Supplementary Material

The contribution of diminishing river sand loads to beach erosion worldwide

Vincent Regard[1,†,*], Rafael Almar[2,†,*], Marcan Graffin[1,2], Sébastien Carretier[1], Edward Anthony[3], Roshanka Ranasinghe[4,5,,6], Pierre Maffre[3,7]

S1 River solid discharge models

River sediment discharge has been computed on a global scale using the BQART formula with a unique retention coefficient (*Te* = 0.2, Syvitski and Miliman, 2007). For the calculation, we used data from the HydroBasins database. The basins are associated with the nearest coastal cell along the coastline. Thus, each point on the coast receives the sum of the watersheds whose outlet is close (some may not receive any sediment discharge). To verify the soundness of this calculation, we compared it to Milliman and Farnsworth's (2011) database (Figure S1). There are some problems in linking the two databases (HydroBasins and Milliman and Farnsworth), mostly due to the fact that the gauging stations in Milliman and Farnsworth's database are far upstream from the mouthSometimes even one basin in HydroBasins corresponds to two basins in Milliman and Farnsworth (2011). That said, Figure S1 shows that the BQART calculation gives information of the right order of magnitude for the vast majority of rivers. The basins that depart significantly from the 1:1 line in Figure S1 are probably those that are greatly influenced by anthropogenic effects.

