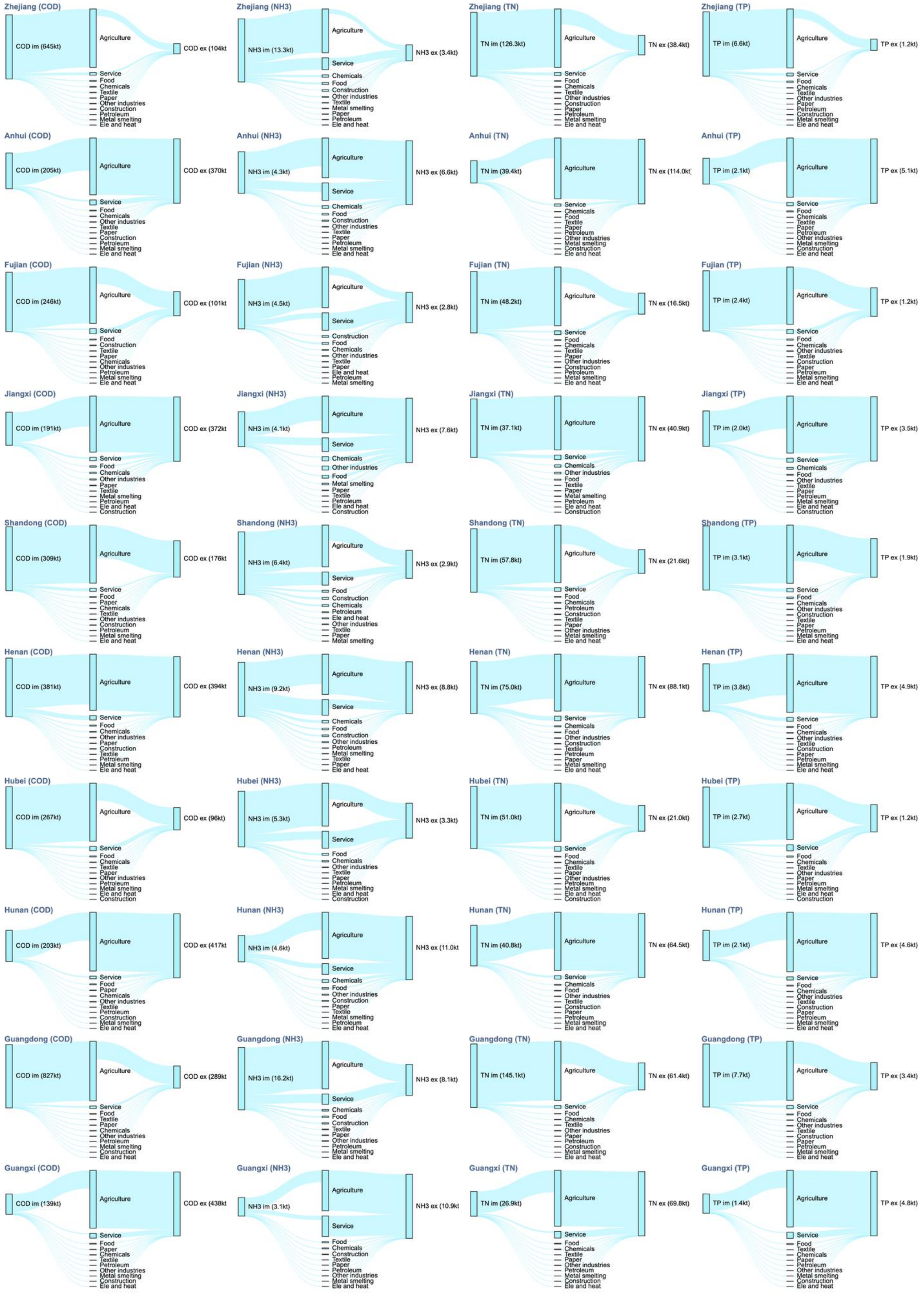
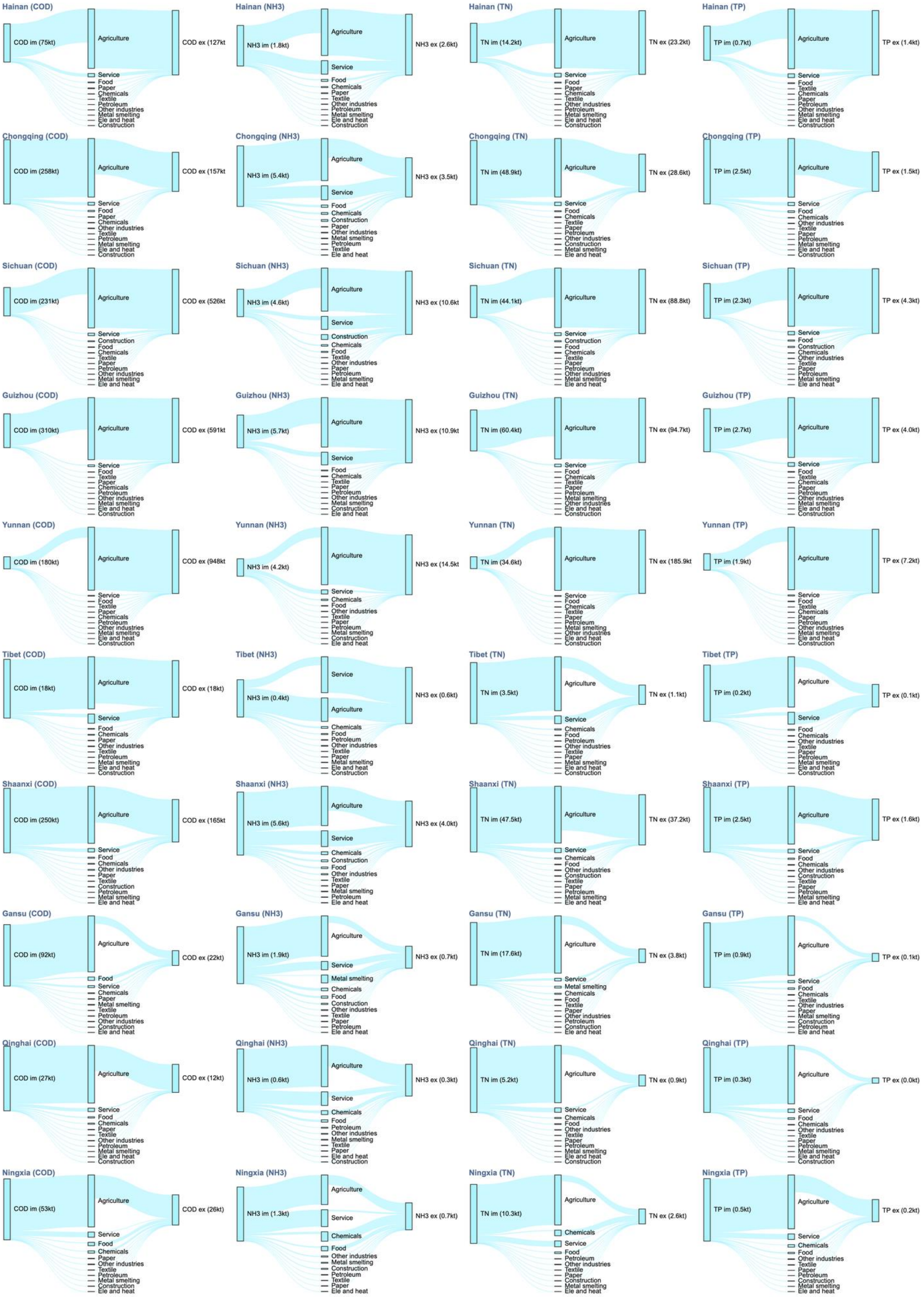


Fig. S3 Physical water pollutants metabolism of 31 regions in China


Beijing (COD)
COD im (291kt)
Agriculture
COD ex (10kt)
Service
Food
Paper
Chemicals
Textile
Other industries
Petroleum
Metal smelting
Ele and heat
Construction
Beijing (NH3)
NH3 im (6.4kt)
Agriculture
Service
NH3 ex (0.2kt)
Chemicals
Food
Other industries
Paper
Textile
Petroleum
Metal smelting
Ele and heat
Construction
Beijing (TN)
TN im (54.4kt)
Agriculture
TN ex (2.0kt)
Service
Chemicals
Food
Textile
Other industries
Paper
Petroleum
Metal smelting
Ele and heat
Construction
Beijing (TP)
TP im (2.9kt)
Agriculture
TP ex (0.1kt)
Service
Food
Chemicals
Textile
Other industries
Paper
Petroleum
Metal smelting
Ele and heat
Construction
Tianjin (COD)
COD im (192kt)
Agriculture
COD ex (22kt)
Service
Food
Textile
Chemicals
Paper
Other industries
Petroleum
Metal smelting
Ele and heat
Construction
Tianjin (NH3)
NH3 im (4.0kt)
Agriculture
NH3 ex (0.4kt)
Service
Chemicals
Food
Other industries
Textile
Paper
Petroleum
Metal smelting
Ele and heat
Construction
Tianjin (TN)
TN im (34.1kt)
Agriculture
TN ex (3.6kt)
Service
Chemicals
Food
Textile
Paper
Petroleum
Other industries
Metal smelting
Ele and heat
Construction
Tianjin (TP)
TP im (1.9kt)
Agriculture
TP ex (0.2kt)
Service
Food
Chemicals
Textile
Paper
Petroleum
Other industries
Metal smelting
Ele and heat
Construction
Hebei (COD)
COD im (209kt)
Agriculture
COD ex (353kt
Service
Food
Chemicals
Other industries
Textile
Paper
Petroleum
Metal smelting
Construction
Ele and heat
Hebei (NH3)
NH3 im (4.7kt)
Agriculture
NH3 ex (5.8kt)
Service
Food
Chemicals
Other industries
Construction
Textile
Petroleum
Paper
Metal smelting
Ele and heat
Hebei (TN)
TN im (40.1kt)
Agriculture
TN ex (52.3kt)
Service
Chemicals
Food
Ele and heat
Other industries
Textile
Petroleum
Construction
Paper
Metal smelting
Hebei (TP)
TP im (2.1kt)
Agriculture
TP ex (3.5kt)
Service
Food
Chemicals
Textile
Other industries
Paper
Petroleum
Construction
Metal smelting
Ele and heat
Shanxi (COD)
COD im (223kt)
Agriculture
COD ex (29kt)
Service
Food
Other industries
Textile
Chemicals
Paper
Petroleum
Metal smelting
Ele and heat
Construction
Shanxi (NH3)
NH3 im (4.2kt)
Agriculture
NH3 ex (1.2kt)
Service
Food
Chemicals
Petroleum
Other industries
Textile
Paper
Metal smelting
Ele and heat
Construction
Shanxi (TN)
TN im (41.7kt)
Agriculture
TN ex (3.6kt)
