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1 **Impact of water-sediment diversion and afflux on erosion-deposition in the Luoshan-Hankou reach,**
2 **middle Yangtze River, China**

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19 Abstract

20 It is not yet fully understood how water-sediment diversion and afflux along a mainstream reach of a
21 river affect erosion-deposition in downstream reaches. This study focuses on the Luoshan-Hankou
22 mainstream reach of the middle Yangtze River, China. The Luoshan-Hankou reach is vitally important for
23 flood control, being located downstream of three diversion mouths and an afflux outlet along the Jingjiang
24 reach. We establish empirical formulae for sediment transport rates at boundary cross-sections, and hence
25 estimate the amount and proportion of erosion-deposition and its relative increase (termed
26 erosion-deposition promotion) in the Luoshan-Hankou reach. We then propose critical net water supplies
27 from Dongting Lake to Luoshan-Hankou reach based on maxima and equilibria of erosion-deposition and its
28 promotion. It is found that net water supply partly drives erosion-deposition in the Luoshan-Hankou reach
29 where maximal proportions of deposition and deposition-promotion may be approximated by $0.01c^{-37.67}$ and
30 $0.01c^{-37.67+c-1}$ in which c is a dimensionless parameter representing the erosion-deposition condition in
31 Luoshan-Hankou reach for no water-sediment exchange. At Zhicheng hydrological station, the critical ratio
32 of net water supply to overall water discharge is $0.418c^{-33.33}-1$, and critical net water supply ratios for
33 equilibria of erosion-deposition and its promotion are -1 (or $c^{-33.33}-1$) and 0 (or $(0.06+3.257c^{54.61})^{-1}-1$). A
34 chart based on net water supply and c is devised representing four types of erosion-deposition and its
35 promotion for the Luoshan-Hankou reach. Historical data over the past 65 years demonstrate that
36 erosion-deposition and its promotion in the reach are respectively governed by c and net water supply; there
37 is a remarkable shift from alternate erosion-deposition to monotonic erosion whilst the erosion-deposition
38 effect remains consistent. The foregoing are in agreement with observed data, and comparable with data for
39 the Jingjiang reach (affected by the three water-sediment diversion mouths). Satisfactory flood-control
40 conditions in the convergence zone between the Yangtze mainstream and Dongting Lake accompanied by
41 increasing erosion in the Luoshan-Hankou reach are predicted for the future.

42 **Keywords:** Luoshan-Hankou reach; Dongting Lake; Water-sediment exchange; Erosion-deposition;

44 **1. Introduction**

45 Water and sediment diversions from a river into distributaries, and affluxes from tributaries into a river
46 affect net erosion-deposition in mainstream reaches. This can have engineering consequences, such as
47 altered flood risk, navigation obstruction and land-resource loss. In China, water diversion for agricultural
48 irrigation along the Kubuqi (Hobq) Desert reach of the Yellow River as it passes through Inner Mongolia has
49 caused the mainstream flow velocity to decrease, enhancing sediment deposition and raising the mainstream
50 flood discharge level (Pan et al., 2015). In the US, large-scale sediment diversion along the lower
51 Mississippi River, through distributaries or small canals to restore sub-deltas, has diminished the deposition
52 rate in mainstream reaches, lowering flood flow lines and effectively reducing navigation-related dredging
53 volumes (Kemp et al., 2014). In South America, the decreasing trend in sediment afflux from the Madeira
54 River (a major tributary of the Amazon River) has partly triggered muddy coast degradation and increased
55 the risk of wetland recession in the Amazon Estuary (Li et al., 2020). Several previous studies have
56 quantitatively dissected the influence mechanism of water-sediment diversion and afflux on
57 erosion-deposition in a river mainstream (Lindner, 1953; Kerssens and Van Urk, 1986; Wang and Yin, 1989).
58 To date, the focus has been on cases where either diversion or afflux solely occurs. However, there is a need
59 to understand how the river mainstream evolves in cases where diversion and afflux occur concurrently
60 along a given river. This is especially pertinent at the present time as many large rivers worldwide are
61 experiencing intense human interference from dam construction, water-soil conservation works, sand
62 excavation, etc.

63 The Yangtze River, China, has received widespread attention regarding erosion-deposition of its
64 riverbed. The Luoshan-Hankou reach is located in the middle Yangtze River, immediately downstream of a
65 water-sediment diversion and afflux system between Jingjiang reach and Dongting Lake, and occupies ~ 90%
66 of the length of the Chenglingji-Hankou reach whose net erosion-deposition is of major concern owing to its

67 critical impact on local flood control, especially near Chenglingji at the afflux outlet of Dongting Lake
68 (Zhou, 2005; Han, 2006; Han et al., 2017). A major debate has taken place as to whether net sediment
69 erosion or deposition would occur in the Chenglingji-Hankou reach after the impoundment of the Three
70 Gorges Dam (TGD). One view (Zhou, 2005) was that riverbed evolution of the Chenglingji-Hankou reach
71 was primarily determined by the amount of coarse sediment (of median diameter $d > 0.1$ mm) entering the
72 reach. Given that the Jingjiang reach had experienced substantial sediment erosion after the impoundment of
73 the TGD and thence supplied abundant coarse sediment to the Chenglingji-Hankou reach, it was most likely
74 that persistent (> 100 years) sediment deposition would occur in the Chenglingji-Hankou reach. Another
75 study (Han, 2006) argued that the Chenglingji-Hankou reach had experienced both sediment erosion and
76 deposition after impoundment of the TGD, with erosion resulting from the sediment trapping effect of the
77 TGD, and deposition from the settling out of eroded material from the Jingjiang reach and a reduction in
78 sediment diversion from the Jingjiang reach into Dongting Lake. This latter argument placed emphasis on
79 the bed-forming effects of both fine ($d < 0.1$ mm) and coarse ($d > 0.1$ mm) sediment present in the river.
80 Later researches demonstrate that the Chenglingji-Hankou reach has indeed experienced erosion after the
81 impoundment of the TGD (Yuan et al., 2012; Han et al., 2017; Guo et al., 2019).

82 The Luoshan-Hankou reach exhibits similar riverbed evolution characteristics to those of the
83 Chenglingji-Hankou reach and also acts as a key river segment for flood control, motivating many studies of
84 its net erosion-deposition (Fang et al., 2012; Dai and Liu, 2013; Han et al., 2017; Lai et al., 2017; Dai Z J et
85 al., 2018; Yang et al., 2018; Guo et al., 2019). The foregoing agree that the Luoshan-Hankou reach has
86 changed from a sediment-sink before the impoundment of the TGD to a sediment-source after, during which
87 time the TGD-induced sharp reduction in sediment delivery downstream has played the dominant role,
88 expedited by water-soil conservation and sand extraction activities (Dai and Liu, 2013; Dai et al., 2018).
89 Meanwhile, the TGD has smoothed downstream hydrologic processes, thus altering the geomorphological
90 evolution of bed features, such as mid-channel bars, in this reach (Mei et al., 2015; Lou et al., 2018).

91 Although the TGD is the determining factor behind erosion-deposition in the Luoshan-Hankou reach, it
92 has also been observed that water-sediment diversion and afflux between the Jingjiang reach and the
93 Dongting Lake also contribute (Han, 2006; Mei et al., 2015; Dai Z J et al., 2018). Specifically, Dongting
94 Lake is not only receiving decreased water-sediment through diversion from the Jingjiang reach while
95 facilitating the entry of additional mainstream water and sediment into the Luoshan-Hankou reach (Han,
96 2006), but has also weakened the flattening effect of the TGD on hydrological behavior in this reach (Mei et
97 al., 2015). Moreover, the lake has also changed from a sediment-sink to a sediment-source (Dai et al., 2018)
98 since TGD impoundment. The foregoing necessarily modulate water and sediment budgets in the
99 Luoshan-Hankou reach and affect its riverbed erosion-deposition. Nevertheless, previous studies have
100 mainly focused on variations in water-sediment diversion and afflux and corresponding erosion-deposition
101 changes in the Dongting Lake area (Chang et al., 2010; Ou et al., 2014; Yang et al., 2014; Zhang et al., 2015;
102 Zhu et al., 2015; Li et al., 2016; Wang et al., 2017; Yu et al., 2018). To date, little attention has been paid to
103 the impact of water-sediment diversion and afflux on riverbed erosion-deposition in the Luoshan-Hankou
104 reach.

105 Hu et al. (2016) carried out a relevant study of the Jingjiang reach which overlaps the three diversion
106 mouths and is located upstream of the afflux outlet of Dongting Lake at Chenglingji. Specifically, Hu et al.
107 (2016) discovered that the water-sediment diversions inherently promote deposition in adjacent mainstream
108 reaches. However, this deposition-promotion has attenuated in recent decades due to the decreasing
109 discharge trend in the water-sediment diversions, with an average deposition-promotion ratio of $\sim 20\%$
110 achieved during 1957-2010. (The deposition-promotion ratio is defined as the proportion of increased
111 sediment deposition caused by the water-sediment diversions, accounted in the sediment flux entering the
112 Jingjiang reach.) The Luoshan-Hankou reach receives water and sediment from the upstream Jingjiang reach
113 (after water-sediment diversion and afflux have occurred) and the Hanjiang River (a tributary of the Yangtze
114 River) (Zhou, 2005; Han, 2006; Han et al., 2017; Yang et al., 2018), and so undoubtedly undergoes a

115 different erosion-deposition response to changes in systemic water-sediment exchanges between the
116 Jingjiang reach and the Dongting Lake.

117 The present study explores the net erosion-deposition response of the Luoshan-Hankou reach to
118 changes in water-sediment diversion and afflux along the Jingjiang reach, based on integrated data on daily
119 water-sediment discharges at selected hydrological stations and multi-year average net erosion-deposition in
120 the Luoshan-Hankou reach over the past 65 years (1955-2019), afforded by sediment-budget computations
121 at prescribed cross-sections. Critical water-sediment exchange conditions are deduced for erosion-deposition
122 and its relative increase (termed erosion-deposition promotion) in the Luoshan-Hankou reach, and an
123 assessment chart devised that delineates four types of erosion-deposition condition. Historical variations of
124 erosion-deposition and its promotion are calculated, and key influence factors identified. Erosion-deposition
125 promotion effects of water-sediment diversion and afflux on the Luoshan-Hankou and Jingjiang reaches are
126 compared, erosion-deposition types to be avoided in the Luoshan-Hankou reach are proposed, and an
127 assessment made of the future flood situation in the reach. This paper quantifies the reaction of riverbed
128 erosion-deposition processes to distributary diversion and tributary afflux along part of the middle Yangtze
129 mainstream, and deepens our knowledge of the interaction between the Yangtze mainstream and Dongting
130 Lake. Our research findings are instructive for water-sediment regulation and regional flood-control in the
131 convergence zone between the Yangtze River and Dongting Lake, and might be applicable to other
132 river-lake connection systems that are also undergoing complex variations in water-sediment exchanges.