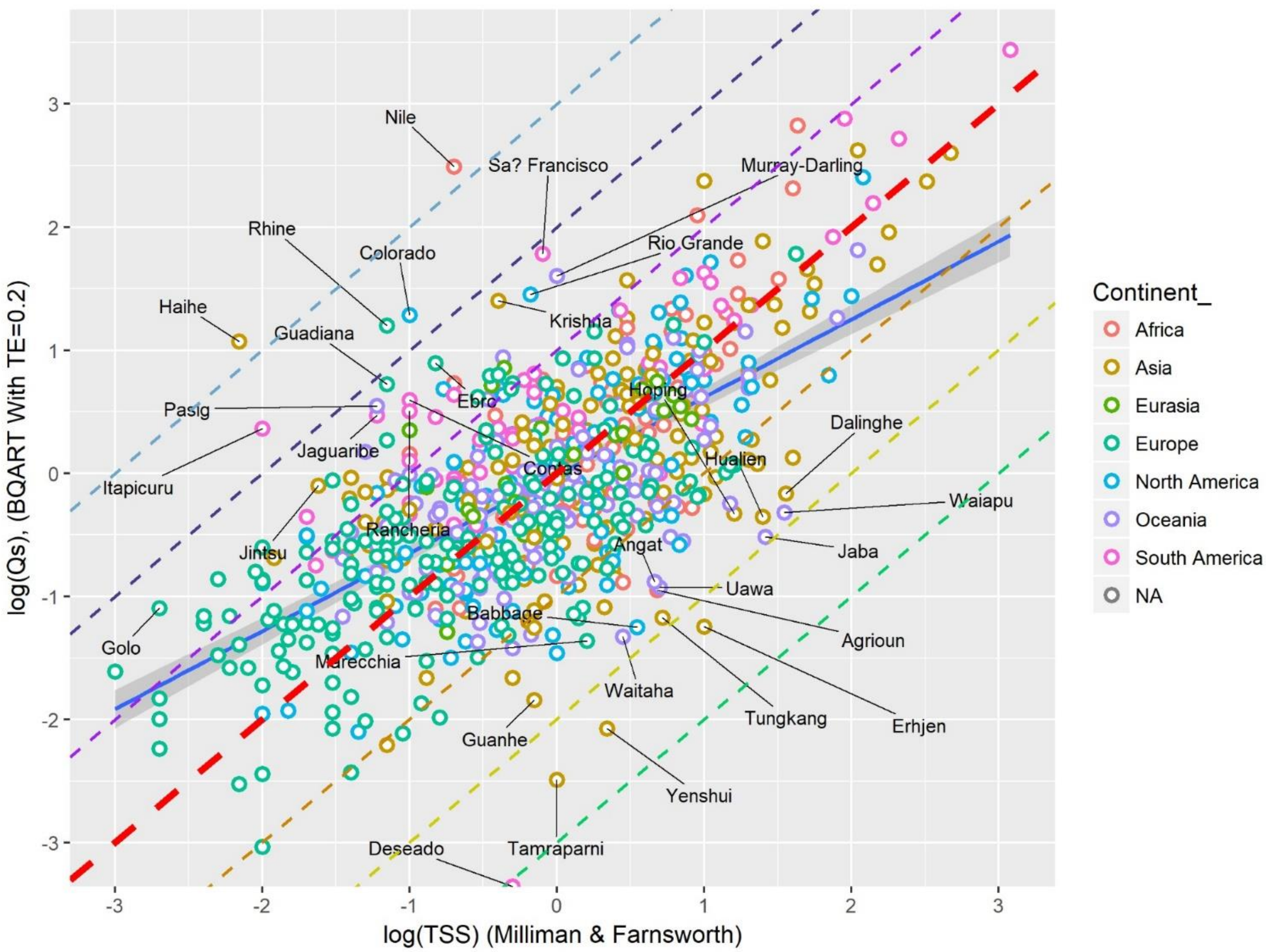

***Figure S1**. Observed vs. modeled solid river discharge. Scatter of observed vs. modeled solid river discharge (logarithmic scale). Observations (X-axis) are from Millman & Farnsworth (2011), modeled rates (Y-axis) are computed using BQART. Red dashed line is the 1:1 line and the blue solid line is the linear regression over the displayed dataset. The labeled basins are those that depart significantly from the 1:1 line.*

S2 Comparison of two river input models

In order to better evaluate the impact of dams on the sediment flux in different catchments, we used a model where the sediment flux can be calculated on every pixel and either summed or partially removed by dams in order to calculate the sediment outflux to the ocean Qriver. This model was proposed by Maffre et al. (2018) on the basis of a 3.75 longitude by 1.9 latitude resolution.

Figure S2 is a scatter plot to compare the two methods without the effect of dams. Obviously, the BQART outputs correlate well with Maffre’s model as they were both calibrated against observed river discharges.

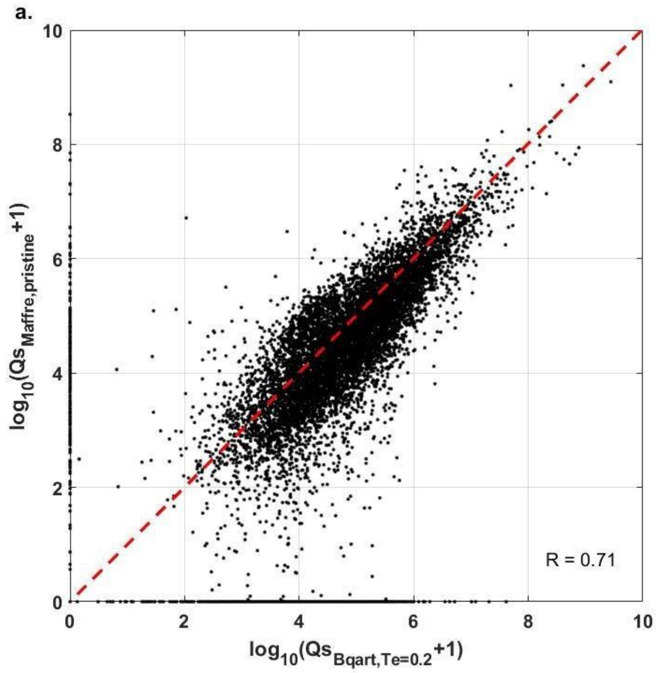

Figure S2. *Comparison of the solid river discharges computed using BQART method with the solid river discharges computed using Maffre et al. method, considering a world with no dams and Te =0.2*

