



Analysis of the sediment deposition characteristics in the Three Gorges Reservoir and its influence factors

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Abstract

Affected by climatic factors and human activities, the conditions of the sediment deposition of the Three Gorges Reservoir (TGR) in the upper Yangtze River have undergone significant changes, the understandings of the sedimentation in TGR and its factors remain unclear. In this paper, the regime for sediment deposition in TGR from 2003 to 2017 is analyzed based on field data, its influence factors are discussed, and the empirical formulas governing the relationships are presented. The results show that the sedimentation pattern of the TGR is discontinuous and that the perennial inundated area is the key sedimentation area, while the reaches of Xiangxizhen, Wushan, Fengjie, Wanxian, Huanghuacheng, Lanzhuba, and Tunaozi are the main deposition reaches in the reservoir, with the same characteristics of wider cross-sections. Sediment deposition in the TGR is affected by the incoming water and sediment, the operation rule of the reservoir, and by the characteristics of different reaches. Compared with the factors influencing the total sediment trapping ratio of the reservoir, local reach conditions are also the main factors influencing the sediment trapping ratio of the reaches due to the difference of sediment carrying capacity between wider reach and narrow reach. The sediment trapping ratios for reservoir scale and reach scale can be good indicators that reflect sedimentation in the TGR; the calculated sediment trapping ratios agree well with field observations. With the continuous construction and operation of the main and tributary reservoirs in the upper Yangtze River, the existing sedimentation regime of the TGR will persist for many years.

Keywords Sedimentation · Three Gorges Reservoir · Influence factor · Sediment trapping ratio

Introduction

Reservoir is key infrastructure to mitigate the effects of climate change by their capacity to store and regulate water supply (Annandale 2013; Field et al. 2014). However, the accumulation of sediments reduces the water storage

capacity of a reservoir (Alemu 2016), and eventually eliminates the capacity for flow regulation which is crucial for assuring the reservoir functions of flood control, navigation, energy production and water supply (Graf 1984; Morris and Fan 1998). To estimate the sedimentation rate and development trend accurately in reservoir is important for reservoir management.

It is known to all that the transport capacity of runoff is reduced as it enters the impoundment region with larger cross-section and smaller flow velocity, causing large particles and aggregates to settle at the bottom of the reservoir (Heinemarm 1981), but the physical contents of the detailed mechanisms are still not yet fully apprehended (Schleiss et al. 2016). Two kinds of methods have been used to evaluate the state of reservoir sedimentation, one is numerical model and the other is the empirical method by in situ data. Although numerical methods developed from fundamental hydrodynamics equations and can effectively simulate the quantity and pattern of sedimentation for individual reservoirs, the excessive data (such as topographic data, grain

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composition data) requirement and the complex calculation process limited its application (Zahabi et al. 2018; Lakzian et al. 2020). On the other hand, robust empirical formulas have been developed decades ago, such as the well-known Brown formula (Brown 1943), the Brune formula (Brune 1953) and its modifications (Gill 1979). Meanwhile, more adaptive empirical formulas have also been developed for specific reservoirs (Tang et al. 2019a, b; Zhang et al. 2019).

The Three Gorges Reservoir (TGR) is the largest water conservancy project in the main stream of the Yangtze River, and also which is the last downstream reservoir of cascade reservoirs. As the key project exploits the Yangtze River, the TGR has significant benefits of flood control, navigation, and power generation. Given the impoundment of the reservoir, the sedimentation is bound to arise for the huge volume of reservoir (Mazhar et al. 2021; Tang et al. 2019a, b; Zhang et al. 2019). Research aimed at understanding sedimentation in the TGR has been ongoing in China since the 1950s. The early research was focused on predictions of sedimentation amount, flood level in the reservoir, navigation problems in the fluctuating backwater region, and sediment problems in the dam region, which strongly supported the construction of the TGR (Pan 2017). A large amount of field survey works have been performed since the TGR operated at 2003, many researchers discussed the phenomenon and mechanism of sediment deposition in the TGR (Yuan et al. 2013; Hu et al. 2013; Li et al. 2015). Since 2003, the TGR has accumulated 110 million tons of sediment per year, with an annual sediment delivery ratio of 23.6%. The reservoir is mainly deposited in the wider reaches of the perennial backwater region. Both the total amount and position of sedimentation are different from the results in the design stage (Li et al. 2015; Yuan et al. 2013). In the previous studies, much attention has been paid to the sediment trapping/delivery ratio, which is the key factor indicates the degree of sedimentation (Jiao and Lin 1982). The classic Brune method based on the inflow of reservoir, reservoir capacity, reservoir length and other factors, set up the reservoir sediment trapping efficiency curve, which can be used to calculate the sediment trapping ratios of reservoir in different periods (Brune 1953). From a physical point of view, this method takes into account the influence of the flow stagnation time, the average velocity of the reservoir and the volume of the reservoir, but the influence of the sediment inflow is still insufficient, and it needs to be modified when applied to the reservoir of a sandy river. It has been recognized by existing researches that the sedimentation in TGR has an important relationship not only with the water level in front of the dam, the upstream water inflow condition, the reservoir storage capacity, but also with the upstream sediment inflow condition (Huang et al. 2013; Yuan et al. 2015; Dong et al. 2017). Meanwhile, the influencing factors of sedimentation may be different for different periods in a year or different reaches in the reservoir. Dong et al. (2017) evaluated the relationship between the water level in

front of the dam and the sediment discharge ratio under different monthly average inflow conditions, and found that the sediment delivery ratio had little relationship with the water level in front of the dam under low discharge during dry season. Li et al. (2015) analyzed the sedimentation difference between wide reach and narrow valley in the reservoir area. Although previous studies have been conducted on the factors affecting sedimentation in TGR, and the influencing factors have been revealed, the current understanding is still not completely unified, and there is a lack of quantitative analysis (Huang et al. 2013; Yuan et al. 2015; Dong et al. 2017; Tang et al. 2019a, b).

