An Acad Bras Cienc (2023) 95(Suppl. 1): e20220576 DOI 10.1590/0001-3765202320220576
Anais da Academia Brasileira de Ciências | *Annals of the Brazilian Academy of Sciences*
Printed ISSN 0001-3765 I Online ISSN 1678-2690
www.scielo.br/aabc | www.fb.com/aabcjournal

GEOSCIENCES

Erosion of four Brazilian coastal deltas: how dam construction is changing the natural pattern of coastal sedimentary systems

EMILIANO C. OLIVEIRA, RAUL D. BARBOZA, BEATRIZ G.G. SILVA & MAURICIO C. DIAZ FILHO

Abstract: Reservoir-building on rivers is still "the Brazilian energy culture", such that many other dams are being constructed and planned, with many other rivers potentially suffering the same impact in their sediment flux. In this study, we evaluated the impacts of reservoir-building on the erosion of the São Francisco, Jequitinhonha, Doce, and Paraíba do Sul river deltas. A time series of Landsat images from 1973 to 2020 was analyzed, with three key highlighted moments (1973, 1997 and 2020) that summarize the erosion processes on these deltas. In addition to the images, continuous river water discharge, sediment discharge and basin rainfall data were analyzed between 1940 and 2020, providing river parameters over a period exceeding that of the satellite data. The findings suggest that coastal erosion has progressed in the four deltas, with higher estimated losses in the São Francisco and Paraíba do Sul over the 47 years of available satellite images. However, despite minimal overall estimated gains, the Jequitinhonha and Doce experienced high erosion at their river mouths, as in the other two rivers, compensated by accretion in distal coastal areas. These results can be explained by reductions in river flux and consequent sediment transport capacity due to reservoirs.

Key words: Delta erosion, landsat time series, reservoir, river impacts, sediment load, South Atlantic rivers.

INTRODUCTION

Delta depositional systems are well recognized as *accumulations of sediment at the end of a channel where it discharges into a standing body of water* (Davis & Davis Jr 1983). The characteristics of this depositional system are, however, influenced by many factors through time, such as sediment supply, waves, tides and river flow, all of which can generate destructive phases in a delta's geological record (Davis & Davis Jr 1983). Another important factor in modifying the balance between accretion and erosion in deltas is human interference, especially on river catchments.

Human activity in rivers is as old as humanity, and evidence of occupation of deltas was observed well before the Roman Empire, firstly leading to increases in the sediment influx in catchment areas, due to extensive use of lands and deforestation, and following the Industrial Revolution, decreases in sediment flux due to the construction of dams, irrigation systems and structures that adversely affect sediment flow (Syvitski & Saito 2007, Evans 2012, Maselli & Trincardi 2013, Anthony et al. 2014, Besset et al. 2019). Modern anthropogenic interferences on rivers and deltas can lead to persistent erosion, often aggravated by exacerbated subsidence in deltas with hydrocarbon/water exploitation

(Syvitski 2008) and, approximately 70% of the large river systems have been fragmented by dam construction (Zarfl et al. 2015). Considering that deltas receive 50% of the sediment budget to the oceans (Syvitski & Saito 2007), this situation contributes to a generalized coastal erosion process around the world (Mentaschi et al. 2018).

A huge number of deltas worldwide, such as those of the Ebro, Nile, Yangtze, Mekong, and Mississippi, suffer from a lack of sediment due to upstream dams (Syvitski et al. 2009, Li et al. 2017). Even the Amazon River is undergoing significant ecological and environmental impacts due to the dams on it's tributaries (Latrubesse et al. 2017). In other environments, the lack of sediment and rising global sea levels modify estuarine delta environments and sediment fluxes (Gao & Wang 2008), water resource management (Vörösmarty et al. 2003), and the carbon cycle (Bianchi & Allison 2009).