S3 Longshore sediment transport formula

In order to evaluate the sensitivity to the choice of the longshore sediment transport (LST), we initially considered four classical formulas: Kamphuis (1991), Kaczmarek et al. (2001), CERC (1984) and Bayram et al., (2007). Common input to the formulas are the nearshore bathymetry (surf zone slope) and a time series of wave height, period, and direction. The average (for each cell) obtained with the four methods is mapped on Figure S3.a. The standard deviation between the four methods, scaled by the local LST average is mapped on Figure S3.b. The scaled standard deviation is systematically below 1 at high latitudes, meaning that the four LST evaluations agree within one order of magnitude. This relative scaled standard deviation increases in closed environments (Figure S3.b) where low mean LST rates are experienced (Figure S3.a). These bulk LST formula have a known tendency to overestimate, particularly in low energy wave environments (Tran et al., 2021) and therefore have to be used cautiously.

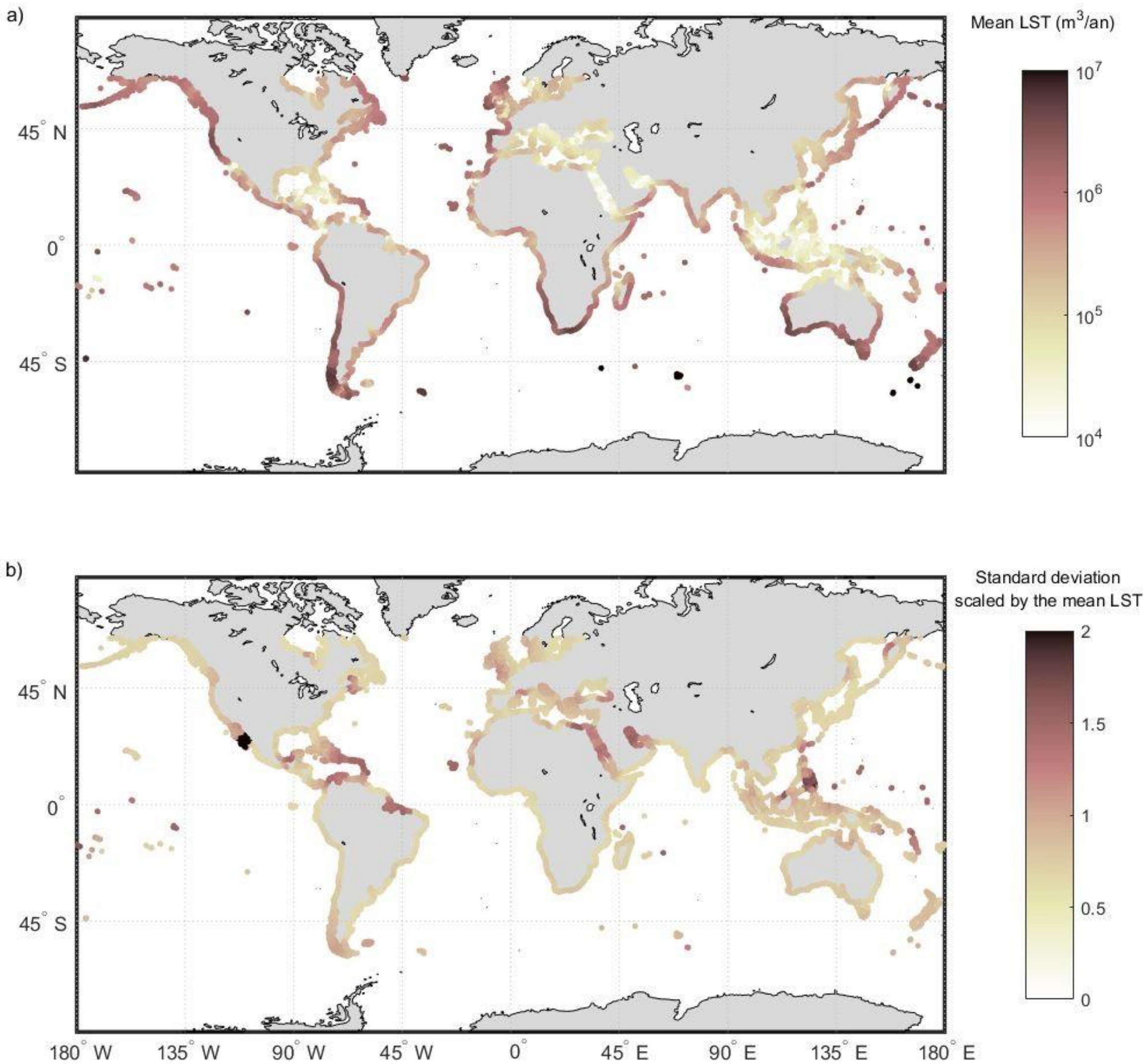

Figure S3*. LST computed fluxes and deviation depending on the model used. (a) average LST computed with four different formulas (Kamphuis, Kaczmarek, CERC and Bayram). (b) standard deviation of the results of the different models, scaled by the average LST at each point (average value mapped in panel a).*

In an exercise to quantitatively validate our necessarily coarse global sediment model and the use of Kamphuis formula, we compared our computed longshore sediment transport (LST) at worldwide monitored sites (Figure S4). Overall, Figure S4 shows that our modeled longshore sediment transport rates are of the same order of magnitude compared to observations. However, we note LST rates computed with Kamphuis formula sometimes fall out of the range of observations (e.g. the 2 blue dots far below the 1:2 line), especially for observed LST rates below 10^5 m^3/yr.