Although the sediment inflow into the TGR shows a decreasing trend on the whole after the operation of Xiangjiaba and Xiluodu reservoirs which located in the upper reach (Li et al. 2016), there are still cases that the sediment inflow exceeds the average level of 2003–2012 in special years (Dong et al. 2017), the rules of sediment inflow into the reservoir is still unstable. At the same time, during the construction of the TGR, the normal water level in front of the dam is constantly adjusted, from 135 to 156 m and finally reached 175 m. In addition, in order to release the flood risk in downstream reach of the dam, the operation rule in flood season of TGR has optimized, and the average water level in front of the dam during flood season has risen significantly than that of previous stage (Yang et al. 2020). Under the comprehensive influence of upstream and downstream boundary changes, the sedimentation process in the TGR has been significantly adjusted.

Here, we explore the sedimentation rules in the TGR by employing the hydrological and topographic data from 2003 to 2017 during the post-TGR period. The specific objectives of the study are to (i) analyze the spatial and temporal sedimentation characteristics in the TGR, and (ii) investigate the sediment trapping/delivery ratios in reservoir scale and reach scale and its governing relationships among different factors.

Overview of study area

Spanning Hubei Province and Chongqing municipality, the TGR is a key water conservancy project that harnesses the Yangtze River with its comprehensive flood control, power generation, navigation, and water supply benefits. The total length of the reservoir area is approximately 760 km from Zhutuo to Yichang. The total storage capacity of reservoir is close to 40 billion m³, and the water surface is approximately 1084 km². The reach from dam to Fuling is about 480 km, which is the perennial inundated area, and the reach from Fuling to Jianjin is about 170 km, which is the fluctuating backwater area. The TGR is a typical river-type reservoir with intervals of wider reaches and narrow reaches, and its average widths are 800 m and 1500 m respectively.

Dozens of tributaries flow into the Yangtze River in a longitudinal direction from Zhutuo to Yichang, among them, the Jialing River and Wujiang River are the main tributaries. The main gauge stations in the reservoir are at Zhuto, Cuntan, Qingxichang, and Wanxian on the main branch, Beibei on the Jialing River, and Wulong in the Wujiang River (Fig. 1).

Data and method

Data

The data analyzed in this paper include hydrological data and section topographic data. The hydrological data, which include water level, flow discharge, and sediment concentration data measured at Zhutuo, Cuntan, Qingxichang, Wanxian, Beibei, and Wulong Station from 2003 to 2017, were collected from hydrological stations within the basin by the Yangtze River Hydrographic Bureau. The topographic data are cross-sectional profiles (387 specific locations) from Zhutuo to dam at 2003 and 2017 measured by the Yangtze River Hydrographic Bureau. Before these datasets are released to the public, they undergo rigorous verification and uncertainty analysis following government protocols, such as those published by the Ministry of Water Resources, China (Dai and Liu 2013).

Method

(1) Calculation of sediment deposition in the reservoir

There are two main methods to calculate sediment deposition: the sediment discharge method and the topographic method. The sediment discharge method uses the runoff discharge and sediment concentration data from the gauge

stations to calculate the total reach deposition between two stations based on the conservation of mass (Eq. 1):

$$W = (Q_i S_i - Q_{i+1} S_{i+1}) \Delta t \quad (1)$$

where W is the sediment amount deposited between section i and $i + 1$ and Q_i, S_i are the runoff discharge and sediment concentration at section i . The incoming sediment is calculated at the Zhutuo, Beibei, and Wulong stations; the outgoing sediment is calculated at the Huanglingmiao station, which is downstream of the dam.

Based on the in-situ gauging data of 387 sections from Zhutuo to the dam during different years, the sediment deposition at the reach scale is calculated using Eq. 2:

$$W = C_1 - C_2 \quad (2)$$

$$C_j = \left(A_i + A_{i+1} + \sqrt{A_i A_{i+1}} \right) \frac{\Delta L}{3} j = 1 \text{ to } 2, i = 1 \text{ to } 416 \quad (3)$$

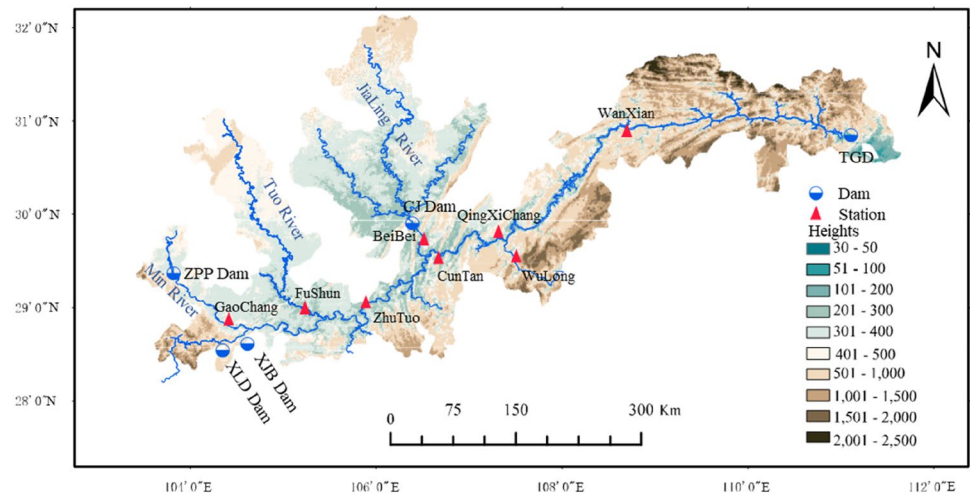
where W is the amount of sediment deposition, C is the storage quantity of the reservoir, A is the section area, and ΔL is the section spacing.