Service
Food
Chemicals
Petroleum
Textile
Other industries
Paper
Metal smelting
Ele and heat
Construction
Shanxi (TP)
TP im (2.3kt)
Agriculture
TP ex (0.2kt)
Service
Food
Chemicals
Textile
Other industries
Paper
Petroleum
Metal smelting
Ele and heat
Construction
Inner Mongolia (COD)
COD im (183kt)
Agriculture
COD ex (51kt)
Service
Food
Chemicals
Paper
Other industries
Textile
Petroleum
Metal smelting
Ele and heat
Construction
Inner Mongolia (NH3)
NH3 im (4.2kt)
Agriculture
NH3 ex (1.7kt)
Service
Food
Chemicals
Petroleum
Other industries
Textile
Paper
Ele and heat
Construction
Metal smelting
Inner Mongolia (TN)
TN im (34.6kt)
Agriculture
TN ex (10.5kt)
Service
Food
Chemicals
Petroleum
Textile
Other industries
Paper
Metal smelting
Ele and heat
Construction
Inner Mongolia (TP)
TP im (1.8kt)
Agriculture
TP ex (0.4kt)
Service
Food
Chemicals
Textile
Other industries
Paper
Petroleum
Metal smelting
Construction
Ele and heat
Liaoning (COD)
COD im (249kt)
Agriculture
COD ex (306kt
Service
Petroleum
Food
Textile
Chemicals
Paper
Other industries
Metal smelting
Construction
Ele and heat
Liaoning (NH3)
NH3 im (5.6kt)
Agriculture
NH3 ex (6.9kt)
Service
Petroleum
Food
Chemicals
Construction
Metal smelting
Textile
Ele and heat
Paper
Other industries
Liaoning (TN)
TN im (47.4kt)
Agriculture
TN ex (51.2kt)
Service
Petroleum
Food
Chemicals
Construction
Textile
Other industries
Paper
Metal smelting
Ele and heat
Liaoning (TP)
TP im (2.5kt)
Agriculture
TP ex (3.1kt)
Service
Food
Petroleum
Chemicals
Other industries
Construction
Textile
Paper
Metal smelting
Ele and heat
Jilin (COD)
COD im (195kt)
Agriculture
COD ex (441kt
Service
Food
Chemicals
Textile
Paper
Petroleum
Other industries
Metal smelting
Construction
Ele and heat
Jilin (NH3)
NH3 im (4.3kt)
Agriculture
NH3 ex (8.1kt)
Service
Food
Chemicals
Construction
Textile
Paper
Petroleum
Other industries
Metal smelting
Ele and heat
Jilin (TN)
TN im (35.9kt)
Agriculture
TN ex (72.8kt)
Service
Food
Chemicals
Textile
Paper
Petroleum
Construction
Metal smelting
Other industries
Ele and heat
Jilin (TP)
TP im (2.0kt)
Agriculture
TP ex (4.5kt)
Food
Service
Chemicals
Textile
Paper
Petroleum
Other industries
Metal smelting
Construction
Ele and heat
Heilongjiang (COD)
COD im (194kt)
Agriculture
COD ex (607kt
Service
Food
Textile
Chemicals
Paper
Petroleum
Other industries
Metal smelting
Construction
Ele and heat
Heilongjiang (NH3)
NH3 im (4.7kt)
Agriculture
NH3 ex (12.5kt