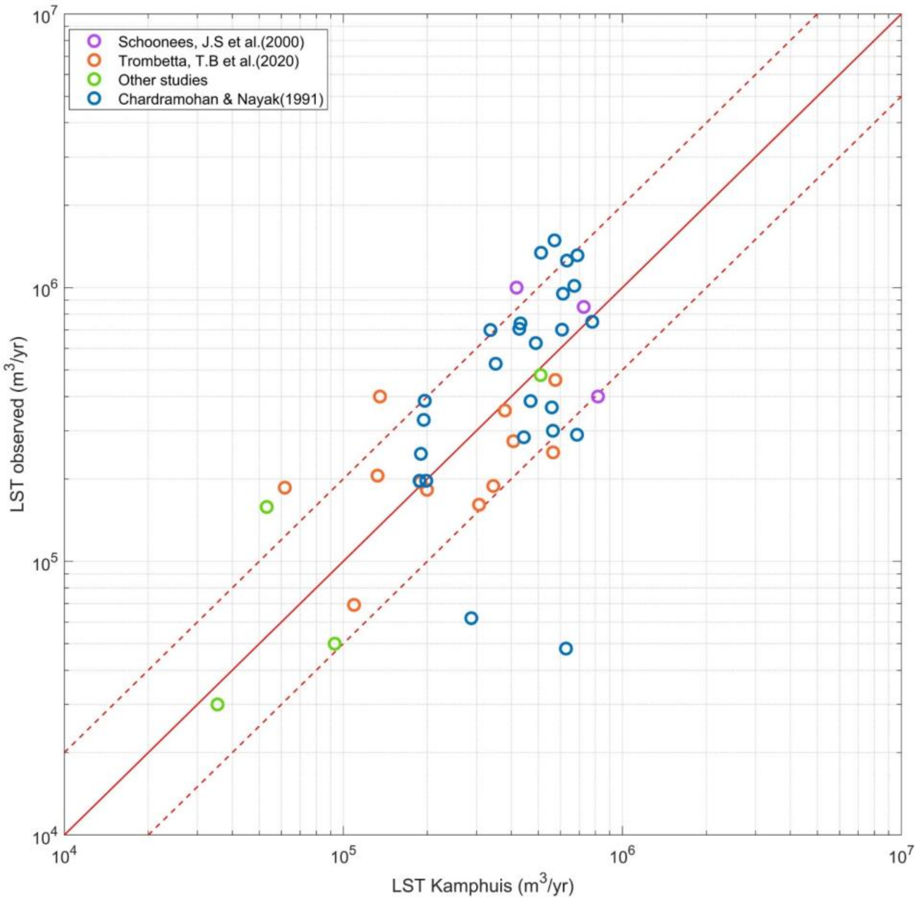

***Figure S4**. Observed vs. modeled longshore sediment transport. Scatter of observed vs. modeled longshore sediment transport on logarithmic scales. Observations are from : Schoonees et al., 2000; Trombetta et al., 2020; Chardramohan & Nayak, 1992; Aagaard et al., 2004; Roger and Ravens, 2008; Appendini et al., 2012; Cipriani and Stone, 2001. Modeled rate are computed using Kamphuis (1991) formula. Red solid line is the 1:1 line and dashed red lines are 2:1 and 1:2 lines.*

S4 Sensitivity of model to sediment grain size and coastal slope