As a main index to evaluate the sediment deposition in the reservoir, the sediment trapping ratio η is expressed by Eq. 4:

$$\eta = \frac{W}{Q_i S_i \Delta t} \quad (4)$$

where W is the amount of sediment deposition, Q_i is the incoming water discharge, S_i is the incoming sediment concentration, Δt is the period of time. If the sediment trapping ratio of the reservoir scale is calculated, the sediment deposition of the whole reservoir and the total incoming water and sediment condition of the reservoir are used. If the sediment trapping ratio of the reach scale is calculated, the sediment deposition in the reach and the water and sediment

Fig. 1 Sketch map of TGR



conditions at the inlet of the reach are used. Meanwhile, the sediment delivery ratio can be calculated by $1 - \eta$.

(2) Calculation of average parameters of different reaches

Considering the uncertainty of measurement would cause deviations in the calculation of the regimes at different sections. Ciaran et al. (2008) found that single parameter changes of up to 42% could be attributed to this uncertainty in floodplain river regime surveys for 114 streams in Australia. To reduce the error, the average section parameters are used for different reaches. Xia et al. (2014) presented an averaging method that combined geometric section spacing and weighted averages to calculate the reach parameters (Eqs. 5–8):

$$\bar{B} = \exp \left[\frac{1}{2L} \sum_{i=1}^{N-1} (\ln B_{i+1} + \ln B_i) \times (x_{i+1} + x_i) \right] \quad (5)$$

$$\bar{H} = \exp \left[\frac{1}{2L} \sum_{i=1}^{N-1} (\ln H_{i+1} + \ln H_i) \times (x_{i+1} + x_i) \right] \quad (6)$$

$$\bar{A} = \bar{B} \times \bar{H} \quad (7)$$

$$\bar{U} = \frac{Q}{\bar{A}} \quad (8)$$

where $\bar{B}$, $\bar{H}$, $\bar{A}$, and $\bar{U}$ are the average width, water depth, section area, and flow velocity of the reach respectively. B_i , H_i is the width and water depth of different section in the reach.

Results

Sediment deposition in the TGR

The sediment deposition in TGR has been calculated based on sediment discharge method from 2003 to 2017 (Table 1). The total amount of sediment deposited in the reservoir is 1650 million tons, which is the equivalent of 114 million tons per year. There are 1545 million tons deposited in the reach from Qingxichang to the dam, which is the perennial inundated area of the reservoir, accounts for 93.6% of the total deposition. In the fluctuating backwater area from Jiangjin to Qingxichang, total sediment deposition was only 105 million tons. The upper reach from Jiangjin to Cuntan shows an erosional trend from 2014 to 2017 due to the impoundment of the Xiluodu and Xiangjiaba reservoirs in the upper reach.

To analyze the distribution of the sedimentation in the reservoir, the sediment erosion and deposition amounts per unit in different reaches are calculated based on the

Table 1 Sediment deposition in the TGR from 2003 to 2017

Year	Incoming sediment (million tons)	Released sediment (million tons)	Sediment deposition (million tons)
2003	208	84	124
2004	166	64	102
2005	254	103	151
2006	96	9	87
2007	220	51	169
2008	217	32	184
2009	183	36	147
2010	230	33	197
2011	101	7	94
2012	221	45	175
2013	127	33	95
2014	49	11	39
2015	31	4	27
2016	39	9	30
2017	33	3	30
Total	2174	524	1650
Average	150	36	114

topographic method (Fig. 2). Sediment deposition is discontinuous in the TGR, which occurs mainly in the perennial inundated area, from Qixichang to the dam, approximately 460 km. The reaches of Xiangxizhen, Wushan, Fengjie, Wanxian, Huanghuacheng, Lanzhuba, and Tunaozi are the main deposition reaches in the reservoir, and both meandering and branching sections in those reaches have the same characteristics of larger width. Due to the impoundment of the upper reservoirs, and the general trend of the fluctuating backwater area of the TGR was erosional from 2013 to 2017.

The annual change in sediment trapping ratio of the TGR from 2003 to 2017 is presented in Fig. 3, which shows that the sediment trapping ratio has demonstrated a gradually increasing trend since 2003, and the average sediment trapping ratio of the TGR is approximately 76%.

The reason for the decrease in the annual sediment delivery ratio is the dual action of periodic rise of water level and the enhanced sediment blocking effect of the upstream reservoirs. In Fig. 3a, the sediment trapping ratio of the TGR decreases with the increase of inflow, and the average sediment trapping ratio is 74.9% during the years when inflow is higher than 350 billion m³. In addition, Fig. 3b shows that there is a certain relationship between the change in sediment trapping ratio and the incoming sediment. With the increase of the incoming sediment, the sediment trapping ratio of TGR increases, and the average sediment trapping ratio is 74.3% during the years where incoming sediment larger than 0.2 billion tons. These results indicate that the