133 **2. Geographical setting**

134 The Luoshan-Hankou reach is situated in the middle Yangtze River, stretching 251 km from Luoshan
135 hydrological station to Hankou hydrological station (Figs. 1a and 1b), and connects to the Hanjiang River, a
136 tributary of the Yangtze River (Figs. 1a and 1b)). The Jingjiang reach is located 31 km upstream of the
137 Luoshan-Hankou reach and extends 347 km from Zhicheng hydrological station to the outlet of Dongting
138 Lake at Chenglingji (Fig. 1b). Three water-sediment diversion mouths at Songzikou, Taipingkou and

139 Ouchikou, are distributed along the south bank of the Jingjiang reach (Fig. 1b). The Jingjiang reach is
140 divided into upper and lower segments according to the location of Ouchikou (Fig. 1b). Water and sediment
141 in the upper Jingjiang segment are diverted into Dongting Lake through the three mouths, and after
142 redistribution in Dongting Lake and mixing with inflows from four tributaries at the southwest of the lake
143 (i.e. Xiangjiang River, Zijiang River, Yuanjiang River, and Lishui River), water and sediment flow back into
144 the Yangtze mainstream at Chenglingji (Fig. 1b). In short, water and sediment in the Luoshan-Hankou reach
145 are supplied from three sources: (1) the upper entrance of the Jingjiang reach after deduction of fluxes
146 through the three diversion mouths and some replenishment of afflux at Chenglingji, (2) eroded riverbed
147 material from the Jingjiang and Chenglingji-Luoshan reaches, and (3) the Hangjiang River.

148 Water and sediment discharges entering the Jingjiang reach and the Luoshan-Hankou reach are
149 recorded at Zhicheng and Luoshan hydrological stations, and those flowing out of the Luoshan-Hankou
150 reach are recorded at Hankou hydrological station (Figs. 1a and 1b). Water and sediment discharges at the
151 three diversion mouths along the south bank of the upper Jingjiang reach are recorded at five hydrological
152 stations in the distributaries. Diversion discharges at Songzikou are evaluated as the sum of flow records
153 obtained at Xinjiangkou and Shadaoguan hydrological stations, those at Taipingkou are acquired from
154 Mituosi hydrological station, and those at Ouchikou are calculated as the sum of records from Kangjiagang
155 and Guanjiapu hydrological stations (Fig. 1b). Water and sediment data from the afflux at Chenglingji and
156 from the Hanjiang River are respectively recorded at Qilishan and Xiantao hydrological stations (Fig. 1b).
157 Water and sediment discharges within the Yangtze mainstream interval between Ouchikou and Chenglingji
158 are recorded at Jianli hydrological station (Figs. 1a and 1b). Data on daily water and sediment time series at
159 the foregoing hydrological stations and multi-year average net erosion-deposition of the Luoshan-Hankou
160 reach over the past 65 years (1955-2019) were acquired from the Changjiang Water Resources Commission
161 (including the Changjiang Sediment Bulletin during 2000-2019, URL:
162 http://www.cjw.gov.cn/zwzc/bmgb/nsgb/List_1.html).

164 **3. Methods**165 *3.1. Identification of impact of water-sediment diversion and afflux on net erosion-deposition in*
166 *Luoshan-Hankou reach*

167 Fig. 2 is a schematic diagram of the Yangtze mainstream side of the river-lake connection system from
168 Zhicheng to Hankou. To identify the impact of the three water-sediment diversions and single afflux on net
169 erosion-deposition in the Luoshan-Hankou reach, sediment transport rates at the two boundaries of the reach
170 are estimated for two cases: Case I, the actual reach with water-sediment diversion and afflux; and Case II,
171 the idealized reach without any water-sediment diversion and afflux. In the middle Yangtze River, sandy
172 bedload accounts for less than 5% of the total sediment discharge (Xia et al., 2016; Han et al., 2017) and so
173 we ignore its effect on riverbed erosion-deposition. The present study considers solely the transport of
174 suspended sediment load.

175 The afflux outlet of the Hanjiang River is very close to the downstream boundary of the
176 Luoshan-Hankou reach (Figs. 1 and 2). Moreover, water and sediment discharges from the Hanjiang River
177 only account for $\sim 5\%$ and $\sim 10\%$ of the mainstream discharges at the multi-year average scale (Table S1).
178 Thus, water and sediment affluxes from the Hanjiang River hardly interfere with net erosion-deposition in
179 the Luoshan-Hankou reach, and so are not taken into consideration.

180 In fluvial rivers, hydrodynamic factors such as flow velocity and water depth are mainly determined by
181 the incoming water discharge. Therefore, the sediment transport rate is usually expressed as a function of
182 water discharge (Qian et al., 1987; Hu et al., 2016). However, extreme flood events and human activities,
183 especially dam construction associated with substantial sediment trapping, can cause severe fluctuations in
184 the riverine sediment concentration. This inevitably disrupts the relatively stable relationship between
185 sediment transport rate and water discharge. By introducing the sediment concentration at an adjacent
186 upstream cross-section, we avoid this kind of problem. Hence, the sediment transport rate at a given

187 cross-section, G (in kg/s), is described by the following power function (Wang and Yin, 1989; Lu et al.,
188 2012):

$$189 \quad G = KQ^\alpha S^\beta \quad (1)$$

190 where Q (in m³/s) is the water discharge at the cross-section, S (in kg/m³) is sediment concentration at an
191 adjacent upstream cross-section, K is a coefficient, and α and β ($\alpha > 1$) are exponents whose sum is
192 approximately 2. It should be noted that there cannot be water-sediment diversion and afflux between the
193 cross-section and the adjacent upstream cross-section when using this equation. Moreover, Eq. (1) neglects
194 sand excavation effects. However, the total amount of sand excavated from the middle Yangtze is less than 5%
195 of the amount eroded from the riverbed (Dai and Liu, 2013), indicating that sand excavation has little impact
196 on the sediment transport rate in the Luoshan-Hankou reach.

197 Sediment transport rates are estimated through multiplication of water discharge and sediment
198 concentration values from data continuously recorded at Luoshan and Hankou hydrological stations.
199 However, the data cannot be used to directly quantify general expressions for erosion-deposition and its
200 promotion in the Luoshan-Hankou reach or for the corresponding critical conditions of water-sediment
201 exchanges between the Yangtze mainstream and Dongting Lake according to the maxima and equilibria of
202 erosion-deposition and its promotion. Moreover, measurements of water discharge and sediment
203 concentration are unavailable for the two stations considered in Case II. Given that K , α and β in Eq. (1) can
204 be calibrated using the measured data at these two stations and their values remain roughly constant for
205 Cases I and II (Wang and Yin, 1989; Lu et al., 2012; Hu et al., 2016), Eq. (1) offers a practical approach by
206 which to estimate the sediment transport rate at these stations. Calibration of the coefficient and exponents
207 of Eq. (1) is based on its transform:

$$208 \quad G = KQ^\alpha S^{2-\alpha} \quad (2)$$

209 which may be rearranged to give

$$\frac{G}{S^2} = K \left(\frac{Q}{S} \right)^\alpha \quad (3)$$

Eq. (3) is fitted to measured data on Q , S and their product, G , at relevant stations and cross-sections to determine values for K and α , noting that $\beta=2-\alpha$.

3.1.1. Case I: Actual reach with water-sediment diversion and afflux

We denote the ratio of the sum of water discharges at the three diversion mouths along the Jingjiang reach to that at Zhicheng station as η_{TDM} , and the ratio of water discharge at Qilishan station to that at Zhicheng station as $\eta_{Qilishan}$, and estimate the sediment concentration at Cross-section 1-1 (a mainstream cross-section immediately downstream of Chenglingji, Fig. 2) from:

$$S_1 = \frac{Q_{Jianli} S_{Jianli} + Q_{Qilishan} S_{Qilishan}}{Q_{Jianli} + Q_{Qilishan}} \quad (4)$$

where Q_{Jianli} (in m^3/s), $Q_{Qilishan}$ (in m^3/s), S_{Jianli} (in kg/m^3) and $S_{Qilishan}$ (in kg/m^3) are water discharges and sediment concentrations at Jianli and Qilishan stations. Sediment transport rates at Luoshan and Hankou stations, $G_{Luoshan}$ (in kg/s) and G_{Hankou} (in kg/s), are then calculated as:

$$G_{Luoshan} = K_{Luoshan} \left\{ \left[1 + (\eta_{Qilishan} - \eta_{TDM}) \right] Q_{Zhicheng} \right\}^{\alpha_{Luoshan}} S_1^{\beta_{Luoshan}} \quad (5)$$

$$G_{Hankou} = K_{Hankou} \left\{ \left[1 + (\eta_{Qilishan} - \eta_{TDM}) \right] Q_{Zhicheng} \right\}^{\alpha_{Hankou}} S_{Luoshan}^{\beta_{Hankou}} \quad (6)$$

where $Q_{Zhicheng}$ (in m^3/s) and $S_{Luoshan}$ (in kg/m^3) are the water discharge and sediment concentration at Zhicheng and Luoshan stations, $K_{Luoshan}$ and K_{Hankou} are coefficients, and $\alpha_{Luoshan}$, α_{Hankou} , $\beta_{Luoshan}$ and β_{Hankou} are power exponents obtained for the Luoshan and Hankou stations.

