Concerns about data linking delta land gain to human action

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River deltas are diverse, economically and ecologically important ecosystems that are increasingly vulnerable to environmental change. A recent study reported that global-scale human impact on delta morphology has led to net land area gain (Nienhuis et al.[1]). However, we argue that an unconventional definition of deltas, miscellaneous coastal features unduly characterized as deltas and misidentified delta area changes led to spurious statistics in the study by Nienhuis et al.[1] and that a recently published correction[2] does not address our concerns. We call for the rigorous verification and analysis of large environmental datasets.

Delta identification

Nienhuis et al.[1] defines marine river mouths with fluvial water and sediment discharge thresholds (respectively >1 m^3/s and > 0.01 kg/s) as deltas. This definition runs counter to standard delta[3-6] geoscience definitions, but nevertheless uses morphological terms that are specific to deltas[3,4] as distinct from estuaries, such as shoreline *protrusion* and *triangular shape*. Simplified assumptions on river-mouth sediment flux redistribution by river, waves and tides used by Nienhuis et al.[1] neglect the sediment-dispersal role of these agents that render most river mouths devoid of deltas[3,5,6]. These assumptions also neglect sedimentation pathways interlinking the connected upbuilding and outbuilding components of deltas (subaerial delta-plain, subaqueous delta-front, pro-delta) that differentiate them from simple estuaries.

Nienhuis et al.[1] uses automatically-generated 'buffer' areas to identify land change from global spatial data[7], arguing for the exclusion of areas distant from channel banks and shorelines. We find that this automatic identification of buffers, without verification of their accuracy, leads to thousands of features wrongly identified as "deltas" by Nienhuis et al.[1], including estuaries, builtup areas, rocky coasts (Fig. 1), beach-ridge plains, and multiple distributary mouths of individual deltas. Unfortunately, considering such a collection of *coastal morphologies* as a simple continuum culminating in 10,848 'river deltas' could undermine the gravity of contemporary concerns on delta vulnerability and the hundreds of millions of people deltas host[8-10]. A random check reveals that only ~50% of the inventoried features may be defined as deltas (Supplementary Methods, Extended Data Table 1). Nienhuis et al.[1] checked the veracity of delta existence based on 212 deltas in Madagascar, which is a biased sample. Instead, such a check should be based on a random selection of their large global dataset.

Claimed link between human-impacted river sediment flux and delta land change

Nienhuis et al.[1] conclude that global-scale human impact on river sediment flux has led to delta land gain, which they argue, is illustrated by their Fig. 3a using a ***ratio*** ($Q^{d}_{river}/Q^{p}_{river}$) of *disturbed* (by dams and land-use changes) and *pristine* (prior to *substantial* human influence) fluvial sediment fluxes, regressed against land change for each delta. Following correspondence with the authors of Nienhuis et al.[1], they affirm not using $Q^{d}_{river}/Q^{p}_{river}$ to support their conclusion but the text (p.516) expression Q^{d}_{river}-Q^{p}_{river} to impute 16% of delta land gain to human impact. However, Nienhuis et al.[1] does not provide evidence, graphic or otherwise, substantiating this conclusion based on Q^{d}_{river}-Q^{p}_{river}. We tested Q^{d}_{river}-Q^{p}_{river} against land change using their original datasets and methodology and obtained an R^2 of 0.16 (hence their 16%, p.516). However, this value is upheld by the Yellow River delta (Fig. 2), a single delta out of 10,848 'river mouths', and simply considered in their published correction[2] as an example for which their *methodology may produce errors.* Our check shows that this delta's land area change of -8.3 km^2/yr in Nienhuis et al.[1] is flawed (Fig. 2a,d). Our buffer yields +2.15 km^2/yr, similar to that published for the same period[11], which identifies this delta among the fastest growing on Earth. Whether Yellow River data are corrected for true land change or removed, the R^2 is 0 with Q^{d}_{river}-Q^{p}_{river}, 0 with $Q^{d}_{river}/Q^{p}_{river}$ and 0.09 (p-value: 0.2) for $Q^{d}_{river}/Q^{p}_{river}$ using binned data, which is not statistically significant (Fig. 2a, Extended data Fig. 1a). This illustrates the need for caution with particularly influential outliers like this one. Our concern is not only that individual delta change rates are inaccurate, but this inaccuracy permeates into the strong but unsupported conclusion regarding a global-scale link to human-induced sediment flux. This single misidentification led to the incorrect attribution of 16% of land change to human modifications. An $R^2 = 0$ excludes the possibility of a quantifiable link.

Errors are recurrent in the automatically-generated buffers of Nienhuis et al.[1], as shown by our analysis of: (1) a random sample of 108 (1%) river mouths and (2) the 100 largest deltas in their dataset (Extended Data Fig. 2b,c). The correlation is very low to nil (R^2 of 0 to 0.13) with our operator-verified buffers. The flawed land change values are not limited to the Yellow River delta. The automatically-generated buffers of Nienhuis et al.[1] are commonly misplaced (hence the plethora of features identified as deltas and deltas with misidentified land change) and/or yield changes neither coastal nor driven by processes claimed by these authors (Extended Data Fig. 2, Extended Data Table 1). The buffer they delimit for the Yangtze, a major world delta, is misplaced by 100 km, yielding land loss instead of strong land gain. Replacing their land change values with those identified from our buffers for the largest 100 deltas in the original (V1) dataset yields bins that are largest for decreased sediment flux ($Q^{d}_{river}/Q^{p}_{river} < 1$), revealing the impact of misidentified negative land change in large deltas as shown by the magenta bins in Extended Data Fig. 1aii. The land-cover dataset[12] employed by Nienhuis et al.[1] to mask anthropogenic delta transformations is inadequate, leading these authors to grossly overestimate, in populous Asian deltas, land loss (e.g., Mekong, Yangtze, Red River), or gain corresponding to human artefacts (Pearl, Krishna) (Extended Data Fig. 2d-k), such as land conversions into fishponds in the Yellow delta (Fig. 2b), which they recorded as natural *land loss*. They base area-change check on 40 deltas in Madagascar and conclude on a standard error of 1%. Madagascar deltas are a biased choice and not a random selection representative of a global-scale dataset. Massive deforestation of this island (44% loss 1953-2014[13]) generates high sediment discharge favourable to delta land gain.