Service
Food
Chemicals
Construction
Textile
Paper
Petroleum
Other industries
Metal smelting
Ele and heat
Heilongjiang (TN)
TN im (36.0kt)
Agriculture
TN ex (106.7kt
Service
Food
Chemicals
Textile
Paper
Petroleum
Other industries
Metal smelting
Construction
Ele and heat
Heilongjiang (TP)
TP im (2.0kt)
Agriculture
TP ex (6.4kt)
Service
Food
Textile
Chemicals
Paper
Petroleum
Other industries
Metal smelting
Construction
Ele and heat
Shanghai (COD)
COD im (139kt)
Agriculture
COD ex (17kt)
Service
Food
Paper
Chemicals
Other industries
Textile
Petroleum
Metal smelting
Ele and heat
Construction
Shanghai (NH3)
NH3 im (3.7kt)
Agriculture
Service
NH3 ex (0.5kt)
Chemicals
Food
Petroleum
Other industries
Textile
Paper
Metal smelting
Ele and heat
Construction
Shanghai (TN)
TN im (28.3kt)
Agriculture
TN ex (6.6kt)
Service
Petroleum
Chemicals
Food
Other industries
Textile
Paper
Metal smelting
Construction
Ele and heat
Shanghai (TP)
TP im (1.4kt)
Agriculture
TP ex (0.2kt)
Service
Other industries
Food
Chemicals
Textile
Paper
Petroleum
Metal smelting
Ele and heat
Construction
Jiangsu (COD)
COD im (469kt)
Agriculture
COD ex (229kt
Service
Chemicals
Food
Textile
Other industries
Paper
Petroleum
Metal smelting
Ele and heat
Construction
Jiangsu (NH3)
NH3 im (10.2kt)
Agriculture
NH3 ex (6.3kt)
Service
Chemicals
Food
Other industries
Textile
Paper
Petroleum
Metal smelting
Construction
Ele and heat
Jiangsu (TN)
TN im (89.4kt)
Agriculture
TN ex (93.8kt)
Service
Chemicals
Other industries
Food
Textile
Paper
Petroleum
Metal smelting
Construction
Ele and heat
Jiangsu (TP)
TP im (4.8kt)
Agriculture
TP ex (3.0kt)
Service
Food
Chemicals
Other industries
Textile
Paper
Petroleum
Metal smelting
Construction
Ele and heat


Zhejiang (COD)
COD im (645kt)
Agriculture
COD ex (104kt
Service
Food
Chemicals
Textile
Paper
Other industries
Construction
Petroleum
Metal smelting
Ele and heat
Zhejiang (NH3)
NH3 im (13.3kt)
Agriculture
Service
NH3 ex (3.4kt)
Chemicals
Food
Construction
Other industries
Textile
Metal smelting
Paper
Petroleum
Ele and heat
Zhejiang (TN)
TN im (126.3kt)
Agriculture
TN ex (38.4kt)
Service
Food
Chemicals
Textile
Other industries
Construction
Paper
Petroleum
Metal smelting
Ele and heat
Zhejiang (TP)
TP im (6.6kt)
Agriculture
TP ex (1.2kt)
Service
Food
Chemicals
Textile
Other industries
Paper
Petroleum
Construction
Metal smelting
Ele and heat
Anhui (COD)
COD im (205kt)
Agriculture
COD ex (370kt
Service