Hence, the net erosion-deposition rate in the actual Luoshan-Hankou reach, $\Delta G_{Luoshan-Hankou}$ (in kg/s) is determined as:

$$\begin{aligned} \Delta G_{Luoshan-Hankou} &= G_{Luoshan} - G_{Hankou} \\ &= K_{Luoshan} \left\{ \left[1 + (\eta_{Qilishan} - \eta_{TDM}) \right] Q_{Zhicheng} \right\}^{\alpha_{Luoshan}} S_1^{\beta_{Luoshan}} - K_{Hankou} \left\{ \left[1 + (\eta_{Qilishan} - \eta_{TDM}) \right] Q_{Zhicheng} \right\}^{\alpha_{Hankou}} S_{Luoshan}^{\beta_{Hankou}} \end{aligned} \quad (7)$$

Given that the net sediment supply ratio from Dongting Lake to the Luoshan-Hankou reach partially correlates with $\eta_{Qilishan} - \eta_{TDM}$, and its impact on erosion-deposition in Luoshan-Hankou reach is contained in

232 S_1 and $S_{Luoshan}$ (mainstream sediment concentrations after water-sediment exchanges between Dongting Lake
 233 and the Yangtze mainstream), the net sediment supply ratio does not feature explicitly in the foregoing
 234 empirical formulae and subsequent analyses.

235 3.1.2. Case II: Idealized reach without water-sediment diversion and afflux

236 In this case, water discharges at Luoshan and Hankou stations approximate that at Zhicheng station,
 237 and sediment concentrations at Cross-section 1-1 and Luoshan station are roughly equal to S_1 and $S_{Luoshan}$
 238 (Text S1). Thus, the sediment transport rates at Luoshan and Hankou stations, $G'_{Luoshan}$ (in kg/s) and G'_{Hankou}
 239 (in kg/s), are expressed as:

$$240 \quad G'_{Luoshan} = K_{Luoshan} Q_{Zhicheng}^{\alpha_{Luoshan}} S_1^{\beta_{Luoshan}} \quad (8)$$

$$241 \quad G'_{Hankou} = K_{Hankou} Q_{Zhicheng}^{\alpha_{Hankou}} S_{Luoshan}^{\beta_{Hankou}} \quad (9)$$

242 Accordingly, the net erosion-deposition rate in the idealized Luoshan-Hankou reach, $\Delta G'_{Luoshan-Hankou}$
 243 (in kg/s), is obtained as:

$$244 \quad \begin{aligned} \Delta G'_{Luoshan-Hankou} &= G'_{Luoshan} - G'_{Hankou} \\ &= K_{Luoshan} Q_{Zhicheng}^{\alpha_{Luoshan}} S_1^{\beta_{Luoshan}} - K_{Hankou} Q_{Zhicheng}^{\alpha_{Hankou}} S_{Luoshan}^{\beta_{Hankou}} \end{aligned} \quad (10)$$

245 3.1.3. Comparison between Case I and Case II

246 In accordance with previous studies (Lu et al., 2012; Hu et al., 2016), the proportion of net
 247 erosion-deposition in the actual Luoshan-Hankou reach to the sediment discharge entering the idealized
 248 Luoshan-Hankou reach, φ , is given by:

$$249 \quad \begin{aligned} \varphi &= \frac{\Delta G'_{Luoshan-Hankou}}{G'_{Luoshan}} \\ &= \left[1 + (\eta_{Qilishan} - \eta_{TDM}) \right]^{\alpha_{Luoshan}} - \frac{K_{Hankou}}{K_{Luoshan}} \left[1 + (\eta_{Qilishan} - \eta_{TDM}) \right]^{\alpha_{Hankou}} Q_{Zhicheng}^{\alpha_{Hankou} - \alpha_{Luoshan}} \frac{S_{Luoshan}^{\beta_{Hankou}}}{S_1^{\beta_{Luoshan}}} \end{aligned} \quad (11)$$

250 The difference in net erosion-deposition rates between the actual and the idealized Luoshan-Hankou
 251 reaches, namely the net erosion-deposition rate caused by the water-sediment diversion and afflux along the
 252 Jingjiang reach, $\delta_{Luoshan-Hankou}$ (in kg/s), is deduced from:

$$\begin{aligned} \delta_{Luoshan-Hankou} &= \Delta G_{Luoshan-Hankou} - \Delta G'_{Luoshan-Hankou} \\ &= K_{Luoshan} Q_{Zhicheng}^{\alpha_{Luoshan}} S_1^{\beta_{Luoshan}} \left\{ \left[1 + (\eta_{Qilishan} - \eta_{TDM}) \right]^{\alpha_{Luoshan}} - 1 \right\} + K_{Hankou} Q_{Zhicheng}^{\alpha_{Hankou}} S_{Luoshan}^{\beta_{Hankou}} \left\{ 1 - \left[1 + (\eta_{Qilishan} - \eta_{TDM}) \right]^{\alpha_{Hankou}} \right\} \end{aligned} \quad (12)$$

The proportion of this net erosion-deposition difference accounted in the sediment discharge entering the idealized Luoshan-Hankou reach, ψ , which we call the net erosion-deposition promotion ratio, is determined from:

$$\begin{aligned} \psi &= \frac{\delta_{Luoshan-Hankou}}{G'_{Luoshan}} \\ &= \left\{ \left[1 + (\eta_{Qilishan} - \eta_{TDM}) \right]^{\alpha_{Luoshan}} - 1 \right\} + \frac{K_{Hankou} Q_{Zhicheng}^{\alpha_{Hankou}} S_{Luoshan}^{\beta_{Hankou}}}{K_{Luoshan} Q_{Zhicheng}^{\alpha_{Luoshan}} S_1^{\beta_{Luoshan}}} \left\{ 1 - \left[1 + (\eta_{Qilishan} - \eta_{TDM}) \right]^{\alpha_{Hankou}} \right\} \end{aligned} \quad (13)$$

To simplify Eqs. (11) and (13), a dimensionless parameter, c , is introduced to represent the erosion-deposition condition of the idealized Luoshan-Hankou reach as:

$$c = \frac{K_{Hankou} Q_{Zhicheng}^{\alpha_{Hankou}} S_{Luoshan}^{\beta_{Hankou}}}{K_{Luoshan} Q_{Zhicheng}^{\alpha_{Luoshan}} S_1^{\beta_{Luoshan}}} \quad (14)$$

where $c = 1$, $c > 1$, and $c < 1$ imply sediment balance, erosion, and deposition in the idealized Luoshan-Hankou reach. Herein, c represents the contributions to erosion-deposition in the Luoshan-Hankou reach from changes in mainstream water and sediment discharges driven by natural factors (e.g. precipitation, basin sediment yield and upper reach erosion-deposition) and human interference (e.g. dam construction and water-soil conservation).

Then, Eqs. (11) and (13) are rewritten as:

$$\varphi = \left[1 + (\eta_{Qilishan} - \eta_{TDM}) \right]^{\alpha_{Luoshan}} - c \left[1 + (\eta_{Qilishan} - \eta_{TDM}) \right]^{\alpha_{Hankou}} \quad (15)$$

$$\psi = \left\{ \left[1 + (\eta_{Qilishan} - \eta_{TDM}) \right]^{\alpha_{Luoshan}} - 1 \right\} + c \left\{ 1 - \left[1 + (\eta_{Qilishan} - \eta_{TDM}) \right]^{\alpha_{Hankou}} \right\} \quad (16)$$

3.2. Critical values of $\eta_{Qilishan} - \eta_{TDM}$

We consider four critical values. The first critical value of $\eta_{Qilishan} - \eta_{TDM}$, corresponding to the sediment erosion-deposition equilibrium of the actual Luoshan-Hankou reach, is determined from $\varphi = 0$ and denoted as $(\eta_{Qilishan} - \eta_{TDM})_1$. The second critical value of $\eta_{Qilishan} - \eta_{TDM}$, corresponding to the largest value of φ

(denoted as φ_m), is determined from $\frac{d\varphi}{d(\eta_{Qilishan} - \eta_{TDM})} = 0$ and denoted as $(\eta_{Qilishan} - \eta_{TDM})_2$. The third critical

274 value of $\eta_{Qilishan}-\eta_{TDM}$, corresponding to the conversion from a deposition-promotion effect to an
 275 erosion-promotion effect of water-sediment diversion and afflux along the Jingjiang reach on net
 276 erosion-deposition in the actual Luoshan-Hankou reach, is determined from $\psi = 0$ and denoted as
 277 $(\eta_{Qilishan}-\eta_{TDM})_3$. The fourth critical value of $\eta_{Qilishan}-\eta_{TDM}$, corresponding to the largest value of ψ (denoted as
 278 ψ_m), is determined from $\frac{d\psi}{d(\eta_{Qilishan}-\eta_{TDM})} = 0$ and denoted as $(\eta_{Qilishan}-\eta_{TDM})_4$.

279 4. Results

280 4.1. Erosion-deposition response of the actual Luoshan-Hankou reach to water diversion and afflux along 281 the Jingjiang reach

282 The actual Luoshan-Hankou reach experiences an overall trend from sediment erosion to deposition as
 283 η_{TDM} increases (Fig. 3a) and from sediment deposition to erosion as $\eta_{Qilishan}$ and $\eta_{Qilishan}-\eta_{TDM}$ increase (Figs.
 284 3b and 3c). In other words, higher η_{TDM} corresponds to decreased Yangtze mainstream discharge entering the
 285 actual Luoshan-Hankou reach, whereas higher $\eta_{Qilishan}$ and $\eta_{Qilishan}-\eta_{TDM}$ indicate an increased net water
 286 supply from Dongting Lake, respectively resulting in lower and higher sediment transport capacities (Tan et
 287 al., 2018) in the reach, and exacerbating the severity of deposition-promotion and erosion-promotion effects.
 288 Moreover, erosion-deposition in the actual Luoshan-Hankou reach exhibits tighter correlation with
 289 $\eta_{Qilishan}-\eta_{TDM}$ than with individual η_{TDM} or $\eta_{Qilishan}$, as indicated by the higher value of R and lower value of P
 290 in Fig. 3c than in Figs. 3a and 3b, implying that $\eta_{Qilishan}-\eta_{TDM}$ is more effective than separate water diversion
 291 or afflux in driving erosion-deposition processes in the actual Luoshan-Hankou reach, especially given that
 292 $P < 0.05$ in Fig. 3c. Nonetheless, many other factors also affect erosion-deposition of the reach; the R and P
 293 values in Fig. 3c remain unsatisfactory, stimulating evaluation of the $\eta_{Qilishan}-\eta_{TDM}$ contribution in the present
 294 study.