There are further inconsistencies in the successive datasets of Nienhuis et al.[1]. Following our concerns, these authors generated a new dataset (version 2, V2, March 2021) on the largest 100 deltas (Max100), resorting, this time, to more cautious manual, rather than automatic, determination of change. This Max100 dataset shows a 5-fold increase in land area (from 12 to 60 km^2/yr), but still no statistically significant relationship with the ratio $Q^{d}_{river}/Q^{p}_{river}$ or the difference Q^{d}_{river}-Q^{p}_{river}, nor with the V1 data (Extended Data Fig. 1b,c). This shows that improved buffer definition does not suffice to validate the finding of net delta land *gain* attributed to humans.

Nienhuis et al.[1] uses automatic buffers that misrepresent deltas and their changes. Quantifying global delta land changes, especially in large populous deltas, requires clarity in identification and analysis. Deltas are complex features, and examining their global-scale links with human actions faces the challenges of acquiring accurate digital datasets and rigorous modelling. This word of caution is relevant to the analysis of coastal systems and landscape geomorphology faced with increasingly large global datasets, and, hopefully, of interest to a wide audience.

Author contributions

All authors developed and contributed to drafts of the text and figures. The concept for this manuscript rebuttal was designed by E.A., F.Z.; F.Z., F.T., M.B. contributed to data analysis and acquisition. All authors (F.Z., E.A., A.V., M.B., F.T.) contributed to the elaboration of the concepts presented here.

Competing interests

The authors declare no competing interest.

Data availability

We used the original data provided by the corresponding author of Nienhuis et al.[1] by email and data uploaded by the authors of Nienhuis et al.[1] on GitHub at https://github.com/jhnienhuis/GlobalDeltaChange.

Code availability

All the MATLAB codes used in data analysis and figure production are uploaded in a GitHub repository at https://github.com/FlorinZai/Global_Delta_Check. Interactive Google Earth Engine scripts are also provided at the links in the GitHub repository that can be used to compare our operator-derived buffers with the automatic buffers of Nienhuis et al.[1].

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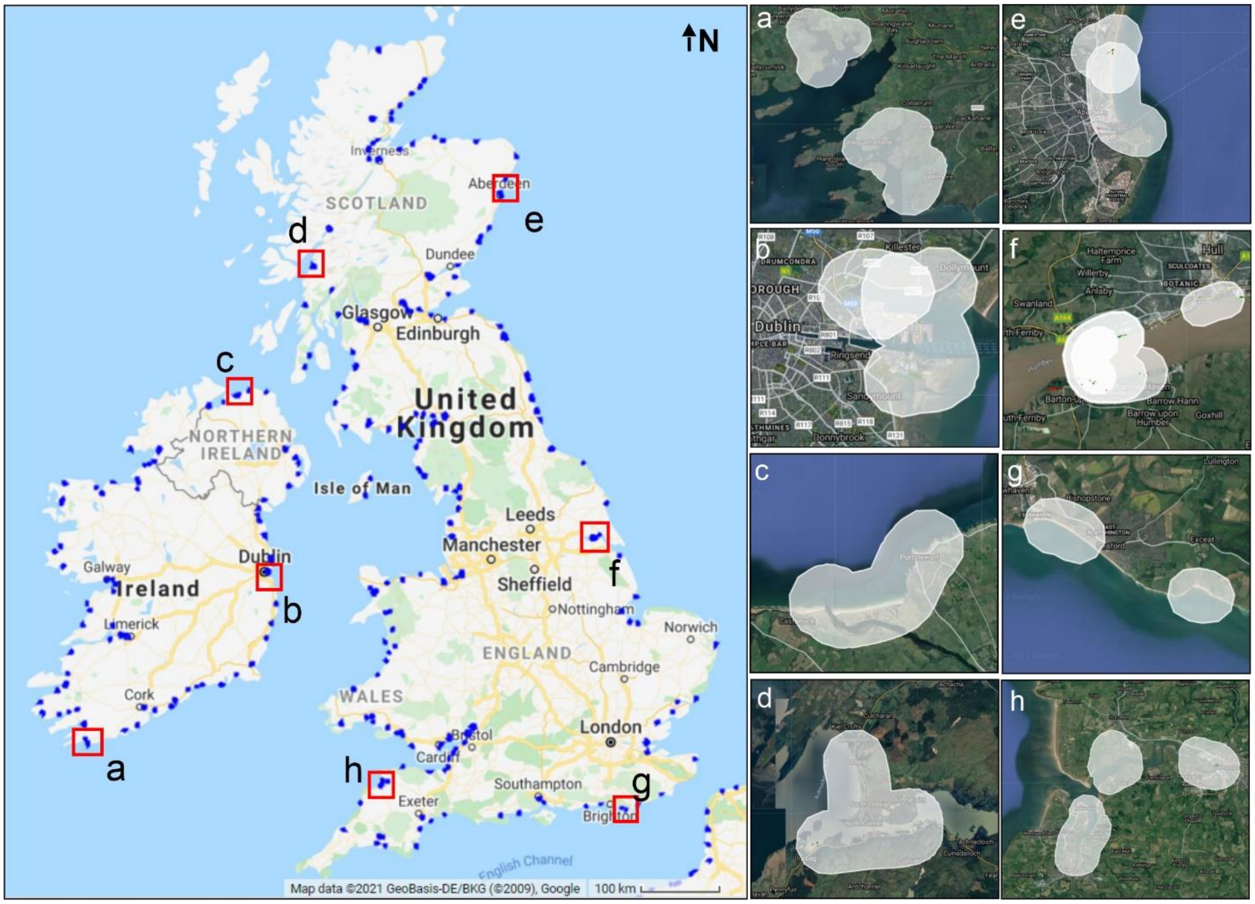