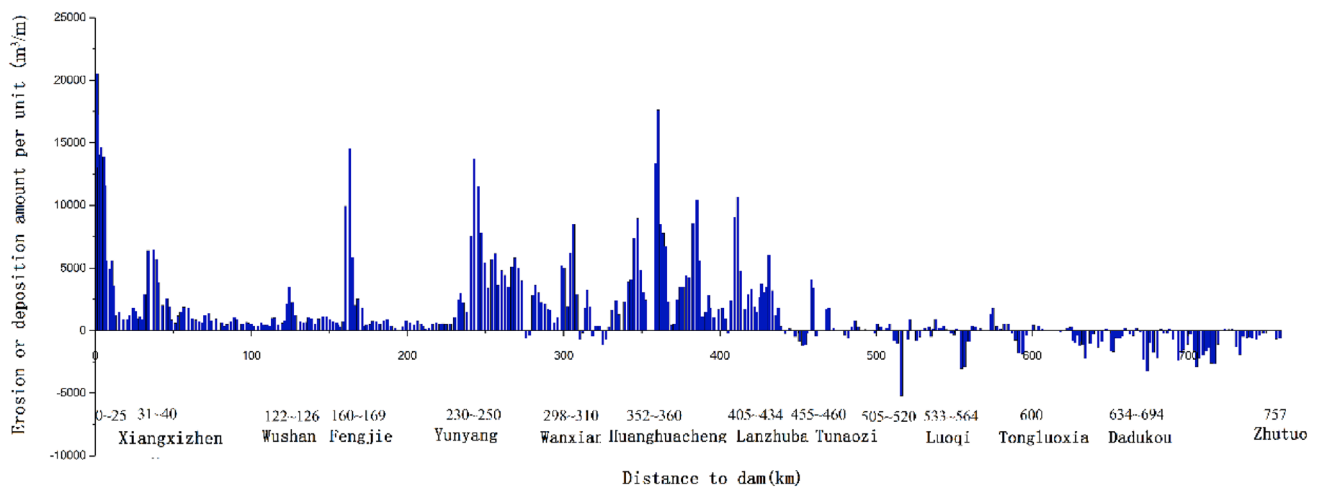


Fig. 2 Cumulative erosion and siltation per unit river length of the TGR from 2003 to 2017. **a** Relationship between sediment trapping ratio and incoming flow discharge. **b** Relationship between sediment trapping ratio and incoming sediment

incoming water and sediment are the important factors for sedimentation in the TGR.

The operation rule of the TGR is “storing clear water in dry season and discharging muddy water in flood season”, which can be satisfied by the need for flood control and reducing sediment deposition in the reservoir. The water level in front of the dam varies during the year, and is higher in the dry season than that in the flood season. It is shown that the sediment trapping ratio in flood season is less than that in dry season except in 2014 and 2015. This is because there are larger inflows and lower water levels in front of the dam in flood season. In 2014 and 2015, the sediment trapping ratio is less in dry season than that in flood season, which is caused by the reduction in the incoming sediment in dry season from impoundment of the upper reservoirs. It is worth noting that the amount of sediment deposition in flood season is approximately 31.5 million tons in 2014–2015, and approximately 1 million tons in dry season, the main sediment deposition period in the year is also the flood season (see Fig. 4).

The empirical formulas of sediment trapping ratio

(1) Total sediment trapping ratio of TGR

The main factors affecting the sedimentation of the TGR are the incoming water and sediment, the operation rule, and the characteristics of the reservoir (Yuan et al. 2013; Hu et al. 2013; Li et al. 2015). Based on existing studies, the influence factors of the total sediment trapping ratio are selected as the annual average sediment discharge ($W_s = QST$), annual average flow discharge (Q), the reservoir volume under the annual average water level at the dam (V), and the water retention coefficient of the reservoir (V/Q). The relationships between the sediment trapping

ratio and each influencing factor are shown in Fig. 5. Considering the difference in the relationship change in the flood season and dry season, the graphics are color-coded during different seasons. Though the change rule in flood season is different from that in dry season. Although the changing regularities in dry season and flood season are different, it can be seen that the sediment trapping ratio is obviously related to the water retention coefficient and the amount of sediment inflow in reservoir. Among them, the influence of the water level in front of the dam is indirectly reflected in the change of reservoir capacity. Refer to the Brune formula and its modifications (Brune 1953; Gill 1979), and introduce the factor of incoming sediment, herein, the empirical formulas of the total sediment trapping ratio of the TGR during the flood season and dry season are presented as Eqs. 9 and 10 based on the nonlinear fitting method:

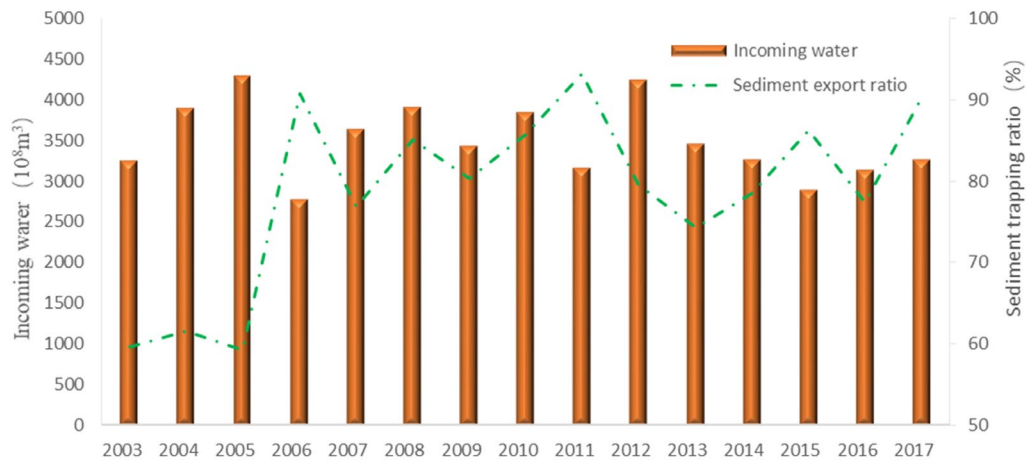
$$\text{Flood season : } \eta = 257.823(V/Q)^{0.556}W_s^{0.064} \quad (9)$$