Figure S5 shows the sensitivity of the model to variations in the input parameters d_{50} (median grain size) and tan(β) (beach slope). Model output are generally stable even for large changes in d_{50} and tan(β).

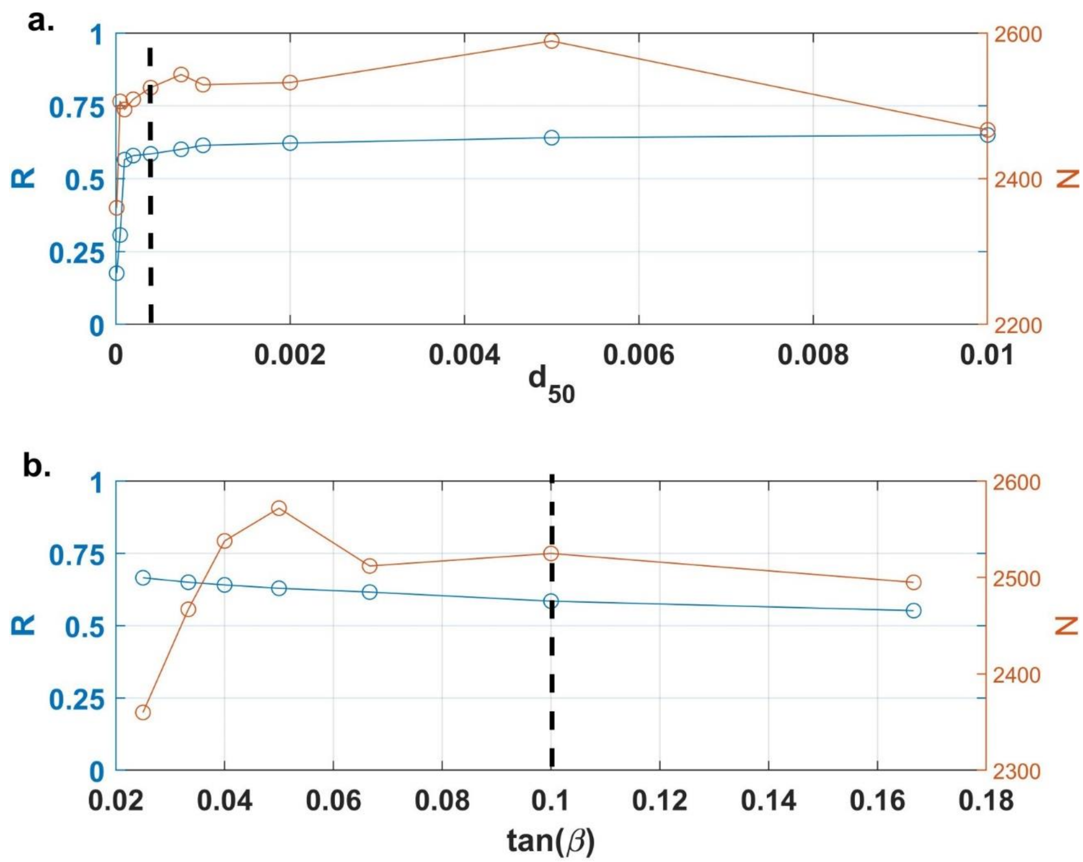

Figure S5*: Sensitivity of the model to two important parameters: sediment grain size and beach slope. Correlation coefficient between modeled sediment budgets and observed erosion trends, R (in blue) and number N of cells (in brown) as a function of: a. the median diameter of sand grains d_{50}; b. the beach slope tanβ. Vertical dashed lines show the values used in this study.*