Food
Chemicals
Other industries
Textile
Paper
Construction
Petroleum
Metal smelting
Ele and heat
Anhui (NH3)
NH3 im (4.3kt)
Agriculture
Service
NH3 ex (6.6kt)
Chemicals
Food
Construction
Other industries
Textile
Paper
Petroleum
Metal smelting
Ele and heat
Anhui (TN)
TN im (39.4kt)
Agriculture
TN ex (114.0kt
Service
Chemicals
Food
Textile
Paper
Petroleum
Other industries
Metal smelting
Construction
Ele and heat
Anhui (TP)
TP im (2.1kt)
Agriculture
TP ex (5.1kt)
Service
Food
Chemicals
Textile
Paper
Petroleum
Other industries
Metal smelting
Construction
Ele and heat
Fujian (COD)
COD im (246kt)
Agriculture
COD ex (101kt
Service
Food
Construction
Textile
Paper
Chemicals
Other industries
Petroleum
Metal smelting
Ele and heat
Fujian (NH3)
NH3 im (4.5kt)
Agriculture
Service
NH3 ex (2.8kt)
Construction
Food
Chemicals
Other industries
Textile
Paper
Ele and heat
Petroleum
Metal smelting
Fujian (TN)
TN im (48.2kt)
Agriculture
TN ex (16.5kt)
Service
Food
Chemicals
Textile
Paper
Other industries
Construction
Petroleum
Metal smelting
Ele and heat
Fujian (TP)
TP im (2.4kt)
Agriculture
TP ex (1.2kt)
Service
Food
Chemicals
Other industries
Textile
Construction
Paper
Petroleum
Metal smelting
Ele and heat
Jiangxi (COD)
COD im (191kt)
Agriculture
COD ex (372kt
Service
Food
Chemicals
Other industries
Paper
Textile
Metal smelting
Petroleum
Ele and heat
Construction
Jiangxi (NH3)
NH3 im (4.1kt)
Agriculture
Service
NH3 ex (7.6kt)
Chemicals
Other industries
Food
Metal smelting
Paper
Textile
Petroleum
Ele and heat
Construction
Jiangxi (TN)
TN im (37.1kt)
Agriculture
TN ex (40.9kt)
Service
Chemicals
Other industries
Food
Textile
Paper
Metal smelting
Petroleum
Ele and heat
Construction
Jiangxi (TP)
TP im (2.0kt)
Agriculture
TP ex (3.5kt)
Service
Chemicals
Food
Other industries
Textile
Paper
Petroleum
Metal smelting
Ele and heat
Construction
Shandong (COD)
COD im (309kt)
Agriculture
COD ex (176kt
Service
Food
Paper
Chemicals
Textile
Other industries
Construction
Petroleum
Metal smelting
Ele and heat
Shandong (NH3)
NH3 im (6.4kt)
Agriculture
Service
NH3 ex (2.9kt)
Food
Construction
Chemicals
Petroleum
Ele and heat
Other industries
Textile
Paper
Metal smelting
Shandong (TN)
TN im (57.8kt)
Agriculture
TN ex (21.6kt
Service
Food
Chemicals
Petroleum
Construction
Textile
Paper
Other industries
Metal smelting
Ele and heat
Shandong (TP)
TP im (3.1kt)
Agriculture
TP ex (1.9kt)
Service
Food
Chemicals
Other industries
Construction
