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Research article

The grey water footprint of the Yangtze River Economic Belt, China: Spatial patterns, driving mechanism, and implications

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Methodology for GWF Calculation

1. Agricultural GWF

(1) GWF derived from planting. Given that nitrogen represents the primary contaminant in substances like pesticides (Hu et al., 2018), and chemical fertilizer does not produce COD contamination after application, we opted for nitrogen as the parameter for assessing the GWF during cultivation. The calculation formula is expressed as follows:

$$GWF_{pla} = \frac{\alpha Appl}{C_{max} - C_{nat}} \tag{1}$$

where α represents the nitrogen leaching rate, i.e., the mass percentage of nitrogen fertilizer entering the water body, which is taken as 7% according to the previous studies (Chukalla et al., 2018; Fu et al., 2022; Xu et al., 2022), *Appl* represents the amount of nitrogen fertilizer applied in the current year that causes wastewater pollution from nitrogen; C_{max} is the maximum acceptable concentration of pollutant in a certain water quality standard; C_{nat} is the background concentration of pollutant in the environment.

(2) GWF from livestock and poultry breeding primarily originates from COD and TN in waste. The research focused on cattle, sheep, pigs, and poultry. Pollution load calculations include the number of animals bred, the content of fecal water pollutants, excretion coefficients, breeding cycles, and loss

rate into the water. In order to avoid double counting, the number of cattle and sheep with a feeding cycle of more than or equal to 1 year was selected as the year-end stocking quantity; the number of poultry and pigs with a feeding cycle of less than 1 year was selected as the year-end slaughtering quantity. Sorting out the existing research information, we determine the feeding cycle and excretion coefficient of the main livestock and poultry in the study area. COD and nitrogen were selected to measure the GWF generated from livestock farming. GWFbre can be calculated from Eq (3), where Lbre represents pollution load in feces and urine which can be computed by Eq (4)

$$GWF_{bre} = max\{GWF_{bre}(COD), GWF_{bre}(TN)\} \tag{2}$$

$$GWF_{bre(i)} = \frac{L_{bre(i)}}{C_{max} - C_{nat}} \tag{3}$$

$$L_{bre(i)} = \sum_{h=1}^{4} N_h \times D_h \times (p_{hsi} \times f_{hs} \times \mu_{hs} + p_{hui} \times f_{hu} \times \mu_{hu}) \tag{4}$$

Here, $GWF_{bre(i)}$ represents the GWF of i (COD or TN) pollutant in the livestock and poultry breeding; $L_{bre(i)}$ stands for the pollution emissions of i pollutant in the livestock and poultry breeding; h represents livestock and poultry (cattle, sheep, pigs and poultry); N_h is the number of feeding h; D_h signifies the feeding cycle; f_{hs} and f_{hu} denote the daily excretion of feces and urine, respectively; p_{hs} and p_{hu} indicate the pollutant content per unit of feces and urine; μ_{hs} and μ_{hu} represent the daily fecal output and urine output, respectively. For specific parameters, see Table 1.

Table 1. Values of parameters for livestock and poultry breeding grey water footprint.

Species of livestock		Cattle	Pig	Sheep	Poultry
Raising cycle		365	199	365	55
Excrement	Daily excretion coefficient (kg d^{-1} $head^{-1}$)	30	2.2	2.6	0.15
	The average amount of COD (kg t^{-1})	31	52	4.63	45
	The average amount of TN (kg t^{-1})	4.37	5.88	7.5	10.4
	Runoff fraction of COD (%)	6.16	5.58	5.5	8.59
	Runoff fraction of TN (%)	5.68	5.34	5.3	8.47
Urine	Daily excretion coefficient (kg d^{-1} $head^{-1}$)	18	2.9	1	-
	The average amount of COD (kg t^{-1})	6.0	9	4.63	-
	The average amount of TN (kg t^{-1})	8	3.3	14	-
	Runoff fraction of COD (%)	50	50	50	-
	Runoff fraction of TN (%)	50	50	50	-

(3) Total agricultural GWF. Water used to assimilate one type of pollutant can concurrently assimilate other pollutants at the same time, then summing the GWF of different pollutants will result in double counting of part of GWF, thus, when calculating the total agricultural GWF, the GWF generated by the same type of pollutant is summed up and the GWF from different types of pollutants takes the maximum value, the calculation of the total agricultural GWF can be represented by Eq (5):

$$GWF_{agr} = max\{GWF_{bre}(COD), GWF_{bre}(TN) + GWF_{pla}\} \quad (5)$$

2. Industrial GWF

Industrial pollution primarily originates from designated outfalls, representing point source pollution and serving as a major contributor to wastewater discharge (Aljerf, 2018; Peng et al., 2023). As evidenced by previous studies (Li et al., 2016; Wu et al., 2016; Zhang et al., 2019), the primary pollutants are COD and NH3-N. Consequently, the current study adopts COD and NH3-N as the key parameters for computing the industrial GWF.

$$GWF_{ind} = max\{GWF_{ind}(COD), GWF_{ind}(NH_3 - N)\} \quad (6)$$

$$GWF_{ind(i)} = \frac{L_{ind(i)}}{C_{max} - C_{nat}} \quad (7)$$

3. Domestic GWF

Domestic GWF comprises rural and urban components. Rural GWF arises mainly from surface-discharged domestic pollutants, complicating data collection. In urban areas, domestic GWF primarily results from point source pollution. In the current study, COD or NH3-N is typically chosen as the representative pollutants for assessing the domestic GWF. The methodology employed for calculating domestic GWF aligns with that utilized for computing the industrial GWF.

$$GWF_{dom} = max\{GWF_{dom}(COD), GWF_{dom}(NH_3 - N)\} \quad (8)$$

$$GWF_{dom(i)} = \frac{L_{dom(i)}}{C_{max} - C_{nat}} \quad (9)$$

4. Regional total GWF

The regional total GWF consists of three components: agricultural, industrial, and domestic GWF. It can be can be represented by Eq (10):

$$GWF = GWF_{agr} + GWF_{ind} + GWF_{dom} \quad (10)$$

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