In Brazil, hundreds of multi-size and multi-purpose reservoirs, for hydropower, water supply and irrigation, have been constructed, according to the Electric Energy National Agency (ANEEL). Twenty-three of them were placed on the catchment area of four rivers that build wave-dominated deltas (Dominguez 1996, 2004, Anthony 2015) on the eastern Brazilian coast: São Francisco; Jequitinhonha, Doce and Paraíba do Sul (Fig. 1). In this scenario of anthropogenically impacted rivers, the aim of this study is to identify the recent changes in these deltas and discuss their possible link to human impacts on river sediment flux over the last 35 years.

The currently dominantly erosive state of the Brazilian coast has been reported in several studies, such as Muehe (2006) and Dominguez (2009), but the most exhaustive panorama is that proposed in the framework of the National Coast Line Conservation Program (PROCOSTA). In PROCOSTA, Muehe (2018) and others present a complete analysis of the Brazilian coast, and especially highlight the fact that all coastal states have, at least, 15% (in some cases 60%) of their coastlines in an erosional situation.

STUDY AREA

The present study analyses the deltas and the rivers of four Brazilian catchment areas (Fig. 1), as defined by the Brazilian National Water Agency (ANA) and its hydrographic division.

The four catchments exhibit different geological and geomorphological characteristics, climate regimes and biomes, resulting in distinct hydrological regimes, with a combined riverine inflow to the Brazilian east coast of 5,370 m^3/s.

The drainage area of the São Francisco (SF) river basin covers 639,219 km^2 (Fig. 1) and the main channel is 2,863 km long and goes through seven states (Minas Gerais, Bahia, Distrito Federal, Goiás, Pernambuco, Sergipe and Alagoas), with variable climatic conditions, from tropical to semi-arid. The average annual catchment rainfall is about 1,000 mm/y and the annual mean water discharge 2,943 m^3/s (ANA 2021). The water management system consists of six reservoirs, located in the main river channel (Xingó [1]; Paulo Afonso [2]; Apolônio Sales [3]; Luiz Gonzaga [4]; Sobradinho [5]; Três Marias [6]).

The Jequitinhonha river (JQ) drainage basin covers a total area of approximately 70,315 km^2 (Fig. 1), in the states of Minas Gerais and Bahia, and has a length of 920 km. Due to its relatively moderate size compared to the SF, the JQ river basin is located within distinct climatic conditions, from tropical to semi-arid, with an average annual rainfall of ~ 1,100 mm/y and has an annual mean discharge of ~ 410 m^3/s (ANA 2021, Ferreira & Silva 2012). The basin water management system consists of two reservoirs in the main channel of the river (Itapebi [7] and Irapé [8]).