Textile
Paper
Petroleum
Metal smelting
Ele and heat
Henan (COD)
COD im (381kt)
Agriculture
COD ex (394kt
Service
Food
Chemicals
Other industries
Paper
Construction
Textile
Petroleum
Metal smelting
Ele and heat
Henan (NH3)
NH3 im (9.2kt)
Agriculture
Service
NH3 ex (8.8kt)
Chemicals
Food
Construction
Other industries
Petroleum
Metal smelting
Textile
Paper
Ele and heat
Henan (TN)
TN im (75.0kt)
Agriculture
TN ex (88.1kt)
Service
Chemicals
Food
Other industries
Construction
Textile
Petroleum
Paper
Metal smelting
Ele and heat
Henan (TP)
TP im (3.8kt)
Agriculture
TP ex (4.9kt)
Service
Food
Chemicals
Other industries
Textile
Construction
Paper
Petroleum
Metal smelting
Ele and heat
Hubei (COD)
COD im (267kt)
Agriculture
COD ex (96kt)
Service
Food
Chemicals
Textile
Paper
Other industries
Petroleum
Metal smelting
Ele and heat
Construction
Hubei (NH3)
NH3 im (5.3kt)
Agriculture
Service
NH3 ex (3.3kt)
Food
Chemicals
Other industries
Textile
Paper
Petroleum
Metal smelting
Ele and heat
Construction
Hubei (TN)
TN im (51.0kt)
Agriculture
TN ex (21.0kt)
Service
Food
Chemicals
Textile
Paper
Other industries
Petroleum
Metal smelting
Ele and heat
Construction
Hubei (TP)
TP im (2.7kt)
Agriculture
TP ex (1.2kt)
Service
Food
Chemicals
Textile
Other industries
Paper
Petroleum
Metal smelting
Ele and heat
Construction
Hunan (COD)
COD im (203kt)
Agriculture
COD ex (417kt
Service
Food
Paper
Chemicals
Other industries
Textile
Petroleum
Construction
Metal smelting
Ele and heat
Hunan (NH3)
NH3 im (4.6kt)
Agriculture
Service
NH3 ex (11.0kt
Chemicals
Food
Other industries
Construction
Paper
Textile
Metal smelting
Petroleum
Ele and heat
Hunan (TN)
TN im (40.8kt)
Agriculture
TN ex (64.5kt)
Service
Chemicals
Food
Other industries
Textile
Construction
Paper
Petroleum
Metal smelting
Ele and heat
Hunan (TP)
TP im (2.1kt)
Agriculture
TP ex (4.6kt)
Service
Food
Chemicals
Other industries
Textile
Construction
Paper
Petroleum
Metal smelting
Ele and heat
Guangdong (COD)
COD im (827kt)
Agriculture
COD ex (289kt
Service
Food
Textile
Paper
Chemicals
Other industries
Petroleum
Metal smelting
Construction
Ele and heat
Guangdong (NH3)
NH3 im (16.2kt)
Agriculture
Service
NH3 ex (8.1kt)
Chemicals
Food
Construction
Textile
Paper
Other industries
Petroleum
Metal smelting
Ele and heat
Guangdong (TN)
TN im (145.1kt)
Agriculture
TN ex (61.4kt)
Service
Food
Chemicals
Textile
Other industries
Paper
Petroleum
Construction
Metal smelting