Map data ©2021 GeoBasis-DE/BKG (©2009), Google 100 km

Figure 1. Spurious categorization by Nienhuis et al.[1] of river mouths as deltas: 270 “deltas” in the British Isles (blue dots, left), none referenced as a delta in scientific bibliographic databases. Grey zone (a-h) shows area of each “delta” used to calculate “natural delta” land change by Nienhuis et al.[1], but wrongly overlain on rocky coasts, beaches, rias, barriers, and cities.

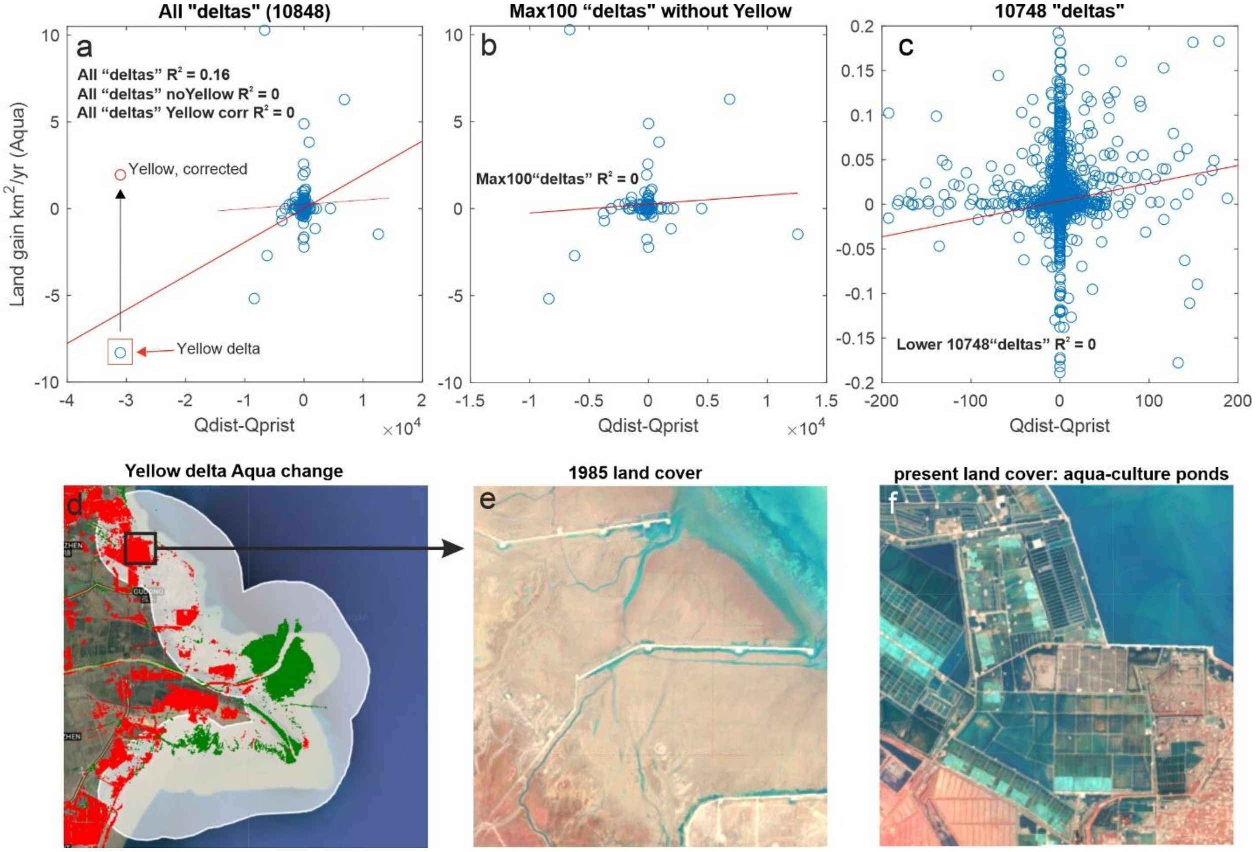
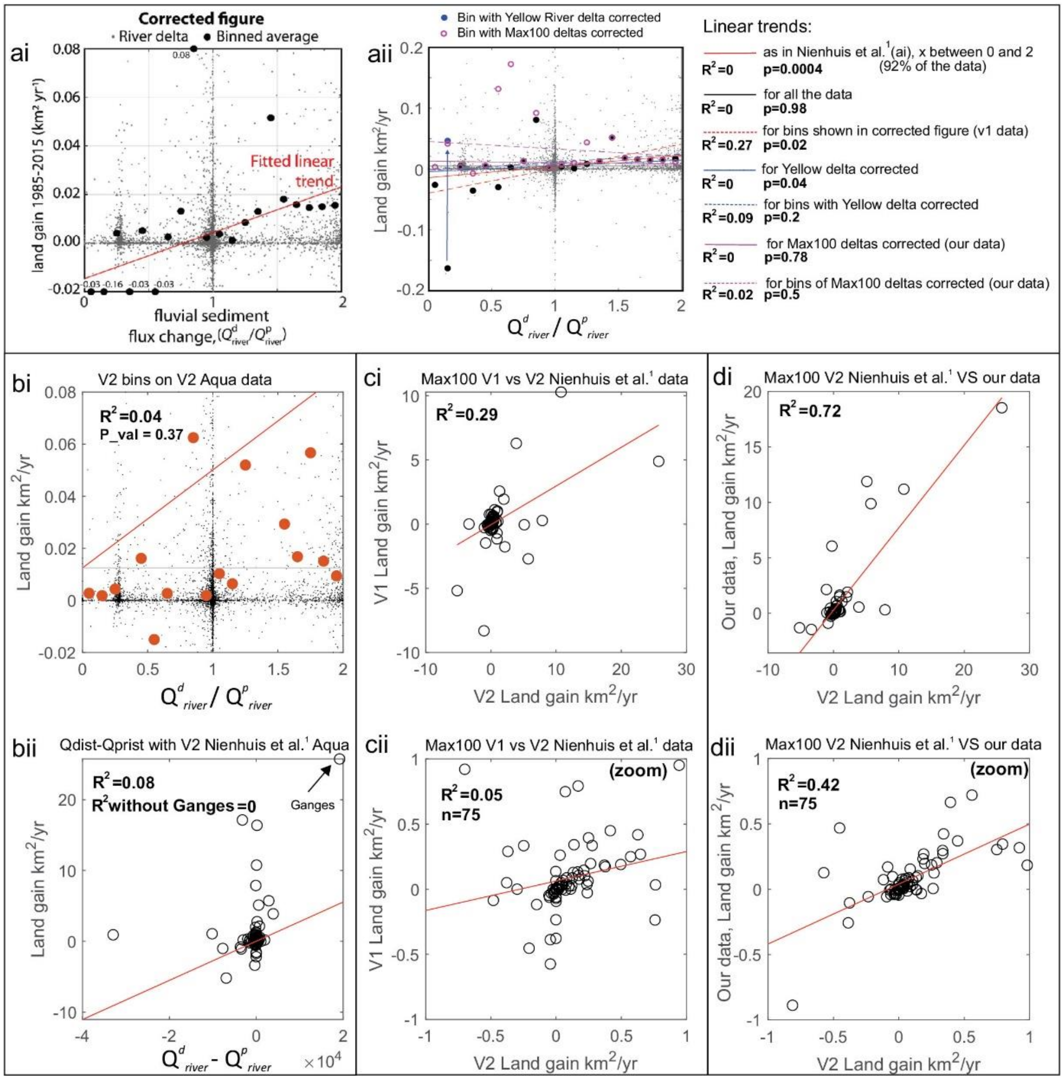
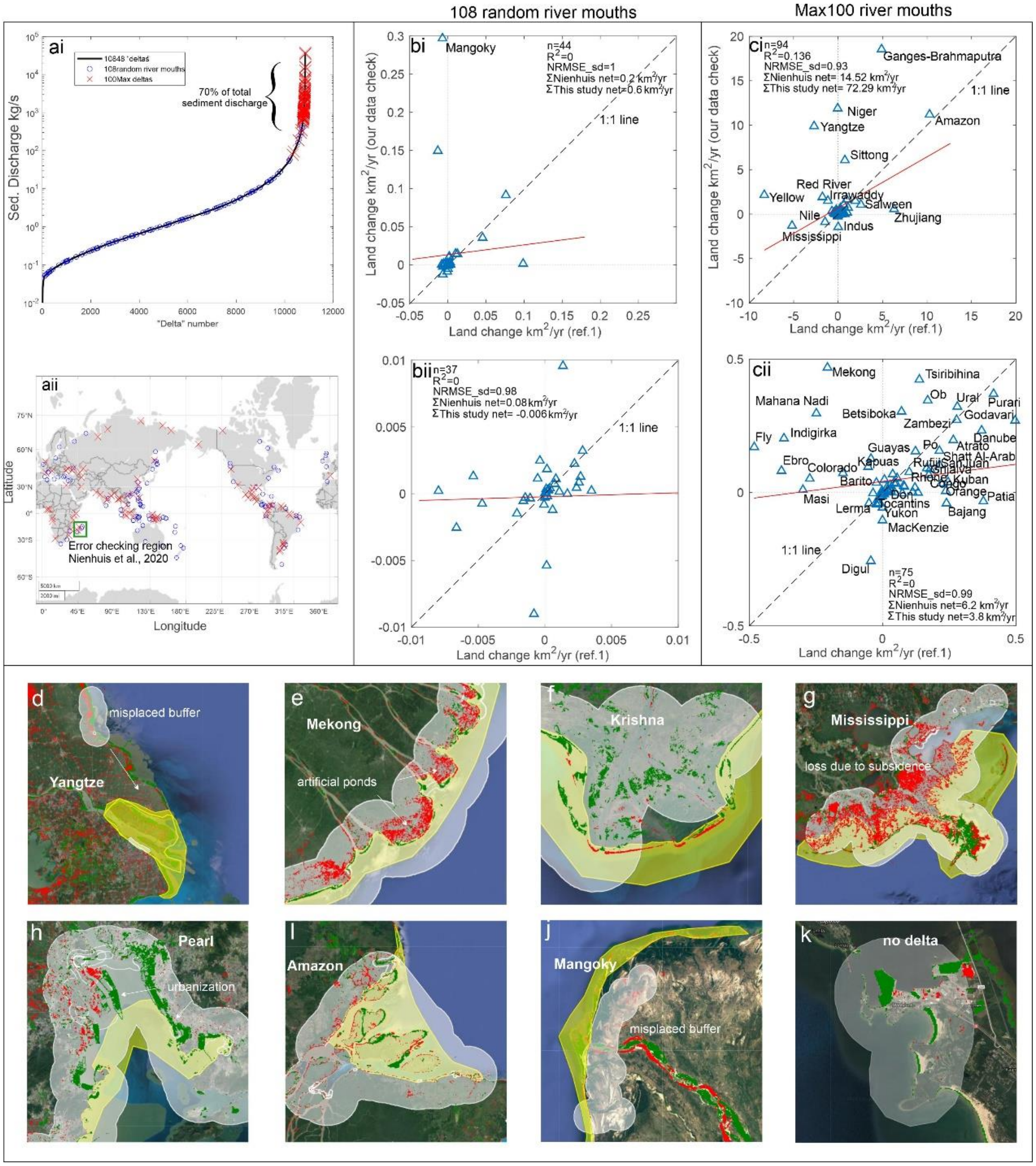