295 4.2. Calibrated K , α , β , calculated φ , ψ , φ_m , ψ_m , and corresponding critical $\eta_{Qilishan}-\eta_{TDM}$ values

296 Fig. 4 shows the calibrated values of $K_{Luoshan}$, $\alpha_{Luoshan}$, K_{Hankou} , and α_{Hankou} using daily measured data of

297 water discharge and sediment concentration at relevant stations and cross-sections throughout 1956-2019 for
 298 Luoshan and 1961-2019 for Hankou. It can be seen from Figs. S2 and S3 that the calibrated values of the
 299 coefficients and exponents remain roughly stable during pre-TGD and post-TGD periods. Moreover, the
 300 high values of R and low values of P in Figs. 4, S2 and S3 indicate tight correlations. Therefore, we adopt
 301 values of $K_{Luoshan}$, $\alpha_{Luoshan}$, K_{Hankou} and α_{Hankou} that are calibrated using data covering the whole period,
 302 namely 0.26, 1.13, 0.17 and 1.16 in Fig. 4, from which we estimate $\beta_{Luoshan}$ to be 0.87 and β_{Hankou} to be 0.84.
 303 These calibrated parameter values produce high consistency between the calculated and measured sediment
 304 transport rates at Luoshan and Hankou stations (Fig. S4). Moreover, the values are similar to previously
 305 published values for the middle Yangtze River (Qian et al., 1987; Hu et al., 2016).

306 Table 1 lists empirical relationships for φ , ψ , φ_m , ψ_m as functions of c and $\eta_{Qilishan-\eta_{TDM}}$. Empirical
 307 formulae for determining critical values of $\eta_{Qilishan-\eta_{TDM}}$ are also supplied. Fig. 5 displays the correlation
 308 between φ/ψ and $\eta_{Qilishan-\eta_{TDM}}$ for different c values.

309 It can be deduced from Table 1 and Fig. 5a that:

310 (1) For $c < 0.94$, the actual Luoshan-Hankou reach always experiences deposition. For $c \geq 0.94$, the
 311 actual Luoshan-Hankou reach undergoes deposition when $-1 < \eta_{Qilishan-\eta_{TDM}} < (c^{-33.33}-1)$ and erosion when
 312 $\eta_{Qilishan-\eta_{TDM}} > (c^{-33.33}-1)$. Moreover, if $\eta_{Qilishan-\eta_{TDM}} = -1$ or $(c^{-33.33}-1)$ (i.e. $(\eta_{Qilishan-\eta_{TDO}})_1$), the actual
 313 Luoshan-Hankou reach remains in a state of erosion-deposition equilibrium for all c values.

314 (2) For each c value, φ of the actual Luoshan-Hankou reach increases progressively with $\eta_{Qilishan-\eta_{TDM}}$
 315 until it attains a peak of $\varphi_m = 0.010c^{-37.67}$ (i.e. the most severe deposition state) at $\eta_{Qilishan-\eta_{TDM}} =$
 316 $(0.418c^{-33.33}-1)$, after which φ declines with further increase in $\eta_{Qilishan-\eta_{TDM}}$.

317 (3) Erosion-deposition in the actual Luoshan-Hankou reach is closely related to that of the idealized
 318 Luoshan-Hankou reach. The more deposition occurs in the idealized Luoshan-Hankou reach (i.e. the lower
 319 the value of c), the more deposition (including maximum deposition) and less erosion are experienced by the
 320 actual Luoshan-Hankou reach. Therefore, higher φ values are obtained under the deposition condition ($c < 1$)

of the idealized Luoshan-Hankou reach than under its erosion condition ($c > 1$). Furthermore, the value of $\eta_{Qilishan}-\eta_{TDM}$ (i.e. $(\eta_{Qilishan}-\eta_{TDO})_2$) associated with maximum deposition in the actual Luoshan-Hankou reach is larger under more severe deposition conditions (i.e. lower c values) in the idealized Luoshan-Hankou reach than under slight deposition or erosion conditions (i.e. higher c values).

It can be deduced from Table 1 and Fig. 5b that:

(1) For $0.93 \leq c \leq 1$, water-sediment exchanges between the Jingjiang reach and Dongting Lake exert no impact on erosion-deposition in the actual Luoshan-Hankou reach (i.e. $\psi = 0$) when $\eta_{Qilishan}-\eta_{TDM} = 0$ and $[(0.06+3.257c^{54.61})^{-1}-1]$, promote deposition in the actual Luoshan-Hankou reach when $\eta_{Qilishan}-\eta_{TDM}$ lies between 0 and $[(0.06+3.257c^{54.61})^{-1}-1]$, and facilitate erosion in the actual Luoshan-Hankou reach when $\eta_{Qilishan}-\eta_{TDM}$ has a value outside the range $\{0, [(0.06+3.257c^{54.61})^{-1}-1]\}$. For $c < 0.93$ or $c > 1$, $\psi=0$ when $\eta_{Qilishan}-\eta_{TDM} = 0$. Deposition-promotion prevails when $\eta_{Qilishan}-\eta_{TDM} > 0$ and erosion-promotion prevails when $\eta_{Qilishan}-\eta_{TDM} < 0$ for $c < 0.93$. Conversely, deposition-promotion dominates when $\eta_{Qilishan}-\eta_{TDM} < 0$ and erosion-promotion dominates when $\eta_{Qilishan}-\eta_{TDM} > 0$ for $c > 1$.

(2) Maximum deposition-promotion (i.e. ψ_m) occurs at $\eta_{Qilishan}-\eta_{TDM} = 0.418c^{-33.33}-1$ for all c values.

(3) For $\eta_{Qilishan}-\eta_{TDM} > 0$, lower c values correspond to higher ψ values, suggesting that more severe deposition in the idealized Luoshan-Hankou reach usually triggers a more significant deposition-promotion effect in the actual Luoshan-Hankou reach after water-sediment exchanges between the Jingjiang reach and the Dongting Lake. For $\eta_{Qilishan}-\eta_{TDM} < 0$, the situation reverses.

4.3. A chart for assessing erosion-deposition and its promotion in the actual Luoshan-Hankou reach

Fig. 6 plots the functions $(\eta_{Qilishan}-\eta_{TDM})_1 = -1$, $(\eta_{Qilishan}-\eta_{TDM})_1 = c^{-33.33}-1$, $(\eta_{Qilishan}-\eta_{TDM})_2 = 0.418c^{-33.33}-1$, $(\eta_{Qilishan}-\eta_{TDM})_3 = 0$, $(\eta_{Qilishan}-\eta_{TDM})_3 = (0.06+3.257c^{54.61})^{-1}-1$ and $(\eta_{Qilishan}-\eta_{TDM})_4 = 0.418c^{-33.33}-1$ with respect to c . The curves traced by $(\eta_{Qilishan}-\eta_{TDM})_1 = -1$, $(\eta_{Qilishan}-\eta_{TDM})_1 = c^{-33.33}-1$, $(\eta_{Qilishan}-\eta_{TDM})_3 = 0$, and $(\eta_{Qilishan}-\eta_{TDM})_3 = (0.06+3.257c^{54.61})^{-1}-1$ divide the diagram into 6 subareas, which in turn are classified as 4 erosion-deposition and erosion-deposition promotion types.

345 **Subarea I** ($\eta_{Qilishan}-\eta_{TDM} > 0$ and $\eta_{Qilishan}-\eta_{TDM} > c^{-33.33}-1$): erosion and erosion-promotion (**Type I**).
346 The actual Luoshan-Hankou reach experiences both erosion and erosion-promotion driven by
347 water-sediment exchanges between the Jingjiang reach and Dongting Lake.

348 **Subareas II** ($0 < \eta_{Qilishan}-\eta_{TDM} < c^{-33.33}-1$ and $(0.06+3.257c^{54.61})^{-1}-1 < \eta_{Qilishan}-\eta_{TDM} < c^{-33.33}-1$) and **IV**
349 ($-1 < \eta_{Qilishan}-\eta_{TDM} < 0$ and $-1 < \eta_{Qilishan}-\eta_{TDM} < (0.06+3.257c^{54.61})^{-1}-1$): deposition and erosion-promotion
350 (**Type II**). Although the actual Luoshan-Hankou reach experiences deposition when $\eta_{Qilishan}-\eta_{TDM}$ is located
351 in these two subareas, such deposition is suppressed by water-sediment exchanges between the Jingjiang
352 reach and the Dongting Lake. Moreover, the idealized Luoshan-Hankou reach also undergoes deposition (i.e.
353 $c < 1$) in these two subareas.

354 **Subareas III** ($0 < \eta_{Qilishan}-\eta_{TDM} < (0.06+3.257c^{54.61})^{-1}-1$) and **V** ($(0.06+3.257c^{54.61})^{-1}-1 < \eta_{Qilishan}-\eta_{TDM}$
355 < 0 and $-1 < \eta_{Qilishan}-\eta_{TDM} < c^{-33.33}-1$): deposition and deposition-promotion (**Type III**). The actual
356 Luoshan-Hankou reach undergoes both deposition and deposition-promotion owing to water-sediment
357 exchanges between the Jingjiang reach and Dongting Lake. Importantly, when $\eta_{Qilishan}-\eta_{TDM}$ is situated along
358 the curve described by $(\eta_{Qilishan}-\eta_{TDM})_2 = (\eta_{Qilishan}-\eta_{TDM})_4 = 0.418c^{-33.33}-1$, deposition and
359 deposition-promotion are most severe. Furthermore, the idealized Luoshan-Hankou reach also experiences
360 deposition (i.e. $c < 1$) in Subarea III.

361 **Subarea VI** ($c^{-33.33}-1 < \eta_{Qilishan}-\eta_{TDO} < 0$): erosion and deposition-promotion (**Type IV**). Although the
362 actual Luoshan-Hankou reach witnesses erosion, this is hindered by water-sediment exchanges between the
363 Jingjiang reach and Dongting Lake. The idealized Luoshan-Hankou reach also undergoes erosion (i.e. $c > 1$)
364 in Subarea VI.

365 4.4. Historical changes in river-lake water exchange and variables related to erosion-deposition in the 366 Luoshan-Hankou reach

367 Fig. 7 shows that the total water diversion at the three mouths along the Jingjiang reach and the water
368 afflux at Qilishan station have experienced synchronous decreases over the past 65 years, resulting in overall

369 stable but yearly fluctuating net water supply and $\eta_{Qilishan-\eta_{TDM}}$ from Dongting Lake into the actual
370 Luoshan-Hankou reach.