Ele and heat
Guangdong (TP)
TP im (7.7kt)
Agriculture
TP ex (3.4kt)
Service
Food
Chemicals
Other industries
Textile
Construction
Paper
Petroleum
Metal smelting
Ele and heat
Guangxi (COD)
COD im (139kt)
Agriculture
COD ex (438kt
Service
Food
Paper
Chemicals
Textile
Petroleum
Other industries
Metal smelting
Construction
Ele and heat
Guangxi (NH3)
NH3 im (3.1kt)
Agriculture
Service
NH3 ex (10.9kt
Food
Chemicals
Construction
Textile
Paper
Petroleum
Other industries
Metal smelting
Ele and heat
Guangxi (TN)
TN im (26.9kt)
Agriculture
TN ex (69.8kt)
Service
Food
Chemicals
Textile
Paper
Other industries
Petroleum
Metal smelting
Construction
Ele and heat
Guangxi (TP)
TP im (1.4kt)
Agriculture
TP ex (4.8kt)
Service
Food
Textile
Chemicals
Paper
Petroleum
Other industries
Metal smelting
Construction
Ele and heat


Hainan (COD)
COD im (75kt)
Agriculture
COD ex (127kt
Service
Food
Paper
Chemicals
Textile
Petroleum
Other industries
Metal smelting
Ele and heat
Construction
Hainan (NH3)
NH3 im (1.8kt)
Agriculture
Service
NH3 ex (2.6kt)
Food
Chemicals
Paper
Textile
Other industries
Petroleum
Metal smelting
Ele and heat
Construction
Hainan (TN)
TN im (14.2kt)
Agriculture
TN ex (23.2kt)
Service
Food
Paper
Chemicals
Textile
Other industries
Petroleum
Metal smelting
Ele and heat
Construction
Hainan (TP)
TP im (0.7kt)
Agriculture
TP ex (1.4kt)
Service
Food
Textile
Chemicals
Paper
Petroleum
Other industries
Metal smelting
Ele and heat
Construction
Chongqing (COD)
COD im (258kt)
Agriculture
COD ex (157kt
Service
Food
Paper
Chemicals
Other industries
Textile
Petroleum
Metal smelting
Ele and heat
Construction
Chongqing (NH3)
NH3 im (5.4kt)
Agriculture
Service
NH3 ex (3.5kt)
Food
Chemicals
Construction
Paper
Other industries
Metal smelting
Petroleum
Textile
Ele and heat
Chongqing (TN)
TN im (48.9kt)
Agriculture
TN ex (28.6kt)
Service
Food
Chemicals
Textile
Paper
Petroleum
Other industries
Construction
Metal smelting
Ele and heat
Chongqing (TP)
TP im (2.5kt)
Agriculture
TP ex (1.5kt)
Service
Food
Chemicals
Other industries
Textile
Paper
Petroleum
Metal smelting
Ele and heat
Construction
Sichuan (COD)
COD im (231kt)
Agriculture
COD ex (526kt
Service
Construction
Food
Chemicals
Textile
Paper
Petroleum
Other industries
Metal smelting
Ele and heat
Sichuan (NH3)
NH3 im (4.6kt)
Agriculture
Service
NH3 ex (10.6kt
Construction
Chemicals
Food
Textile
Other industries
Paper
Petroleum
Metal smelting
Ele and heat
Sichuan (TN)