Figure 2. Delta land gain versus human-impacted fluvial sediment flux, Qdist – Qprist, shows a weak correlation, R^2 = 0.16, and zero correlation R^2 = 0 with the Yellow River delta removed or corrected (a), and R^2 = 0 for both large (b) and small deltas (c). Aquaculture ponds (in red within grey buffer) in Yellow River delta are misidentified by Nienhuis et al.[1] as natural loss (d). Buffers should capture only natural land change, not human-transformed lands. Green is land gain.



Extended Data Figure 1. Statistical relationships further invalidating claim of delta land area *gain* due to Humans. Corrected Fig.3a of Nienhuis et al.[1] (ai) is compared with the same sediment flux change ratio with different data corrections for the V1 dataset. R^2 of 0 with p = 0.0004 is obtained with x between 0 and 2 (92%) of the data. When the whole dataset is considered p becomes non-significant (p=0.98). A correction for the Yellow delta land changes results in R^2 of 0 or very close to 0, and a p-value that is not statistically significant for bins (aii, blue). Max100 land change (our data) replaced into V1 dataset shows $R^2 = 0$ and p that is not significant. Continuous lines show regressions for all the 'delta' points; dashed lines show regressions for the 20 bin averages; axes are extended to show the full variability of bins. Most of the large deltas fall beyond the chart's y axis. Comparison of the ratio $Q^d_{river} / Q^p_{river}$ with version 2 (V2) land changes (bi), and of the difference $Q^d_{river} - Q^p_{river}$ with V2 land changes of Nienhuis et al.[1] (bii); comparison of version 1 (V1, original) and V2 datasets of Nienhuis et al.[1] for Max100 deltas shows low agreement for all deltas (ci), and no agreement for 75 deltas within ± 1 km² land change (cii); comparison of V2 dataset of Nienhuis et al.[1] with Max100 land change obtained through our data check and our buffers shows good agreement for all deltas (di), and fair agreement for 75 deltas within ± 1 km² land change (dii).



Extended Data Figure 2. Distribution of our 108 random samples and the 100 largest deltas (Max100) on the sediment discharge continuum of Nienhuis et al.[1] (ai), and their global distribution (aii). Note biased error check of Nienhuis et al.[1] limited to Madagascar Island (aii) (see further comment on the Madagascar choice in the Supplementary Discussion); comparisons of land changes of Nienhuis et al.[1] with our 108 random samples (44 polygons, bi, bii- zoom on data), and with the Max100 deltas (ci, cii- zoom on data). Plots bii, cii show subsets of their respective datasets, all with $R^2 = 0$. Examples of wrongly identified land changes by Nienhuis et al.[1] obtained on a selection of large deltas as a result of misplaced buffers (d, j), human-induced land transformations wrongly reported as natural land changes (e, f, h), and misidentified deltas (k). Original buffers (light grey) of Nienhuis et al.[1] are compared with our re-drawn data-check buffers (yellow) based on which only natural, and not human-transformed, delta coastal change should be calculated.