$$\text{Dry season : } \eta = 179.779(V/Q)^{-0.23}W_s^{0.119} \quad (10)$$

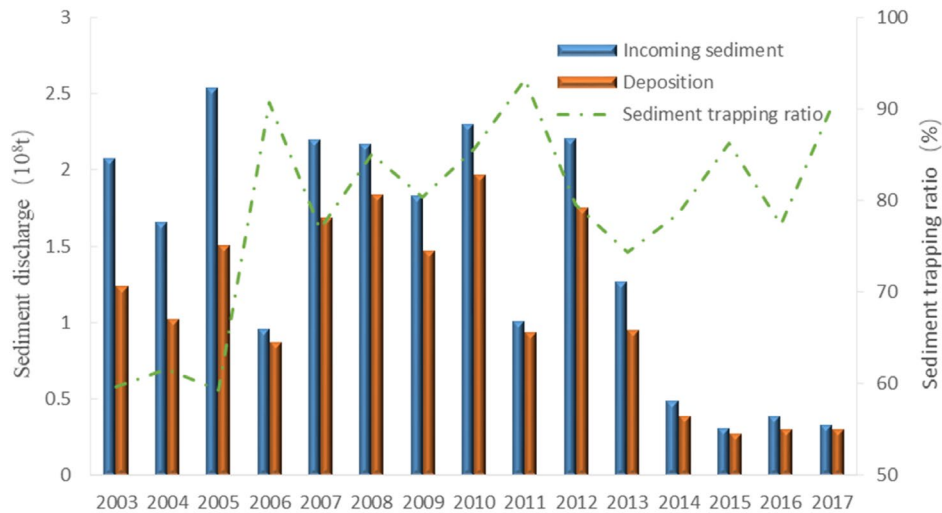
Based on field data from 2003–2017, the field sediment trapping ratios during flood season and dry season are calculated and compared to those calculated by the empirical formulas shown in Fig. 6. The relationship between the calculated sediment trapping ratio and the measured sediment trapping ratio is good, and its coefficient of association is 0.8511 in the flood season and 0.7863 in the dry season, respectively.

(2) Sediment trapping ratio at the reach scale

At the reach scale, sediment trapping is connected to the incoming water and sediment and the reach form



(a) Relationship between sediment trapping ratio and incoming flow discharge



(b) Relationship between sediment trapping ratio and incoming sediment

Fig. 3 The annual change of sediment trapping ratio of TGR from 2003 to 2017

characteristics, and the ratio of sediment trapping can be defined as the ratio of sediment deposition per unit length of a river reach to sediment transport at its inlet section. As we know, the hydraulic parameters are different from upstream to downstream along the reservoir, and are also affected by the incoming water, incoming sediment, and the operation rules of the reservoir. The distribution of the sediment deposition in the TGR indicates the difference along the river. According to the differences of river pattern and width, the whole region of TGR is divided into 53 river reaches from upstream to downstream, where the average length of the reach is approximately 15 km. To analyze the sediment trapping ratio of the reach (η_r), average velocity of the reach

($\bar{U}$), hydrodynamic index ($\bar{U}^3/\bar{H}$), average width ($\bar{B}$), and sediment transport rate per width of the reach ($W_s/\bar{B}$) are chosen as the evaluation factors. The relationships between the sediment trapping ratio of the reach and each influence factor are shown in Fig. 7. The flood season and dry season are not distinguished by color in the figure, because the above parameters can reflect the change of the reach during the entire year.

It can be seen that the same negative correlation trend is present for the relationship between the sediment trapping ratio of the reach with the factors $\bar{U}$, $\bar{U}^3/\bar{H}$, and $W_s/\bar{B}$, which are all affected by the incoming water and sediment condition and the operation rule at the dam, while there is a