TN im (44.1kt)
Agriculture
TN ex (88.8kt)
Service
Construction
Food
Chemicals
Textile
Paper
Petroleum
Other industries
Metal smelting
Ele and heat
Sichuan (TP)
TP im (2.3kt)
Agriculture
TP ex (4.3kt)
Service
Food
Construction
Chemicals
Other industries
Textile
Paper
Petroleum
Metal smelting
Ele and heat
Guizhou (COD)
COD im (310kt)
Agriculture
COD ex (591kt
Service
Food
Textile
Paper
Chemicals
Petroleum
Other industries
Metal smelting
Ele and heat
Construction
Guizhou (NH3)
NH3 im (5.7kt)
Agriculture
Service
NH3 ex (10.9kt
Food
Chemicals
Textile
Paper
Petroleum
Other industries
Metal smelting
Construction
Ele and heat
Guizhou (TN)
TN im (60.4kt)
Agriculture
TN ex (94.7kt)
Service
Food
Chemicals
Textile
Paper
Petroleum
Metal smelting
Other industries
Ele and heat
Construction
Guizhou (TP)
TP im (2.7kt)
Agriculture
TP ex (4.0kt)
Service
Food
Textile
Chemicals
Paper
Petroleum
Other industries
Metal smelting
Ele and heat
Construction
Yunnan (COD)
COD im (180kt)
Agriculture
COD ex (948kt
Service
Food
Textile
Paper
Chemicals
Petroleum
Other industries
Metal smelting
Ele and heat
Construction
Yunnan (NH3)
NH3 im (4.2kt)
Agriculture
NH3 ex (14.5kt
Service
Chemicals
Food
Other industries
Textile
Paper
Petroleum
Metal smelting
Construction
Ele and heat
Yunnan (TN)
TN im (34.6kt)
Agriculture
TN ex (185.9kt
Service
Food
Chemicals
Textile
Paper
Petroleum
Metal smelting
Other industries
Ele and heat
Construction
Yunnan (TP)
TP im (1.9kt)
Agriculture
TP ex (7.2kt)
Service
Food
Textile
Chemicals
Paper
Petroleum
Other industries
Metal smelting
Ele and heat
Construction
Tibet (COD)
COD im (18kt)
Agriculture
COD ex (18kt)
Service
Food
Chemicals
Paper
Other industries
Textile
Petroleum
Metal smelting
Ele and heat
Construction
Tibet (NH3)
Service
NH3 im (0.4kt)
Agriculture
NH3 ex (0.6kt)
Chemicals
Food
Petroleum
Other industries
Textile
Paper
Metal smelting
Ele and heat
Construction
Tibet (TN)
TN im (3.5kt)
Agriculture
TN ex (1.1kt)
Service
Chemicals
Food
Petroleum
Other industries
Textile
Paper
Metal smelting
Ele and heat
Construction
Tibet (TP)
TP im (0.2kt)
Agriculture
TP ex (0.1kt)
Service
Food
Chemicals
Other industries
Textile
Paper
Petroleum
Metal smelting
Ele and heat
Construction
Shaanxi (COD)
COD im (250kt)
Agriculture
COD ex (165kt
Service
Food
Chemicals
Other industries
Paper
Textile
Construction
Petroleum
Metal smelting
Ele and heat
Shaanxi (NH3)
NH3 im (5.6kt)
Agriculture
Service
NH3 ex (4.0kt)