EE Delta	BasinID	Polygon	Delta	River mouth type	Anthrop.	Anthrop. filtering	Interior change	Small buffer	Buffer overlap	Obs.
0	69	0	1	delta	0	NaN	0	0	0	
1	87861	1	1	delta	0	NaN	1	1	0	River and estuarine dynamics
2	87825	0	0	nondelta	NaN	NaN	NaN	NaN	0	tidal inlet
3	227807	1	1	delta	1	0	0	0	0	Dikes
4	299177	1	1	delta	0	NaN	1	0	0	
5	201340	0	1	anthropogenic river mouth	1	0	0	0	0	Port development, dikes
6	135103	1	1	delta	0	NaN	1	0	0	
7	103071	0	0	river mouth	NaN	NaN	NaN	NaN	0	Dike
8	74573	0	0	interdune channel mouth	NaN	NaN	NaN	NaN	1	No mouth
9	250920	0	0	estuary(ria)	NaN	NaN	NaN	NaN	0	Rocky estuary, river mouth is far
10	135935	0	0	tidal inlets	NaN	NaN	NaN	NaN	0	
11	170497	0	1	delta	0	NaN	1	0	0	
12	157003	0	0	river mouth	NaN	NaN	NaN	NaN	0	No change
13	314898	1	1	delta	0	NaN	0	1	1	Small buffer
14	162388	1	1	delta, anthropogenic river mouth	1	0	0	0	0	Urban development
15	203988	0	0	anthropogenic river mouth	NaN	NaN	NaN	NaN	0	City of Nice
16	2769	1	1	delta	0	NaN	1	0	0	
17	574716	1	1	delta	0	NaN	0	0	0	
18	383601	1	1	delta, anthropogenic river mouth	1	0	0	0	0	Urban development, dikes
19	7818	1	1	delta	0	NaN	1	0	0	
20	276923	0	0	estuary	NaN	NaN	NaN	NaN	0	Dikes, ports, ships, shrimp farms
21	225	0	0	no river mouth	NaN	NaN	NaN	NaN	0	No river mouth
22	151202	0	1	delta	0	NaN	0	0	0	Change from vegetation
23	141533	0	0	river mouth	NaN	NaN	NaN	NaN	0	
24	3018	1	1	delta	0	NaN	1	0	0	
25	673450	0	0	estuary	NaN	NaN	NaN	NaN	0	
26	147976	0	0	estuary	NaN	NaN	NaN	NaN	0	
27	632150	1	1	delta	1	0	0	0	1	Aquaculture, Shrimp farms
28	237383	0	0	estuary(tributary)	NaN	NaN	NaN	NaN	1	No coast
29	119979	0	0	estuary(tributary)	NaN	NaN	NaN	NaN	0	No coast
30	145404	0	0	estuary	NaN	NaN	NaN	NaN	1	
31	27687	0	1	delta	0	NaN	0	0	0	
32	472086	1	1	delta	1	0	1	0	0	
33	382322	1	1	delta	1	0	0	0	0	Urban evelopment
34	124733	0	0	estuary	NaN	NaN	NaN	NaN	0	
35	324962	0	1	delta, anthropogenic river mouth	1	0	0	0	0	Dike, change from vegetation
36	91673	0	0	river mouth	NaN	NaN	NaN	NaN	0	Salt ponds, shrimp farms
37	394758	0	0	estuary	NaN	NaN	NaN	NaN	1	estuary
38	51818	0	1	delta	0	NaN	0	0	0	No change
39	689340	0	0	no river mouth	NaN	NaN	NaN	NaN	0	No river mouth
40	295697	1	1	delta	0	NaN	1	0	1	
41	53848	0	0	river mouth	NaN	NaN	NaN	NaN	0	
42	422862	1	1	delta	0	NaN	0	0	1	Vegetation change
43	667218	1	1	delta	0	NaN	0	0	0	
44	738891	0	0	river mouth	NaN	NaN	NaN	NaN	0	No delta, Slope too steep, rocky
45	93	0	0	no river mouth	NaN	NaN	NaN	NaN	0	No river mouth
46	20123	1	1	delta	0	NaN	0	1	0	
47	286863	0	0	river mouth	NaN	NaN	NaN	NaN	0	No delta, Slope too steep, rocky
48	264925	1	1	delta	1	0	0	0	1	Shrimp ponds, dikes
49	249328	1	1	delta	0	NaN	1	1	0	
50	146686	0	0	anthropogenic river mouth	NaN	NaN	NaN	NaN	1	
51	193701	0	0	no river mouth	NaN	NaN	NaN	NaN	0	100% anthropogenic
52	132009	1	1	delta	0	NaN	0	0	0	Few pixels on bar estuary
53	158128	1	1	delta	0	NaN	1	0	0	
54	211649	1	1	delta	0	NaN	0	0	0	
55	199306	0	0	anthropogenic river mouth	NaN	NaN	NaN	NaN	1	Development
56	316765	0	0	no river mouth	NaN	NaN	NaN	NaN	0	
57	262538	1	1	delta	1	0	0	1	0	Anthropogenic ponds
58	718850	1	1	delta	1	0	0	0	0	
59	94741	0	0	no river mouth	NaN	NaN	NaN	NaN	0	
60	412843	1	1	delta	0	NaN	0	1	0	Didn't get spit tip accumulation
61	638519	0	0	river mouth	NaN	NaN	NaN	NaN	1	
62	216515	0	0	river mouth	NaN	NaN	NaN	NaN	0	Fjord?
63	147544	1	1	delta	0	NaN	0	1	0	Small buffer
64	420134	0	0	river mouth	NaN	NaN	NaN	NaN	0	Doesn't look like a delta
65	674974	1	1	delta	1	0	1	0	1	River dynamics, coastal works
66	139009	0	1	delta	0	NaN	0	0	1	
67	213083	0	0	delta	NaN	NaN	NaN	NaN	1	Urban development, same delta as #97
68	126813	0	0	no river mouth	NaN	NaN	NaN	NaN	0	No river mouth
69	26952	1	1	delta	0	NaN	1	0	0	
70	145789	1	1	delta	0	NaN	0	0	0	
71	160787	0	0	river mouth	NaN	NaN	NaN	NaN	0	Srtm high coastal elevation
72	25943	0	0	river mouth	NaN	NaN	NaN	NaN	0	
73	145	0	0	no river mouth	NaN	NaN	NaN	NaN	0	No river mouth
74	32721	0	1	delta	0	NaN	0	0	0	Lagoonal delta
75	136526	0	0	river mouth	NaN	NaN	NaN	NaN	1	Barrier diverted river mouth
76	40547	0	0	river mouth	NaN	NaN	NaN	NaN	0	Srtm high coastal elevation
77	71749	1	1	delta	0	NaN	1	1	0	Small &Misplaced buffer
78	296274	1	1	delta	0	NaN	1	0	0	
79	48430	1	1	delta	0	NaN	1	0	1	change is River dynamics
80	42223	1	1	delta	0	NaN	0	0	0	Barrier diverted river mouth
81	259998	0	0	river mouth	NaN	NaN	NaN	NaN	0	No delta, Srtm high coastal elevation
82	63338	0	0	tidal inlet	NaN	NaN	NaN	NaN	0	tidal
83	262402	1	1	delta	0	NaN	0	0	1	
84	275141	1	1	delta	0	NaN	0	0	0	
85	34059	0	0	river mouth	NaN	NaN	NaN	NaN	1	River dynamics,Inside bigger delta
86	30270	0	1	delta	0	NaN	0	0	0	
87	395256	0	0	nondelta	NaN	NaN	NaN	NaN	0	seasonal river mouth
88	654755	1	1	delta	0	NaN	0	0	0	
89	634660	0	1	delta	0	NaN	0	0	1	Buffer overlap
90	165985	1	1	delta	0	NaN	1	0	0	Barrier diverted river mouth
91	323297	1	1	delta	0	NaN	0	0	0	jetties at mouth
92	373957	0	0	nondelta	NaN	NaN	NaN	NaN	0	tidal inlet
93	36503	0	0	river mouth	NaN	NaN	NaN	NaN	0	Estuary
94	149	1	1	delta	0	NaN	1	1	0	Small, misplaced buffer
95	331379	1	1	delta	0	NaN	1	0	1	River dynamics
96	39958	0	1	delta	0	NaN	0	0	0	River dynamics, vegetation change
97	213107	1	1	delta	1	0	0	0	1	Urban development
98	598116	0	0	nondelta	NaN	NaN	NaN	NaN	0	No river mouth, tidal creek
99	630689	0	1	delta, anthropogenic river mouth	1	0	0	0	1	Urban development
100	620926	1	1	delta	0	NaN	1	0	0	River dynamics
101	416223	0	0	no river mouth	NaN	NaN	NaN	NaN	0	No river mouth, delta restoration
102	75078	0	0	canals	NaN	NaN	NaN	NaN	1	Aquaculture, shrimp
103	730746	0	0	river mouth	NaN	NaN	NaN	NaN	1	Barrier diverted river mouth
104	583610	0	0	tidal creek	NaN	NaN	NaN	NaN	0	Not delta, not linked to any real river
105	128186	0	0	nondelta	NaN	NaN	NaN	NaN	1	No river mouth,Dikes
106	77603	1	1	delta	1	0	1	0	1	Aquaculture, Inside bigger delta
107	659760	0	0	river mouth	NaN	NaN	NaN	NaN	0	Barrier diverted river mouth
Percentage(%)		**41**	**53**		**14**	**0**	**19**	**8**	**25**	