Fig. 4 The changes of sediment trapping ratio of TGR during flood and dry season

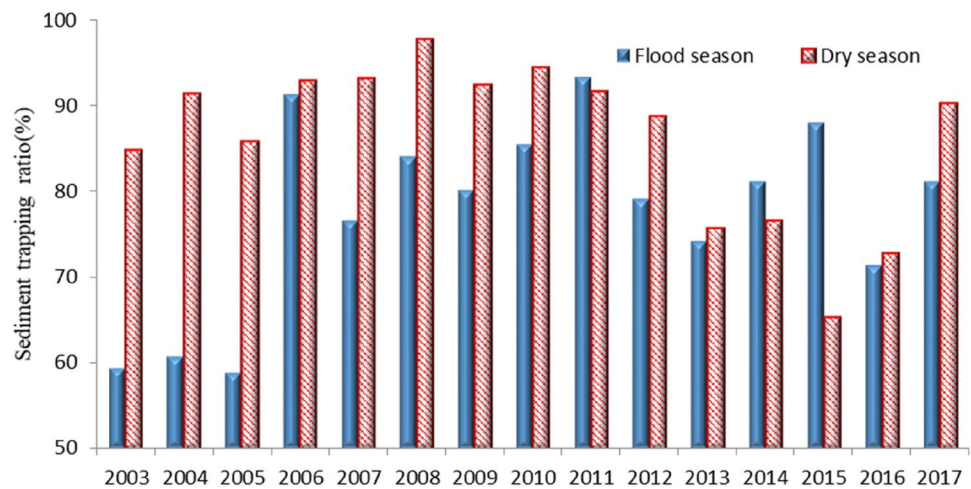


Fig. 5 Relationship between sediment trapping ratio and its influence factors

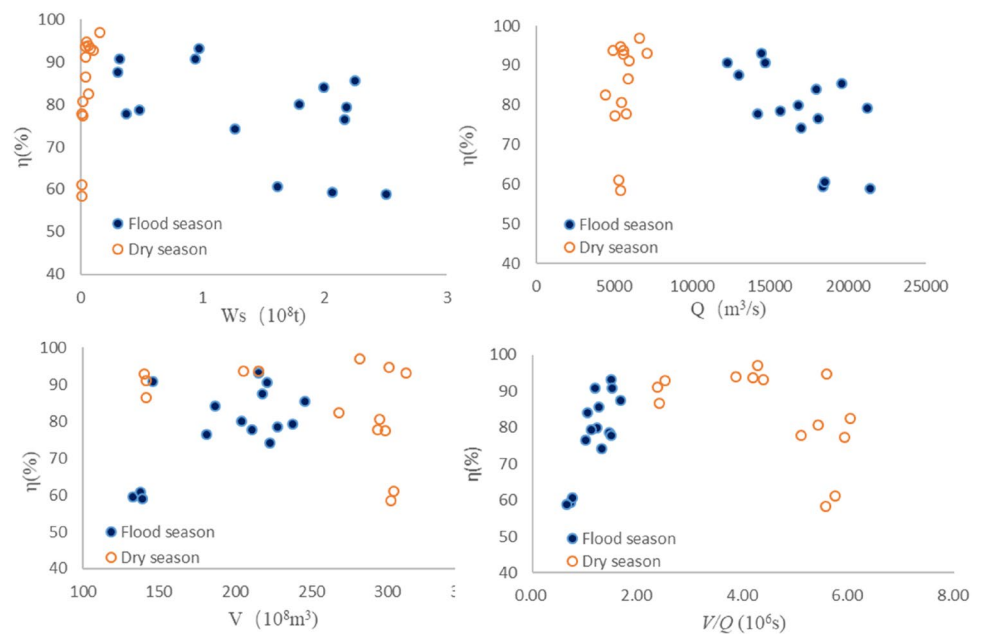
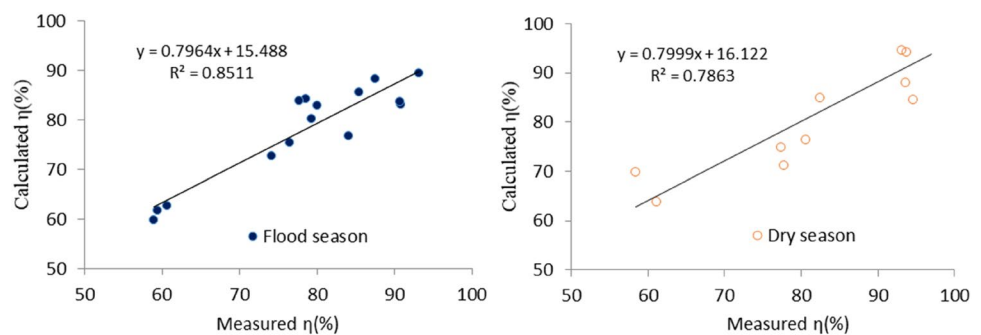


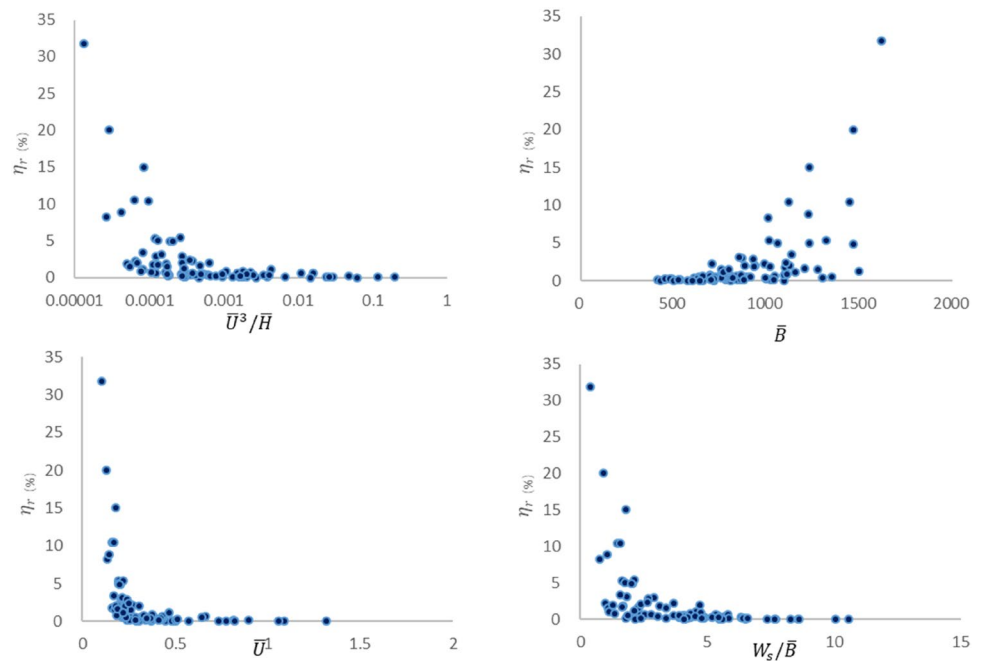
Fig. 6 Relationship between calculated η and measured η



clear positive correlation trend between the sediment trapping ratio of the reach and the reach width $\bar{B}$. As the most important indicator of flow power, flow velocity is directly associated with erosion and deposition in the reach. With

the increase in velocity, the sediment trapping rate in the reach gradually decreases, and when the flow velocity of the reach is greater than 0.5 m/s, deposition is difficult. Compared with the influence factors for the total sediment

Fig. 7 Relationship between η_r and its influence factors



tripping ratio of the reservoir, the local reach conditions are also main influencing factors on the sediment trapping ratio of the reach.