371 Based on Fig. 7, variables related to erosion-deposition in the actual Luoshan-Hankou reach are
372 evaluated. Table 2 lists the results, which demonstrate that:

373 (1) Due to net water supply from Dongting Lake, the actual Luoshan-Hankou reach underwent
374 consistent erosion-promotion throughout all the periods of interest. This finding is also supported by the
375 correlations in Figs. 3b and 3c.

376 (2) Considering net erosion-deposition, the actual Luoshan-Hankou reach experienced alternating
377 prevalent deposition and inferior erosion processes before 2003, but underwent continuous erosion after
378 2003 under the significant sediment trapping effect of the TGD (Yuan et al., 2012; Dai and Lu, 2014; Han et
379 al., 2017; Guo et al., 2019). Moreover, $\Delta G_{Luoshan-Hankou}$ presented an acceptable approximation to T ,
380 indicating that Eq. (7) could effectively calculate net erosion-deposition in the actual Luoshan-Hankou
381 reach.

382 (3) Based on the linear regression equations in Table 2, erosion-deposition and its promotion
383 respectively depended on c and $\eta_{Qilishan-\eta_{TDM}}$. Consequently, while the actual Luoshan-Hankou reach
384 experienced an overall change from alternate erosion and deposition events to monotonic erosion conditions
385 as c increased under the sharp reduction in incoming sediment from the upstream reach, it also underwent an
386 erosion-promotion effect with no obvious unidirectional trend, given the relatively stable value of
387 $\eta_{Qilishan-\eta_{TDM}}$.

388 (4) $\eta_{Qilishan-\eta_{TDM}}$, c and calculated φ and ψ during the periods of interest were mainly located in
389 Subareas I and II of Fig. 6. This not only verifies Fig. 6, but also implies that the actual Luoshan-Hankou
390 reach encounters two major conditions at the multi-year average scale: erosion and erosion-promotion, and
391 deposition and erosion-promotion.

392 5. Discussion

5.1. Erosion-deposition promotion in different mainstream reaches

The Luoshan-Hankou reach is located downstream of three diversion mouths and an afflux outlet, which are overlapped by the Jingjiang reach (Figs. 1b and 2). Discrepancies therefore occur in the erosion-deposition promotions produced by the mainstream-lake water and sediment exchanges in the two Yangtze mainstream reaches. Erosion-deposition promotion in the Luoshan-Hankou reach is determined by the net water supply from the Dongting Lake. Water afflux at Chenglingji is generally larger than the sum of water diversions at the three mouths (Fig. 7), and so erosion-promotion persists in the Luoshan-Hankou reach and even alters the reach from sediment deposition condition to erosion conditions as $\eta_{Qilishan}-\eta_{TDM}$ increases (Fig. 3c). Over the past decades, $\eta_{Qilishan}-\eta_{TDM}$ has fluctuated, causing erosion-promotion also to fluctuate (Table 2). By comparison, erosion-deposition promotion in the Jingjiang reach depends on water diversion at the three mouths, which reduces the water discharge and weakens the sediment carrying capacity of the mainstream, leading to consistent deposition-promotion in the reach (Hu et al., 2016). Under the decreasing trend in water-diversion discharge, deposition-promotion has correspondingly declined (Hu et al., 2016). In terms of erosion-deposition promotion ratio, the multi-year average $|\psi|$ for the Luoshan-Hankou reach was $\sim 10\%$ over the 1959-2019 period (Table 2), whereas that for the mainstream reaches about the three diversion mouths along the Jingjiang reach was $\sim 20\%$ over the 1957-2010 period (Hu et al., 2016). If Hu et al. (2016) had focused on the whole Jingjiang reach, we believe that the two $|\psi|$ values would have been more comparable. Similar erosion-deposition promotion events caused by water-sediment diversion and afflux along the mainstream have also been observed in other rivers, such as the Yellow River (Pan et al., 2015), Mississippi River (Kemp et al., 2014; Wang and Xu, 2020), and Amazon River (Li et al., 2020).

A much better understanding is presently needed of erosion-deposition processes in river mainstream reaches located upstream of water-sediment diversion mouths and afflux outlets. It has been speculated that a river mainstream upstream of diversion mouths is prone to suffer erosion-promotion because water

417 diversion steepens the water surface slope and increases the velocity of the mainstream flow, and hence its
418 sediment carrying capacity (Wang and Hu, 2004; Viparelli et al., 2015), whereas a river mainstream reach
419 located upstream of afflux outlets is likely to experience deposition-promotion due to the jacking effects of
420 the water afflux on the water discharge in the mainstream, reducing its water surface slope and flow velocity
421 (Ou et al., 2014; Sun et al., 2014; Chen et al., 2018, 2020). As water diversion or afflux discharges increase,
422 erosion-promotion and deposition-promotion events are likely to be more pronounced.

423 5.2. Practical use of the assessment chart for erosion-deposition and its promotion

424 Fig. 6 is useful from a flood-risk management perspective. Subarea I in Fig. 6 reinforces sediment
425 erosion in the Luoshan-Hankou reach, and helps maintain satisfactory flood-control conditions in this reach
426 and the region around Chenglingji. Conversely, subareas III and V, especially those areas in the vicinity of
427 the function curve $(\eta_{Qilishan}-\eta_{TDM})_2 = (\eta_{Qilishan}-\eta_{TDM})_4 = 0.418c^{-33.33}-1$, greatly strengthen sediment deposition
428 and must be avoided. Subareas II and IV suggest a deposition state for both of the actual and idealized
429 Luoshan-Hankou reaches, where deposition is hindered due to the erosion-promotion effect. Therefore, these
430 two subareas are also beneficial for regional flood-control. Subarea VI implies an erosion state for both the
431 actual and idealized Luoshan-Hankou reaches, where erosion is hampered by the deposition-promotion
432 effect. This situation is likely to occur during mainstream flood events when water diversion at the three
433 mouths is largely enhanced (Xia et al., 2014; Li et al., 2016). Although the water afflux at Chenglingji is
434 synchronously augmented at these times by the enhanced discharge at the three diversion mouths and the
435 raised flood water level within Dongting Lake (Fig. 7; Hayashi et al., 2008), this augmentation is restricted
436 by the jacking effect of the high water level in the Yangtze mainstream, resulting in a constringent increase
437 in net water supply from Dongting Lake into the Luoshan-Hankou reach (Chang et al., 2010; Zhan et al.,
438 2015; Dai X et al., 2018). Hence, subarea VI should also be avoided.

439 In Table 2, 1966, 1981, 2003 and 2008 are years in which implementation commenced of the lower
440 Jingjiang Cutoff Projects (Fig. 1b), the impoundment of the Gezhou Dam (Fig. 1), the initial impoundment

of the TGD (Fig. 1) and the experimental impoundment of the TGD. In 1986, the Gezhou Dam ceased to exert further influence on the evolution of the downstream reach (Zhu et al., 2015; Guo et al., 2019). All these major engineering projects have caused riverbed incision along the Jingjiang reach (Xia et al., 2016; Han et al., 2017, 2018). Dam operations have also clipped flood peaks in the reach (Han et al., 2018; Li et al., 2018; Chen et al., 2019). Taken together, these have greatly reduced water diversion from the Jingjiang river into Dongting Lake (Zhang et al., 2015; Zhu et al., 2015; Yu et al., 2018), which has consequently diminished water afflux from Dongting Lake into the Luoshan-Hankou reach over the past decades (Fig. 7). As a result, a relatively stable net water supply has occurred from Dongting Lake to the Luoshan-Hankou reach (Fig. 7). As riverbed incision in the Jingjiang reach weakens (Yuan et al., 2012; Hu et al., 2015; Zhu et al., 2015) and dam-induced flood-peak clip persists (Duan et al., 2016; Han et al., 2018; Zhu et al., 2020), the multi-year average net water supply (i.e. $\eta_{Qilishan}-\eta_{TDM}$) is likely to remain at a roughly stable value of $\sim 60\%$ in the future. Meanwhile, the state of $c > 1$ that has occurred since 2003 (Table 2) will persist over following decades because of the continuous low sediment influx from the upstream reach under the sediment trapping effect of large cascade reservoirs in the upper Yangtze River (Yang et al., 2014; Guo et al., 2019). Therefore, subarea I in Fig. 6 is most likely to match future behavior in the reach, while also providing a satisfactory regional flood-control condition. If flood control and drought resistance (e.g. prevention of zero-flow events along the three diversion distributaries) within the whole river-lake connection system are comprehensively considered (Hayashi et al., 2008; Han et al., 2017; Wang et al., 2017; Xia et al., 2018), systematic engineering measures, such as construction of sluice gates at the diversion mouths and the afflux outlet, may need to be implemented to regulate water-sediment exchanges between the Yangtze mainstream and Dongting Lake (Wang et al., 2017).

6. Conclusion

We present empirical formulae for evaluating the amount and proportion of erosion-deposition and its promotion caused by river-lake water-sediment exchanges in the Luoshan-Hankou reach of the middle

465 Yangtze River, and deduce critical $\eta_{Qilishan}-\eta_{TDM}$ values from Dongting Lake to the reach for the maxima and
466 equilibria of erosion-deposition and its promotion. An erosion-deposition assessment chart, consisting of six
467 subareas, has been devised based on two parameters, c and $\eta_{Qilishan}-\eta_{TDM}$. The chart was used to classify
468 erosion-deposition in the Luoshan-Hankou reach into four types. We find that over the past 65 years, the
469 annual value of $\eta_{Qilishan}-\eta_{TDM}$ changed slightly whereas the yearly sediment load from the upstream reach
470 reduced sharply after impoundment of the TGD. This has resulted in a complete transformation of the
471 Luoshan-Hankou reach from alternate erosion-deposition conditions before 2003 to monotonic erosion
472 afterwards. Fluctuation was evident in erosion-deposition promotion throughout.