Extended Data Table 1: Analysis of 108 randomly selected ‘river mouths’ from data of Nienhuis et al.[1] showing numerous discrepancies. Delta number is EE Delta. Presence is marked 1, absence marked 0; no data due to the absence of a delta is NaN.

Supplementary Methods

Nienhuis et al.[1] applies thresholds of water and sediment discharge (respectively >1 m^3/s and > 0.01 kg/s) to identify river deltas globally, and employs some filtering to exclude small basins (1 km^2 for HydroSheds, and either 50 km^2 or 1000 km^2, based on a drainage divide altitude, for ETOPO1 grid above 60° lat) and deltas draining into fjords. Nienhuis et al.[1] determined land change for each delta from delta extent along the NOAA vectorized shoreline dataset. Nienhuis et al.[1] used Google Earth Engine[14] to retrieve surface-water changes within their selected buffer areas, but noted the potential for sizeable anthropogenic effects and therefore attempts to mask out portions of each delta that are classified as urban/artificial (class 190) by the GlobCover[12] dataset. By selecting only land area change near the NOAA shorelines, Nienhuis et al.[1] claims that land–water conversion within delta interiors is excluded. The delta morphologies identified by Nienhuis et al.[1] are based on quantified river, wave and tidal fluxes, and additional non-quantified criteria reflecting wave and tidal influence deduced from visual observation of features (see their section: "Accuracy of delta morphology prediction") such as shoreline protrusion and deflection and a triangular shape. These are common plan-view criteria for recognizing deltas as a distinct category of river mouth.

We critically examined the dataset and methodology of Nienhuis et al.[1]:
(i) Firstly, we randomly selected 108 'river mouths', representing 1% of their original dataset ~~of~~ (Extended Data Fig. 2b) to identify delta presence and retrieve land changes. We based this on the afore-mentioned "delta morphology prediction" criteria (including bayhead deltas), and avoiding exclusion where doubt prevailed, but discarding river mouths that had surrounding high elevation based on SRTM data (NASA SRTM Digital Elevation 30 m layer in Earth Engine). From the 108 random river mouth dataset we identify only 57 deltas, the rest being simple estuaries, non-river mouths, etc, but wrongly identified by Nienhuis et al.[1] as deltas (Extended Data Table 1). We carefully constructed polygons (n=44) only where deltas were present, and based on the criteria of Nienhuis et al.[1], on the deltaic coastal fringes to obtain area changes that are representative of the coastal dynamics of each delta, excluding any interior change. Our operator-based method relies, in line with the essence of this approach, on expert opinion and potentially arbitrary decisions, but no more than their automatic buffer method which also relies on arbitrary delta presence and buffer size definitions. A fundamental difference between the two methods is that an expert operator has the overarching and uncontestable advantage of being able to discern whether identified delta land changes are pertinent or not to the processes and forms under scrutiny. We did not draw polygons where deltas had no change or showed overwhelming anthropogenic influence. The remaining deltas are thus not relevant for change analysis and not even one pixel of land change was detected.