Considering that $\bar{U}$ and $\bar{U}^3/\bar{H}$ are the same type of factors, and the $W_s/\bar{B}$ factor includes $\bar{B}$, we choose $\bar{U}$ and $W_s/\bar{B}$ as the main indexes to present the empirical formula. Based on the nonlinear fitting method, the empirical formula of the sediment trapping ratio at the reach scale in TGR is presented as Eq. 11. The coefficient of the relationship between the calculated η_r and the measured η_r is 0.632 (Fig. 8).

$$\eta_r = 6.976 \times 10^{-7} (\bar{U})^{-1.611} \left(\frac{W_s}{\bar{B}} \right)^{-0.456} \quad (11)$$

Discussion

As mentioned above, sediment deposition in TGR has its own characteristics on reservoir scale and river reach scale, and its main influencing factors have both similarities and differences. In order to test the applicability of the formulas proposed in this paper, the empirical formulas of sediment trapping ratio at reservoir scale and river reach scale were tested based on the measured data at gauging stations from 2018 to 2020 and the topography data at fixed sections of 2018. At the same time, based on the measured topographic data in 2003, the variation of sediment carrying capacity of each section of the reservoir under flood condition is analyzed, and the causes of the differences in sedimentation

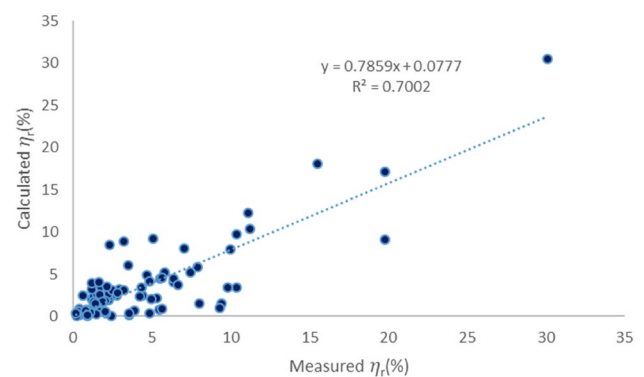


Fig. 8 Relationship between calculated η_r and measured η_r

characteristics between wide and narrow sections of the reservoir are revealed (see Fig. 9).

Verification of the empirical equations

The variation of incoming water and sediment in TGR from 2018 to 2020 shows that the amount of incoming water is more, and the amount of incoming sediment is more in 2018 and 2020, but less in 2019, comparing with that from 2003 to 2017. Table 2 provides the comparison of the characteristic values of water and sediment inflow in flood season and dry season from 2018 to 2020, as well as the average water level in front of the dam. It can be found that the inflow of water and sediment is more concentrated in flood season, account 72–76% for inflow of water and 97–99% for inflow of sediment. The average water level at dam is maintained

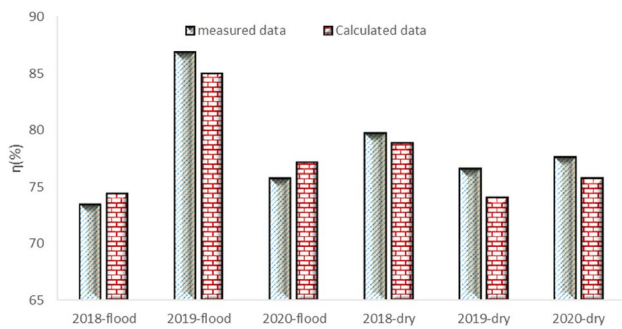


Fig. 9 Comparison of calculated and measured sediment trapping ratio from 2018 to 2020

at a low level and fluctuates between 148 and 155 m in flood season and at a higher level between 169 and 171 m in dry season. The water level of TGR varies greatly between the flood season and the dry season, but varies little in each flood season or dry season of different year, which is also the reason why the water level at dam does not appear directly in the formula parameters in this paper. According to Eqs. 9 and 10, the sediment trapping ratio during the flood and dry seasons from 2018 to 2020 was calculated and compared with the measured data, as shown in Fig. 9. The calculated values are in good agreement with the measured values, and the root-mean-square error during the flood and dry seasons are 1.45 and 1.86, respectively.

Based on the measured topography data at fixed sections in October at 2018, the water depth, river width, velocity and

cross-section area of each reach along the river were calculated based on a one-dimensional model using the average discharge during flood season and the corresponding average water level at dam, and the sediment trapping ratios at reach scale were calculated by Eq. 11, as shown in Fig. 10. It can be seen that the overall trend of calculated values and measured values is consistent, and the root-mean-square error is 1.76.

Change of sediment carrying capacity of river reach in reservoir area

The flat form of TGR is alternately wide and narrow, and the section varies greatly along the way. Figure 11 shows the variation of the river width in the perennial backwater area of the reservoir (480 km from the dam). It can be seen that the river width varies greatly along the way, and the water surface of the canyon section is narrow, with an average width of 300 m, while that of the wide valley section is wide and shallow, with an average width of 800 m. Near the dam, the width of the water surface widens to about 3500 m. In addition, the water depth of the reservoir gradually changes from downstream at dam to upper reach after impounding, and the hydraulic factors of each reach are obviously changed, and the sediment carrying capacity of the flow is different in wider reach and narrow reach, which leads to the obvious differences in the sedimentation of each reach. The sediment carrying capacity index can be expressed as follows:

Table 2 Incoming water and sediment of TGR from 2018 to 2020

Year	Incoming water in flood season (10^8m^3)	Incoming sediment in flood season (10^8t)	Average water level at dam in flood season (m)	Incoming water in dry season (10^8m^3)	Incoming sediment in dry season (10^8t)	Average water level at dam in dry season (m)
2018	3289	1.32	151.6	1023	0.013	169.4
2019	2948	0.64	148.9	1139	0.015	170.1
2020	3762	1.92	154.7	1124	0.016	169.3