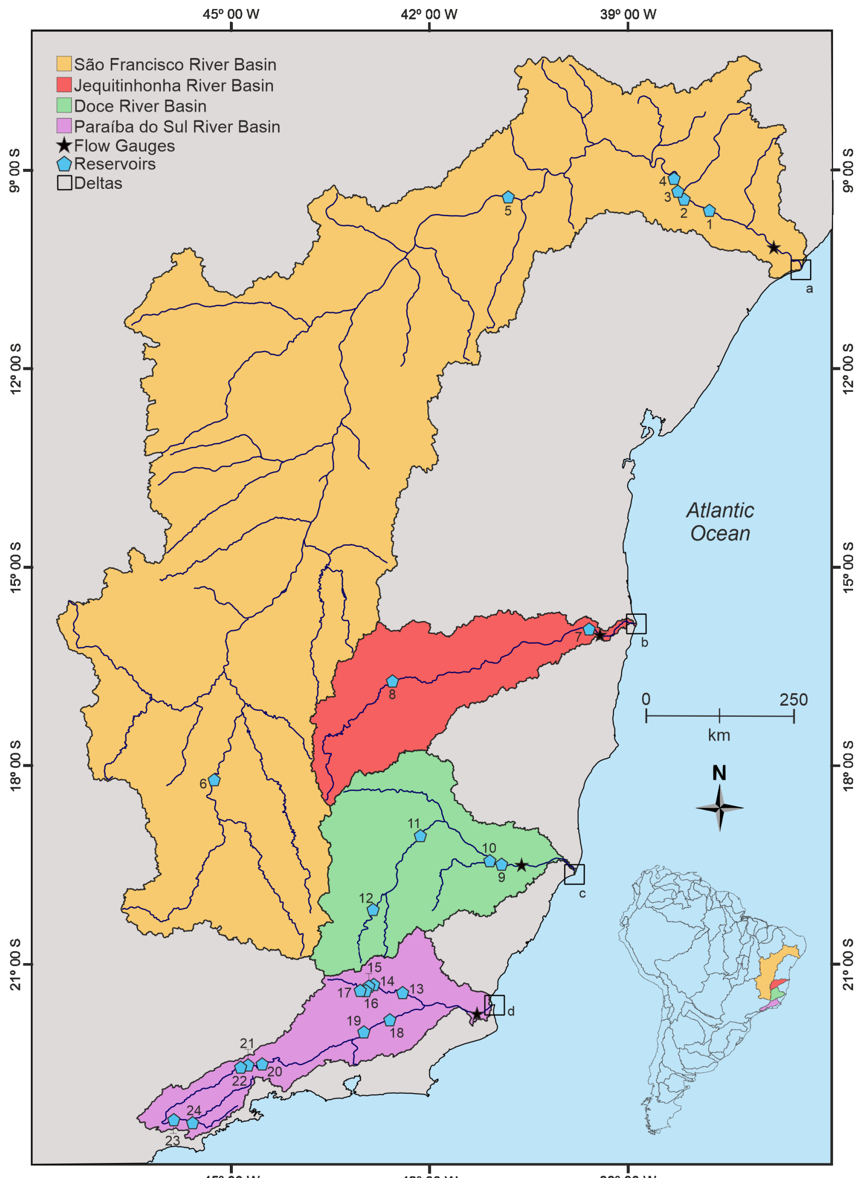

Figure 1. Map of the four river basins presented in this study, with deltaic area highlighted as: São Francisco (a), Jequitinhonha (b), Doce (c), Paraíba do Sul (d).

The drainage area of the Doce river (DC) basin covers 83,400 km² (Fig. 1), in Minas Gerais and Espírito Santo states. The main channel length is 853 km, totally under tropical conditions, with an average annual rainfall of about 1,200 mm/y and a mean annual water discharge around 900 m³/s (ANA 2021). The DC water management system consists of four reservoirs in the main river channel (Mascarenhas [9]; Aimorés [10]; Baguarí [11] and Risoleta Neves [12]).

The Paraíba do Sul river (PS) drainage basin has a total area of approximately 56,500 km² (Fig. 1), located in São Paulo, Rio de Janeiro and Minas Gerais states, and its main channel has a length of 1137 km. The basin experiences a tropical climate, with an average annual rainfall of ~ 1450 mm/y (Marengo & Alves 2005) and an average annual water flux of ~ 1118 m³/s (ANA 2021). The PS has one of the biggest water management systems in Brazil, with two water diversion systems, in Rio de Janeiro and in São Paulo, comprising twelve reservoirs (Barra do Brauna [13]; Ivan Botelho III [14]; Zé Tunin [15]; Ivan Botelho II [16]; Ivan Botelho I [17]; Ilha dos

Pombos [18]; Simplício [19]; Funil [20]; Queluz [21]; Lavrinhas [22]; Santa Branca [23]; Paraibuna [24]).

MATERIALS AND METHODS

In order to gain an understanding of rain and water fluxes and their changes in the four river basins, gauged monthly basin rainfall, gauged monthly flow volume time series for the terminal stations, and available but incomplete series of sediment load, were downloaded from the Hydrological Information System (HidroWeb; https://www.snirh.gov.br/hidroweb) of the Brazilian National Water Agency (ANA), with variable data periods in each station, but consistently starting around the 1940's. The data are periodically reviewed by ANA, identifying errors and filling gap series using regional weighting and linear regression. Information on existing reservoirs and their storage were obtained from the National Electric System Operator (ONS) website (http://www.ons.org.br/paginas/energia-agora/reservatorios).