473 Unlike the consistent deposition-promotion in the Jingjiang reach induced by the three water diversions,
474 erosion-promotion persists in the Luoshan-Hankou reach due to the net water supply from Dongting Lake.
475 Both these kinds of promotion effects are comparable in terms of their ratios. We used the assessment chart
476 to suggest types of erosion-deposition and its promotion that should be either averted or encouraged in the
477 Luoshan-Hankou reach in order to maintain satisfactory flood-control conditions in the convergence zone
478 between the Yangtze mainstream and Dongting Lake. In the future, $\eta_{Qilishan}-\eta_{TDM}$ is likely to maintain a
479 roughly constant value of $\sim 60\%$, whereas the sediment load from the upstream reach will continuously
480 decrease, helping to optimize erosion-deposition and its promotion in the Luoshan-Hankou reach, and
481 subsequently ensure proper flood-control conditions in the river-lake connection system.

482 *CRedit authorship contribution statement*

483 Design of the research framework: B.Y.Z., J.H.Q., Y.T.L and A.G.L.B. Data collection: B.Y.Z., J.H.Q.
484 and G.X.Z.L. Main analysis of the paper, writing of the main manuscript, and preparation of the Appendix A.
485 Supplementary data: B.Y.Z., J.H.Q., Y.T.L and A.G.L.B. Preparation of figures and tables: G.X.Z.L., Q.X.
486 and L.F.L.

487 **Declaration of Competing Interest**

488 The authors declare that they have no known competing financial interests or personal relationships that

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496 **Appendix A. Supplementary data**

497 Supplementary data associated with this article can be found, in the online version, at

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Figure Captions

Fig. 1. Overview of the Yangtze basin and the study area. (a) Outline map of the Yangtze basin indicating the location of the study area. (b) Plan view of the study area, which shows the water-sediment diversion and afflux system between the Yangtze River and Dongting Lake, and the geographical extent of the Luoshan-Hankou reach, with major dams, hydrological stations and distributaries/tributaries identified.

Fig. 2. Schematic diagram of the Yangtze mainstream side of the river-lake connection system from Zhicheng to Hankou.

Fig. 3. Correlations between the net erosion-deposition rate (positive representing deposition and negative representing erosion) of the bankfull channel of the actual Luoshan-Hankou reach and η_{TDM} (a), $\eta_{Qilishan}$ (b), and $\eta_{Qilishan}-\eta_{TDM}$ (c) based on multi-year average values. In the legends, n is the number of data points, R is correlation coefficient, and P is the significance level of the linear regression analysis.

Fig. 4. Power-function regressions between $G_{Luoshan}/S_1^2$ and $Q_{Luoshan}/S_1$ (a) and between $G_{Hankou}/S_{Luoshan}^2$ and $Q_{Hankou}/S_{Luoshan}$ (b) using daily data during 1956-2019 and 1961-2019, respectively. In the legends, n is the number of data points, R is the correlation coefficient, and P is the significance level of the regression analysis.

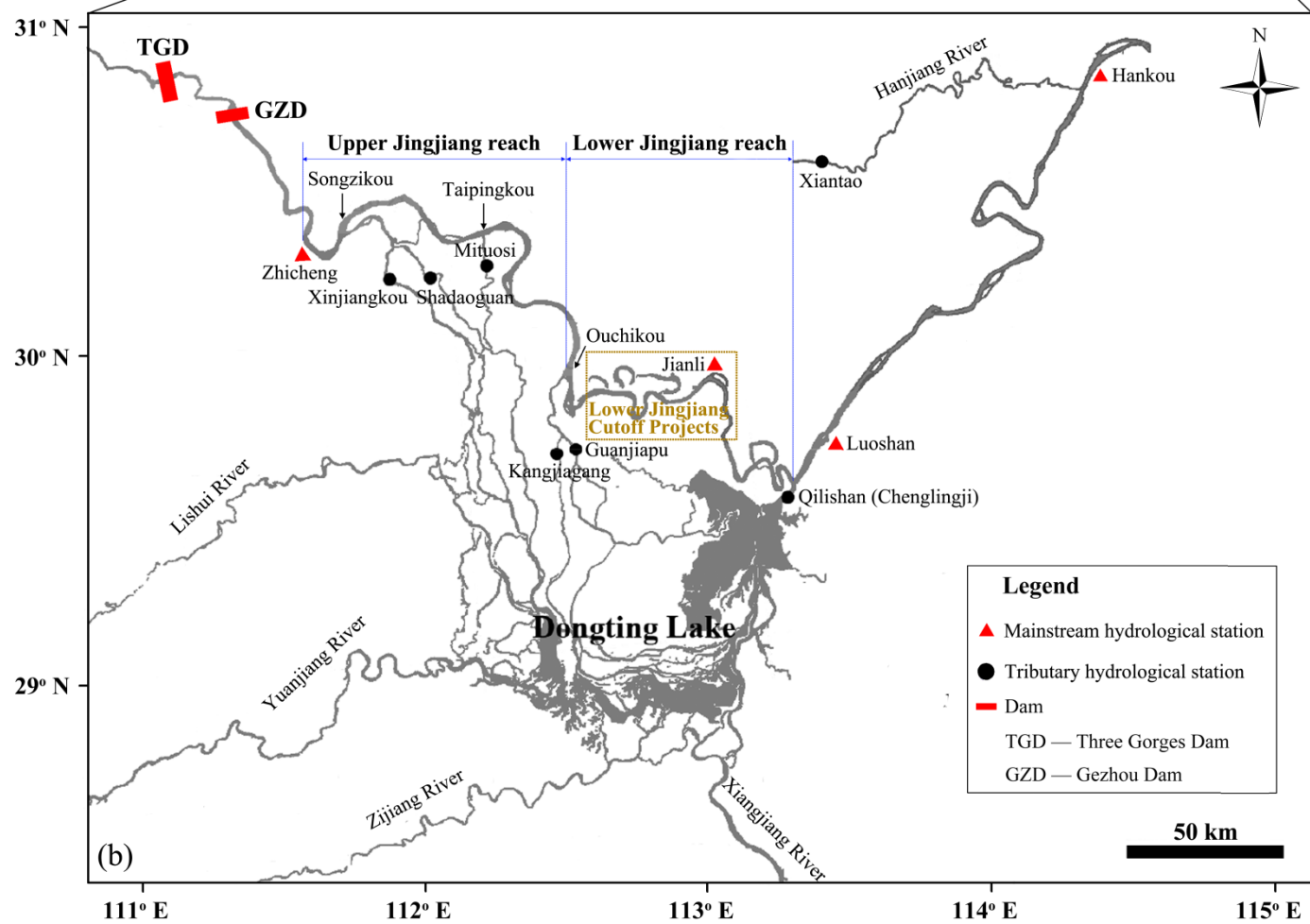
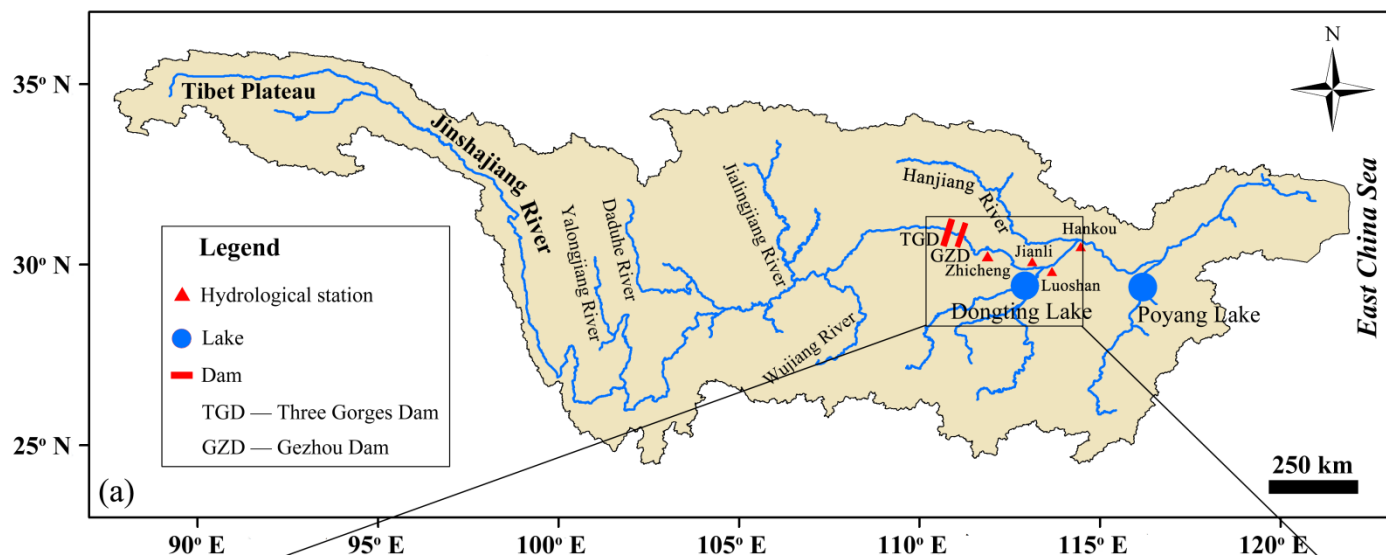
Fig. 5. Variations in φ (a) and ψ (b) with $\eta_{Qilishan}-\eta_{TDM}$ for different c values.