References

Aagaard, T., Davidson-Arnott, R., Greenwood, B., & Nielsen, J. (2004). Sediment supply from shoreface to dunes: linking sediment transport measurements and long-term morphological evolution. Geomorphology, 60(1-2), 205-224.

Appendini, C. M., Salles, P., Mendoza, E. T., López, J., & Torres-Freyermuth, A. (2012). Longshore sediment transport on the northern coast of the Yucatan Peninsula. Journal of Coastal Research, 28(6), 1404-1417.

Bayram, A., Larson, M., & Hanson, H. (2007). A new formula for the total longshore sediment transport rate. *Coastal Engineering*, *54*(9), 700-710

CERC. Dept. of the Army, Waterways Experiment Station. Cerc. shore protection manual. Supt. of Docs., U.S. G.P.O., (Vicksburg, Miss, Washington, DC), 4th ed., 1984.

Cipriani, L. E., & Stone, G. W. (2001). Net longshore sediment transport and textural changes in beach sediments along the southwest Alabama and Mississippi barrier islands, USA. Journal of Coastal Research, 443-458.

Chandramohan, P., & Nayak, B. U. (1992). Longshore sediment transport model for the Indian west coast. Journal of coastal research, 775-787.

Kaczmarek, L. M., Ostrowski, R., Balouin, Y., & Howa, H. (2001). Longshore sediment transport model against field tracer data at Ancao Peninsula (Portugal) and Lubiatowo (Poland). In *Coastal Dynamics' 01* (pp. 122-131) Kamphuis. Alonshore sediment transport rate. Coastal and Oc. Engrg., 117:624–640, 1991.

Luijendijk, A., Hagenaars, G., Ranasinghe, R., Baart, F., Donchyts, G., & Aarninkhof, S. (2018). The state of the world’s beaches. *Scientific reports*, *8*(1), 1-11

Maffre, P., Ladant, J.-B., Moquet, J.-S., Carretier, S., Labat, D., Goddéris, Y., 2018. Mountain ranges, climate and weathering. Do orogens strengthen or weaken the si- licate weathering carbon sink? Earth Planet. Sci. Lett. 493, 174–185. https://doi.org/ 10.1016/j.epsl.2018.04.034.

Mil Homens, J. Longshore sediment transport: Bulk formulas and process based models. PhD thesis, Delft University of Technology, 2016.

Mulligan, M. van Soesbergen, A., and Saenz, L. GOODD, a global dataset of more than 38,000 georeferenced dams, 2020.

Peduzzi, P., 2014. Sand, rarer than one thinks. Environmental Development, 11, 208-218.

Rogers, A. L., & Ravens, T. M. (2008). Measurement of longshore sediment transport rates in the surf zone on Galveston Island, Texas. Journal of Coastal Research, (24 (10024)), 62-73.

Schoonees, J. S. (2000). Annual variation in the net longshore sediment transport rate. Coastal engineering, 40(2), 141-160.

Tran, Y. H., Marchesiello, P., Almar, R., Ho, D. T., Nguyen, T., Thuan, D. H., & Barthélemy, E. (2021). Combined longshore and cross-shore modeling for low-energy embayed sandy beaches. *Journal of Marine Science and Engineering*, *9*(9), 979.

Trombetta, T. B., Marques, W. C., Guimarães, R. C., & Costi, J. (2020). An overview of longshore sediment transport on the Brazilian coast. Regional Studies in Marine Science, 35, 101099.

UNEP, 2019. Sand and Sustainability: Finding New Solutions for Environmental Governance of Global Sand Resources