To characterize the shoreline morphological changes in the four deltas (Fig. 1a-d), a set of 188 remote sensing images were analyzed. The images were obtained from the Earth Explorer Open Database (https://earthexplorer.usgs.gov), and covered the period 1973, to 2020 forming a time series of 47 images for each delta. The images were provided by Landsat 1 Multispectral Scanner (MSS) with a spatial resolution of 80 m (1973), Landsat 7 Enhanced Thematic Mapper (ETM+) with a spatial resolution of 30 m (2000), and Landsat 8 Operational Land Imager (OLI) with a spatial resolution of 30 m (2020). Some basic layer compositions were used to enhance morphological changes in the deltas, such as 4,2,1 for Landsat 7 images and 4,3,2 for Landsat 8 images. One-layer images (band 6) were used for Landsat 1 images, due to incomplete datasets. The images were enhanced (brightness, contrast and saturation) in QGIS 3.20.2 Odense software, to obtain the requirements for coastal mapping and delineation of water bodies. The coastline identification methodology was based on that used by Gamage & Smakhtin (2009), Hereher (2011), Anthony et al. (2015), Ali & El-Magd (2016), Li et al. (2017) and Ghorai & Mahapatra (2019). With the coastline manually marked in all images and, the same projection system (Lat/Lon), the images were organized under the same resolution and zoom, creating a layered historical series. The 1973 images were considered as the reference coastline that was compared with the 2000 and 2020 images in order to determine erosion and accretion zones between 1973 and 2020. The same procedure was carried out with geographical information system (GIS) tools (automatic coastline determination), using the methodology proposed by Ghorai & Mahapatra (2019), with sequential procedures consisting of preprocessing, coastal water index preparation, bright pixel enhancement, thresholding, binary image classification, vectorization, shoreline selection, and shoreline geometry simplification. The result of these procedures was the extraction of the delta coastlines from each image.

These estimations of gain/loss area are based on the satellite image analysis (area differences between superimposed lines) and express the fact that the net multi-decadal area variations observed are higher than the expected seasonal area variations for delta coastlines (Gamage & Smakhtin 2009).

RESULTS

Figure 2 shows the time series of reservoir storage growth, gauged monthly flow volume for the terminal stations, inconsistent series of sediment load, and gauged monthly basin