(ii) Secondly, we checked the 100 river mouths with maximum discharge (Max100) from the V2 database (see below) of Nienhuis et al.[1] uploaded on Github (https://github.com/jhnienhuis/GlobalDeltaChange/tree/master/land_area_change). Following correspondence with these authors, they uploaded this new V2 dataset, which retrieves land changes for the 100 river mouths with the largest discharge (Max100), based on manually drawn polygons. These 100 river mouths represent 70% of global sediment discharge (Extended Data Fig. 2c). Out of these, we identified 94 true deltas (94%). Large rivers such as the St. Lawrence, Victoria, Nelson, form estuaries, often bounded by rocky coasts, and the Volga, a true delta, experienced land change caused by water-level variability of the Caspian Sea, and thus cannot be included in this type of study. Area change was obtained based on the same methodology as mentioned above for the 108 random river mouths, first by drawing manually polygons that excluded delta-plain changes representing human occupation, and then retrieving Aqua changes with scripts.

Both these datasets (108 random river mouths and Max100 deltas) cover all the spectrum of sediment discharge and are distributed globally (Extended Fig. 2a). Linear regression was applied to both the averaged bins and all the data. We used root-mean-square error (RMSE) and normalized-root-mean-square-error (NRMSE) to quantify errors of the regression model compared to observed values. NRMSE_sd was obtained by dividing the RMSE by the standard deviation of the data.

Earth Engine scripts are provided with which users can verify each of the 108 random river mouths (https://code.earthengine.google.com/1c074d96779371d7bf20922916ca22f9) and check our Max100 delta land change values and buffers. (https://code.earthengine.google.com/24d503c385872724f0fc8fe785f2cf42).

Supplementary Discussion

(i) 108 random samples

Regarding the 108 random samples, too many deltas had land change caused by anthropogenic modifications (27%, Extended Data Table 1), indicating unsuccessful filtering by Nienhuis et al.[1], or buffers were misplaced or captured interior delta plain change, and thus leading to an R^2 of 0 with their data (Extended Data Fig. 2c,d). In correspondence with the authors, they expressed concerns with our analysis because it is based, they claimed, on a small (<1%), biased subset of their data that does not satisfy basic measures of statistical significance and is limited mostly to small deltas with a combined sediment flux less than 0.5% of the global total. We reiterate that our 1% subset (of which only 0.5% are true deltas) is randomly generated from their global dataset (Extended Data Fig. 2a,b). We also reiterate that Nienhuis et al.[1] did not use random selections from their own dataset to verify affirmations on their global trends.

(ii) Largest 100 deltas

We report our findings relative to the original V1 dataset provided by the corresponding author of Nienhuis et al.[1] by email. Our checks show that there is no agreement between the V1 and V2 datasets (Extended Data Fig. 1ci,cii) of Nienhuis et al.[1]. In fact, there is more agreement between our manually drawn buffers and the V2 dataset of Max100 deltas (Extended Data Fig. 1di,dii). This actually signifies that the V1 dataset used in the publication of Nienhuis et al.[1] is invalid and confirms our contention that automatic generation of buffers for delta land area change detection is unreliable, as shown by a number of examples from large deltas (Extended Data Fig. 2d-k). It is interesting to note that delta lands with limited anthropogenic presence, such as the Amazon, show good agreement (Extended Data Fig. 2i). Hence the approach of Nienhuis et al.[1] of using 40 deltas from one single geographic location, Madagascar (Extended Data Fig. 2aii), to check the veracity of delta land areas changes is inappropriate, because anthropogenic modification of deltaic land in this site is virtually nil. Such a check should be based on a random selection of their large global dataset, and not on a statistically untenable criterion of 'coastal continuity' used by Nienhuis et al.[1] to justify the choice of Madagascar. Furthermore, bin averaging (Extended Data Fig. 1a) is inappropriate on a dataset extremely skewed towards large deltas; the first 20 river mouths carry as much sediment as the remaining 10,828. The dataset is noisy, but also has a few extremely large outliers. Any errors in large deltas propagate towards the entire dataset and the bin averages. The authors resort to cutting off the data where $Q^{d}_{river}/Q^{p}_{river} > 2$ which showed a $R^2 = 0$ and $p = 0.0004$. Nevertheless, $p = 0.98$, and is therefore not significant when all data are included (Extended Data Fig. 1aii). Clipping off some of the data is not an appropriate approach because normally, a greater increase in sediment flux would result in an even larger land gain signal and a stronger regression.

Finally, we draw attention to another inconsistency in Nienhuis et al.[1] regarding calculation of delta area. Nienhuis et al.[1] approximated delta area by setting a minimum radius of 2 km for small deltas (1 km shown in the provided codes), adding buffers along the delta shorelines based on delta radius, with an additional 1 km added (shown only in codes, not in paper). To this end, they use in their text the equation of[15]: $((1.07\times Q_{river}^{1.1}\times Q_{w,river}^{0,45}/\mathrm{Dsh}(\sim 100)/\mathrm{pi})^{1/2}$, but then provide a different equation in their Matlab dataset: $((1.07\times Q_{river}^{0.7}\times Q_{w,river}^{0.45}/\mathrm{pi})/\mathrm{Dsh}(111)\times(\cos(\mathrm{MouthLat})))^{1/2}$. Nienhuis et al.[1] provided no justification for changing the first exponent of Qriver from 1.1 to 0.7, for adding a MouthLat cosine bias, and for moving /Dsh after the division with pi outside of the area formula.

References:

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