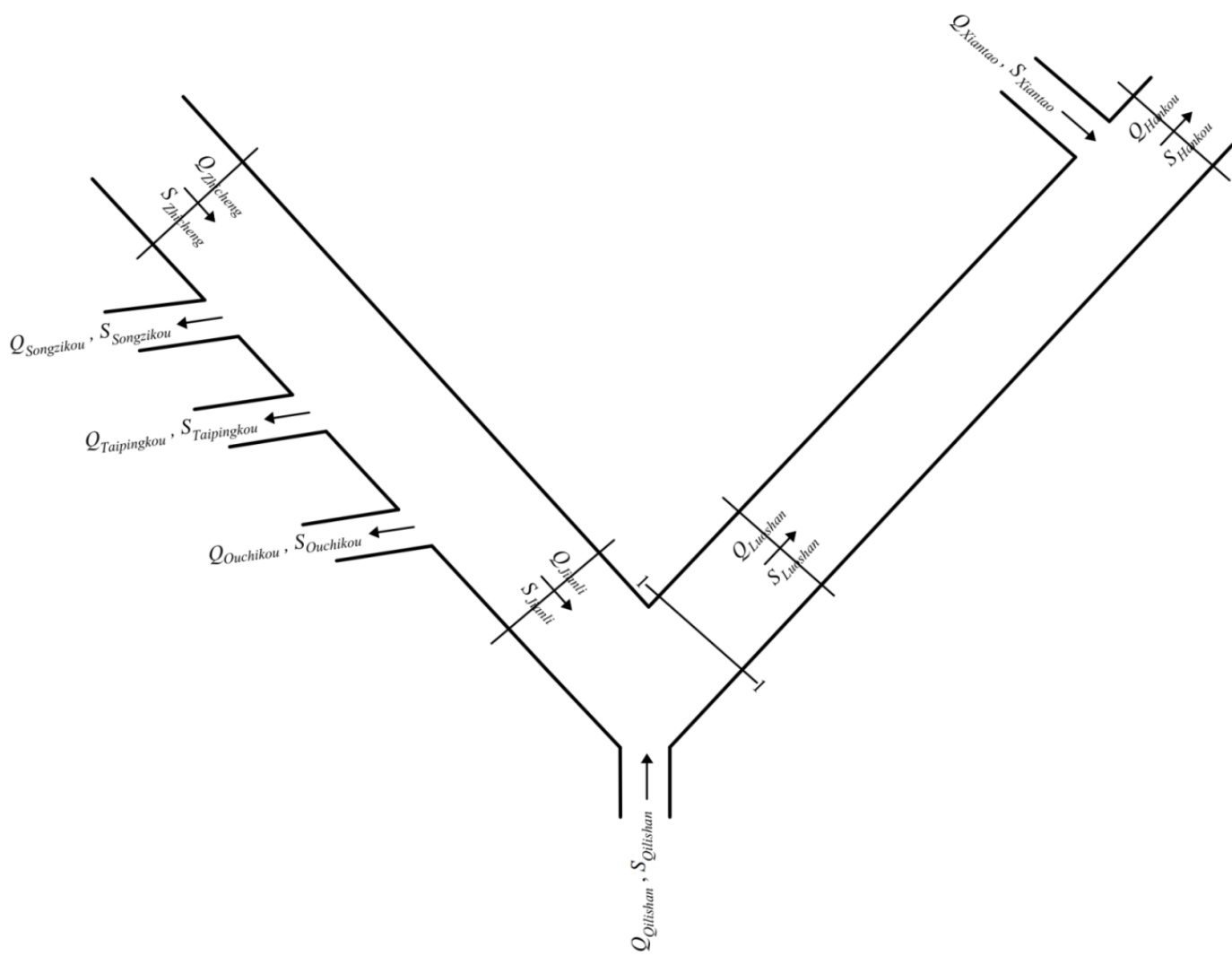
Fig. 6. Chart for assessing erosion-deposition and its promotion in the actual Luoshan-Hankou reach, consisting of 6 subareas classified into 4 types.

Fig. 7. Yearly water discharge time series at the three diversion mouths along the Jingjiang reach and the afflux outlet at

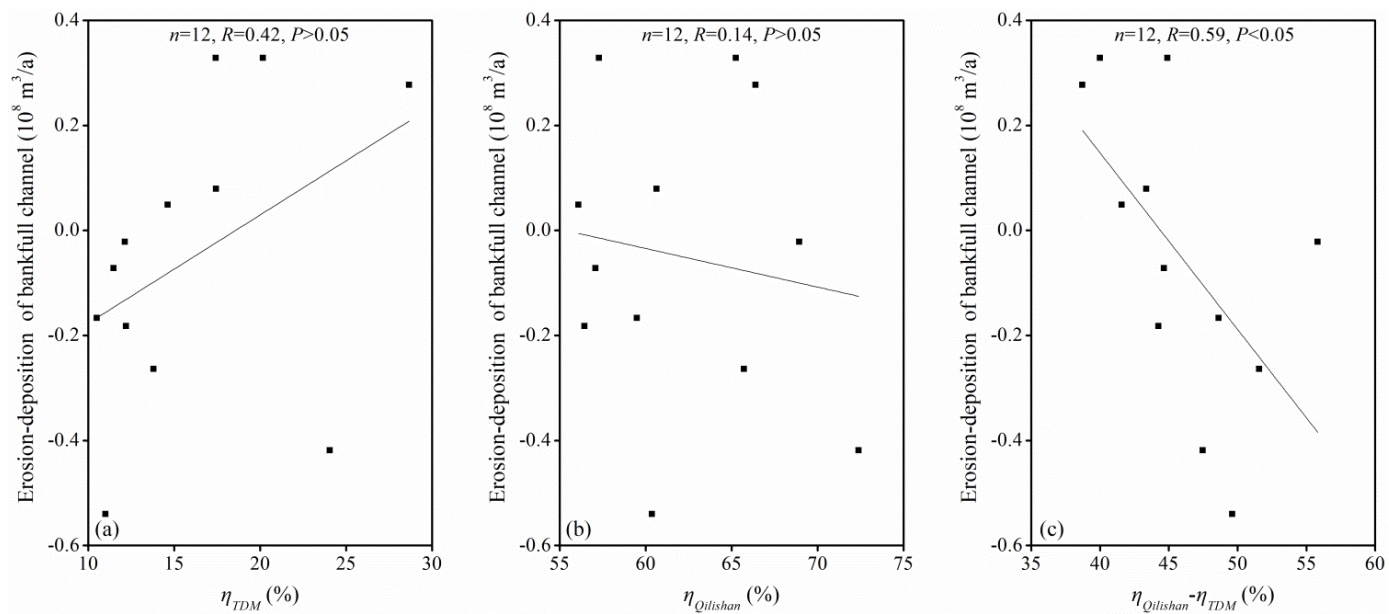
646 Chenglingji (a), and associated proportions accounted at Zhicheng station (b) over the past 65 years, from which the yearly
647 net water supply and $\eta_{Qilishan}-\eta_{TDM}$ from the Dongting Lake into the actual Luoshan-Hankou reach are obtained.
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Fig. 1





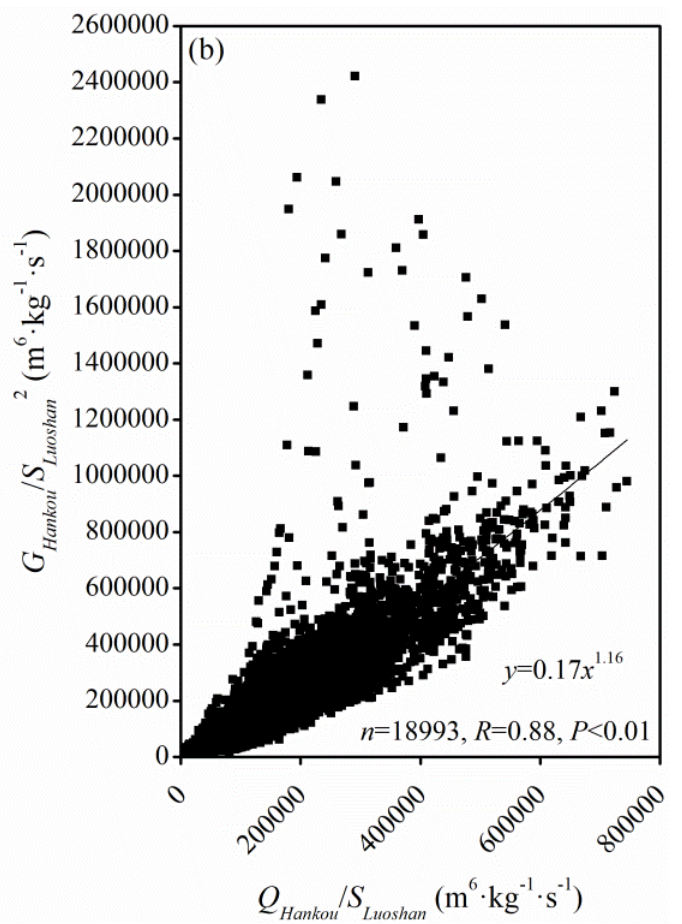
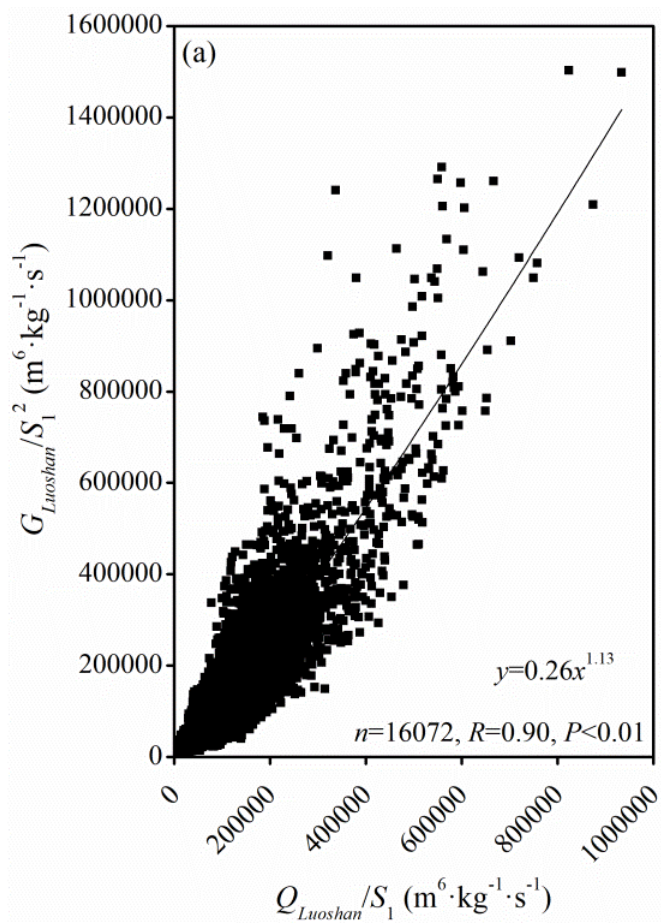
655 **Fig. 3**