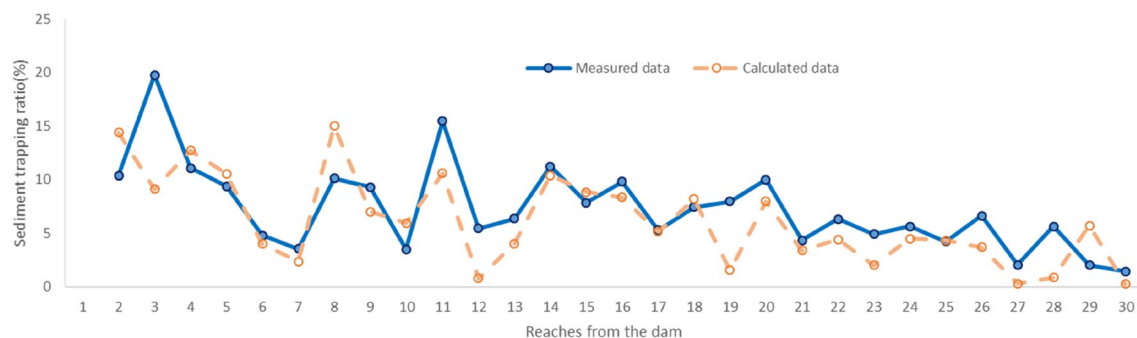


Fig. 10 Comparison of calculated and measured sediment trapping ratio in different reaches at 2018

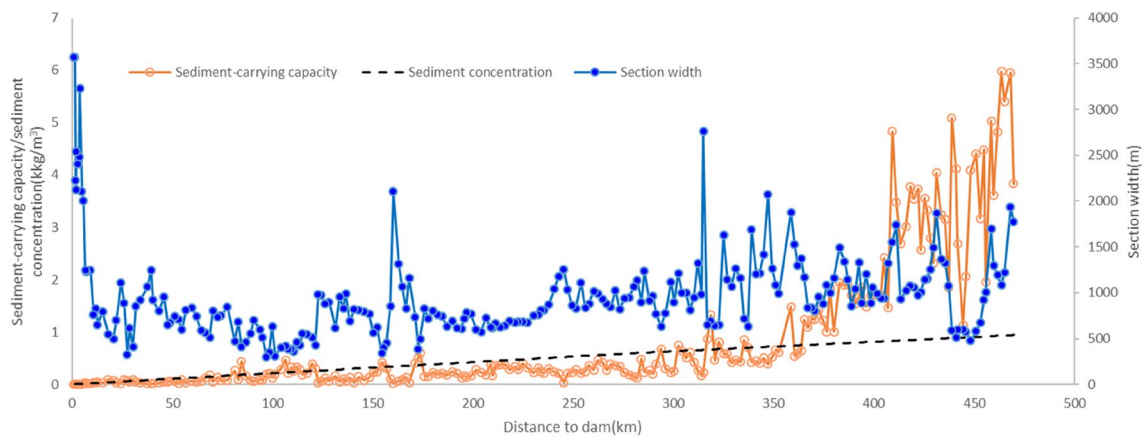


Fig. 11 Change of Sediment-carrying capacity and width of each section in the perennial inundated area of TGR

$$S_*(i) = k \left(\frac{u(i)^3}{gR(i)\omega(i)} \right)^m \quad (12)$$

where S_* is the sediment carrying capacity, U is the average velocity of the section, R is the hydraulic radius of the section, and ω is the settling velocity of the sediment.

Based on the topography of the TGR in the initial period of impoundment (October 2003), the typical flood discharge (30,000 m³/s) and corresponding water level at dam (145 m) in flood season were selected to calculate the change of sediment carrying capacity of each section within 480 km in front of the dam (the perennial backwater area) using Eq. 12. The comparison of calculated sediment carrying capacity and measured sediment concentration at each section are presented in Fig. 11. Where, the sediment concentration at each section was obtained by linear interpolation of the measured data at Qingxichang, Wanxian and Miaohe stations. It can be seen that the sediment carrying capacity of the flow is larger in the canyon section with smaller river width, and less in the wide valley section with large river width. Even at the narrow section closed to dam, its sediment carrying capacity is larger than measured sediment concentration, which resulting in a large amount of sediment deposition in the wide valley section, while there is basically no sedimentation in the canyon section. This is also the main reason for the discontinuous distribution of longitudinal sedimentation in the reservoir, which also leads to the difference in sediment trapping rates among the various river sections.

Conclusions

From 2003 to 2017, the total amount of sediment deposition in the Three Gorges Reservoir is 1650 million tons, and the sediment distribution is discontinuous and mainly deposited

in the perennial inundated area. With the continuous construction and operation of the main and tributary reservoirs in the upper reaches of the Yangtze River, the existing sedimentation regime of the Three Gorges Reservoir will persist for many years.

The sediment deposition in the TGR is affected not only by the incoming water and sediment and the operation rule of the reservoir, but also by the reach characteristics. Compared with the influence factors for the sediment trapping ratio of the reservoir, the local reach conditions also are influence factors on the sediment trapping ratio of the reach. *The sediment carrying capacity of the flow is larger in the canyon section with smaller river width, and less in the wide valley section with large river width, which is the main reason for the discontinuous distribution of longitudinal sedimentation in the reservoir, also leads to the difference in sediment trapping rates among the various river sections.*

Using the sediment trapping ratio as an indicator, the influencing factors of the sediment trapping ratios at the reservoir scale and reach scale are analyzed, and the empirical formulas is presented. *Based on the measured data at gauging stations from 2018 to 2020 and the topography data at fixed sections of 2018, the applicability of the formulas proposed in this paper is verified.* The result can provide reference for future sediment deposition prediction of the TGR.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of Interest The authors declare no competing interests.

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