Chemicals
Construction
Food
Other industries
Textile
Paper
Metal smelting
Petroleum
Ele and heat
Shaanxi (TN)
TN im (47.5kt)
Agriculture
TN ex (37.2kt)
Service
Chemicals
Food
Other industries
Construction
Textile
Paper
Petroleum
Metal smelting
Ele and heat
Shaanxi (TP)
TP im (2.5kt)
Agriculture
TP ex (1.6kt)
Service
Food
Chemicals
Other industries
Construction
Textile
Paper
Petroleum
Metal smelting
Ele and heat
Gansu (COD)
COD im (92kt)
Agriculture
COD ex (22kt)
Food
Service
Chemicals
Paper
Metal smelting
Textile
Petroleum
Other industries
Construction
Ele and heat
Gansu (NH3)
NH3 im (1.9kt)
Agriculture
Service
NH3 ex (0.7kt)
Metal smelting
Chemicals
Food
Construction
Other industries
Textile
Paper
Petroleum
Ele and heat
Gansu (TN)
TN im (17.6kt)
Agriculture
TN ex (3.8kt)
Service
Metal smelting
Chemicals
Food
Textile
Paper
Other industries
Petroleum
Construction
Ele and heat
Gansu (TP)
TP im (0.9kt)
Agriculture
TP ex (0.1kt)
Service
Food
Chemicals
Textile
Other industries
Paper
Metal smelting
Construction
Petroleum
Ele and heat
Qinghai (COD)
COD im (27kt)
Agriculture
COD ex (12kt)
Service
Food
Chemicals
Paper
Textile
Other industries
Petroleum
Metal smelting
Ele and heat
Construction
Qinghai (NH3)
NH3 im (0.6kt)
Agriculture
Service
NH3 ex (0.3kt)
Chemicals
Food
Petroleum
Other industries
Metal smelting
Textile
Paper
Ele and heat
Construction
Qinghai (TN)
TN im (5.2kt)
Agriculture
TN ex (0.9kt)
Service
Chemicals
Food
Other industries
Textile
Paper
Petroleum
Metal smelting
Ele and heat
Construction
Qinghai (TP)
TP im (0.3kt)
Agriculture
TP ex (0.0kt)
Service
Food
Chemicals
Other industries
Textile
Paper
Petroleum
Metal smelting
Ele and heat
Construction
Ningxia (COD)
COD im (53kt)
Agriculture
COD ex (26kt)
Service
Food
Chemicals
Paper
Other industries
Textile
Petroleum
Metal smelting
Construction
Ele and heat
Ningxia (NH3)
Agriculture
NH3 im (1.3kt)
Service
NH3 ex (0.7kt)
Chemicals
Food
Other industries
Metal smelting
Construction
Petroleum
Textile
Paper
Ele and heat
Ningxia (TN)
TN im (10.3kt)
Agriculture
TN ex (2.6kt)
Chemicals
Service
Food
Petroleum
Other industries
Textile
Paper
Construction
Metal smelting
Ele and heat
Ningxia (TP)
TP im (0.5kt)
Agriculture
TP ex (0.2kt)
Service
Chemicals
Food
Other industries
Textile
Paper
Petroleum
Construction
Metal smelting
Ele and heat

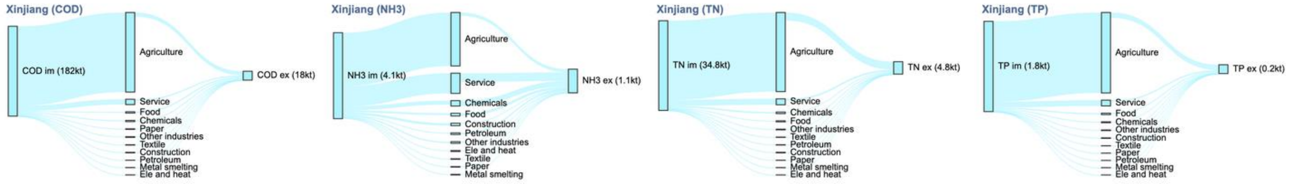


Fig. S4 Virtual water pollutants metabolism of 31 regions in China