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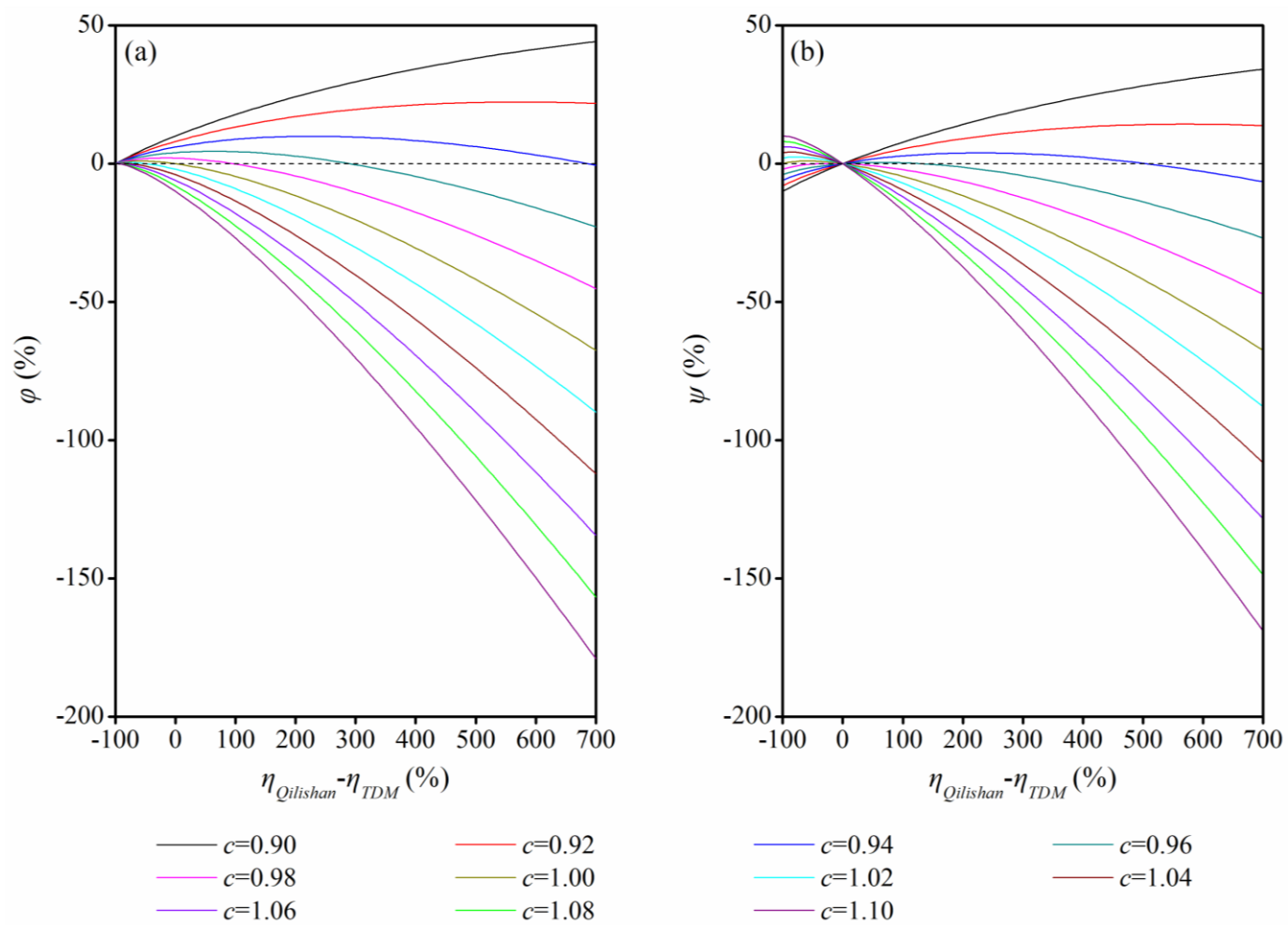
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Fig. 4



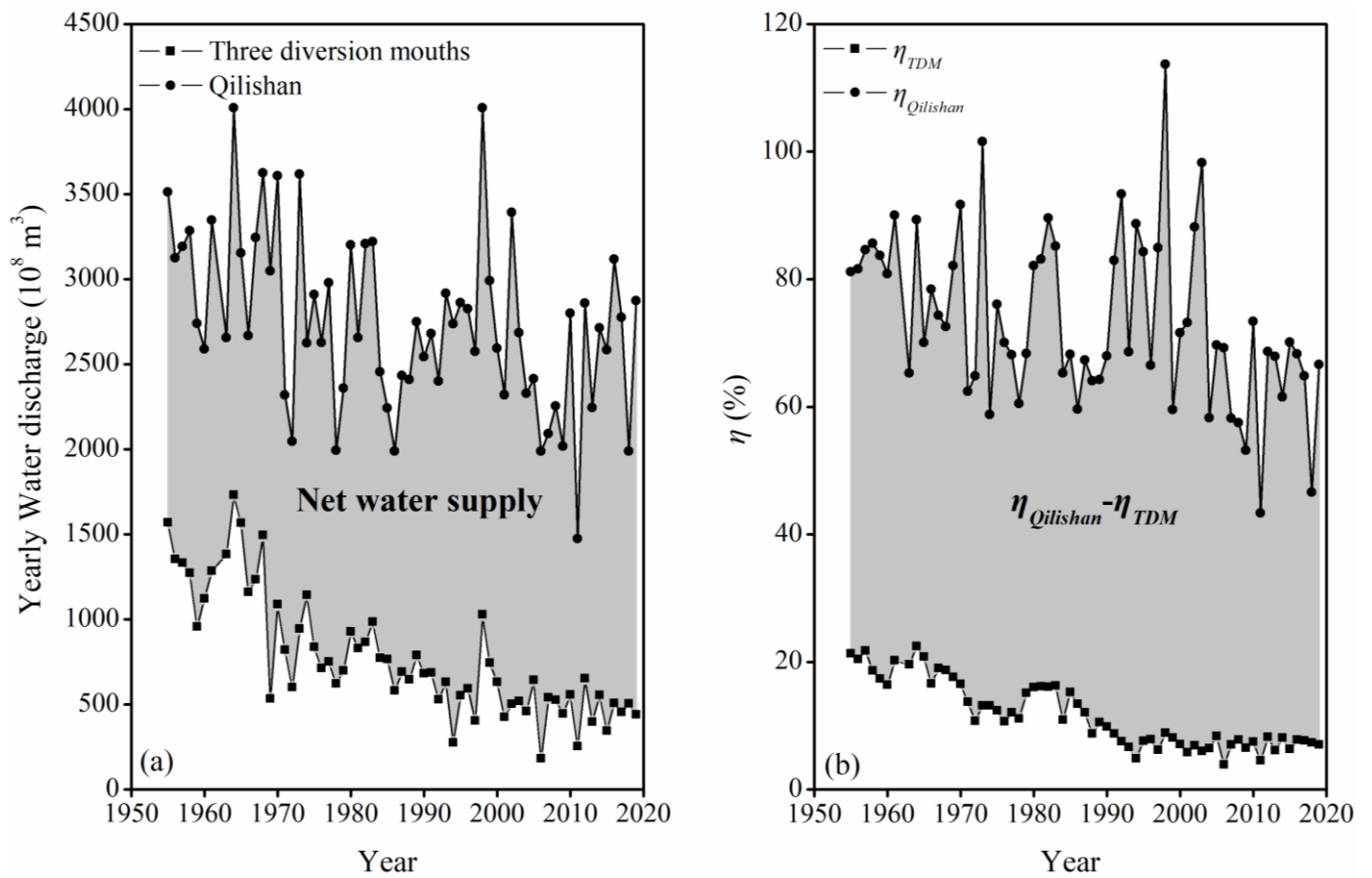
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667 **Fig. 7**



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Table 1

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Empirical formulae for φ , ψ , φ_m , ψ_m , and critical values of $\eta_{Qilishan}-\eta_{TDM}$ in terms of c and $\eta_{Qilishan}-\eta_{TDM}$.

Subject		Formula/Value
Erosion-deposition	φ	$\left[1 + (\eta_{Qilishan} - \eta_{TDO})\right]^{1.13} - c \left[1 + (\eta_{Qilishan} - \eta_{TDO})\right]^{1.16}$
	φ_m	$0.010c^{-37.67}$
	$(\eta_{Qilishan}-\eta_{TDM})_1$	-1 or $(c^{-33.33} - 1)$
	$(\eta_{Qilishan}-\eta_{TDM})_2$	$0.418c^{-33.33} - 1$
Erosion-deposition promotion	ψ	$\left\{ \left[1 + (\eta_{Qilishan} - \eta_{TDO})\right]^{1.13} - 1 \right\} + c \left\{ 1 - \left[1 + (\eta_{Qilishan} - \eta_{TDO})\right]^{1.16} \right\}$
	ψ_m	$0.010c^{-37.67} + c - 1$
	$(\eta_{Qilishan}-\eta_{TDM})_3$	0 or $\left[(0.06 + 3.257c^{54.61})^{-1} - 1 \right]$
	$(\eta_{Qilishan}-\eta_{TDM})_4$	$0.418c^{-33.33} - 1$

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Table 2

Multi-year average variables related to river-lake water exchange and erosion-deposition (and its promotion) in the Luoshan-Hankou reach.

Period	$\eta_{Qilishan-\eta_{TDM}}$ (%)	c	T^a (10^8 t/a)	$\Delta G_{Luoshan-Hankou}$ (10^8 t/a)	φ (%)	δ (10^8 t/a)	ψ (%)
1959-1966	60.00	0.98	0.37	0.43	14.73	-0.18	-6.00
1966-1981	58.59	1.02	0.06	-0.01	-0.28	-0.35	-9.68
1981-1986	60.48	0.98	0.44	0.47	11.69	-0.39	-9.72
1986-2003	69.45	1.00	-0.18	-0.26	-9.89	-0.34	-12.77
2003-2008	61.92	1.01	-0.10	-0.07	-6.93	-0.11	-11.09
2008-2019	56.15	1.02	-0.11	-0.13	-20.31	-0.05	-7.28
1959-2019	61.20	1.00	0.02	-0.02	-1.83	-0.23	-9.42
Linear regression equation: $\varphi = -0.10(\eta_{Qilishan} - \eta_{TDM}) + 0.04$; $n=7$, $R=0.03$, $P>0.05$					$\varphi = -5.88c + 5.87$; $n=7$, $R=0.81$, $P<0.05$		
$\psi = -0.42(\eta_{Qilishan} - \eta_{TDM}) + 0.16$; $n=7$, $R=0.77$, $P<0.05$					$\psi = -0.25c + 0.15$; $n=7$, $R=0.18$, $P>0.05$		

^a T represents net erosion-deposition rate of bankfull channel of the actual Luoshan-Hankou reach provided by the Changjiang Water Resources Commission.