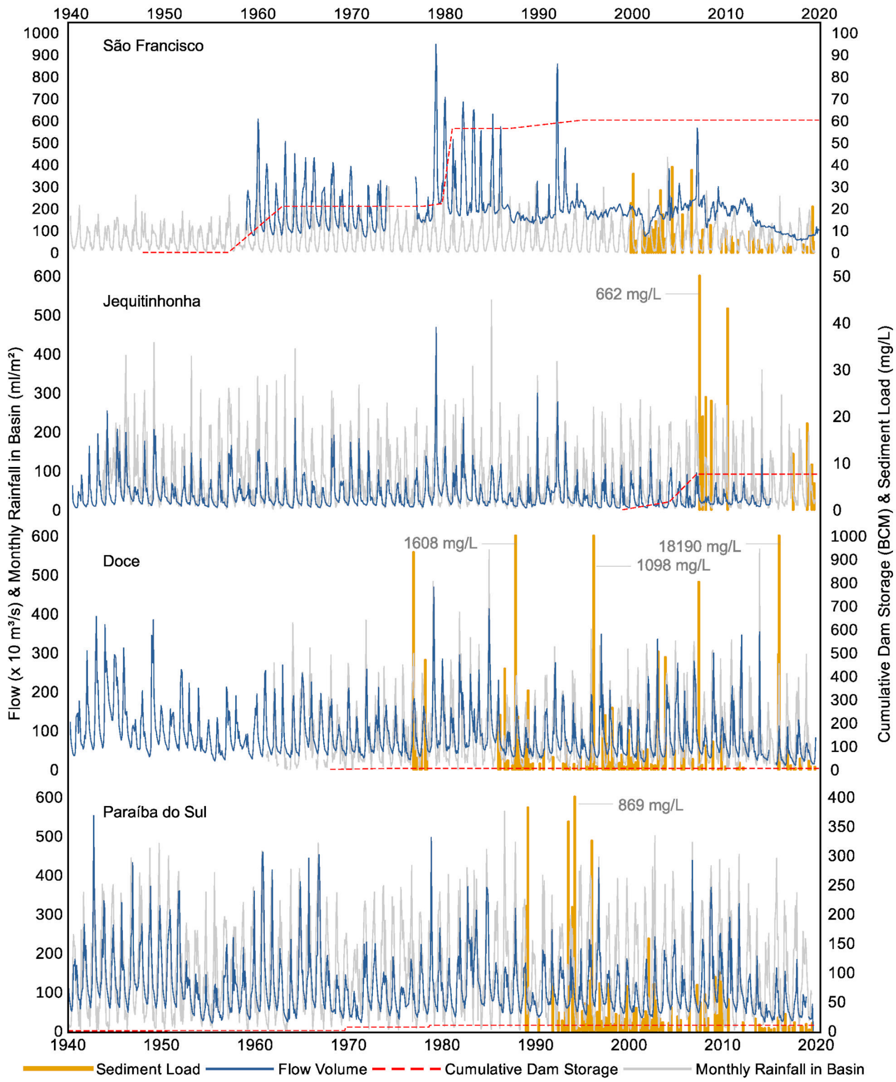

Figure 2. **Time series of sediment load, flow volume, cumulative dam storage and monthly rainfall in the four basins.**

rainfall for the four basins between 1940 and 2020.

The gauged monthly flow volume time series (Fig. 2) analyzed for the SF have some missing data between 1940 and 1958 and between 1974 and 1977, and the gauged monthly rainfall series (Fig. 2) analyzed for the DC have missing data between 1940 and 1961, but these two parameters show consistency in the historical series for all four rivers.

The sediment load series shows many gaps (Fig. 2) in all four rivers, but could be assembled for the SF over the last twenty years, the JQ over the last fifteen years, the DC over the last 40 years and the PS over the last 30 years. In the SF and JQ, the sediment load peaked to attain 40 mg/l in the early 2000s, and no more than 20 mg/l in the late 2010s. In the DC, it reached 1000 mg/l in the mid-1990s, but was no more than 100 mg/l in the late 2010s. The abnormal peak in the DC data, related to the effects of the tailing dam failure of Fundão (Mariana, MG) in 2015 (Quaresma et al. 2020), reached 18190 mg/l; in the PS, it reached 400 mg/l in the early 1990s but dropped to no more than 20 mg/l in the late 2010s.

Cumulative dam storage (Fig. 2) started increasing in the late 1960s in the SF, and kept growing until the mid-1990s, when it reached 60.23 billion cubic meters (BCM), due to the construction of the six related dams, but the greatest increment can be noticed in the early 1980s, with the conclusion of the Sobradinho [5] dam. In the JQ (7.59 BCM), the cumulative dam storage started to grow in the late 1990s and stabilized in 2006, with the conclusion of the Irapé [8] dam. The same evolution occurred in the DC, but there are four dams in this basin (4.27 BCM), with an increase in storage in the late 1960s and early 1970s. In the PS, the cumulative dam storage started increasing in the mid 1970s, and reached its current volume, with twelve dams (14,29 BCM) in the early 2010s, following the commissioning of the Queluz [21] and Lavrinhas [22] dams.

The composite figure obtained from the satellite images for 1973, 1997 and 2020, with the reference of the 1973 coastline (red line) for the four deltas is presented in Fig. 3.

Using the 1973 images as a reference for the 1997 images, we note erosion in the river mouths of the SF and the PS (Fig. 3a-2, d-2), but in the

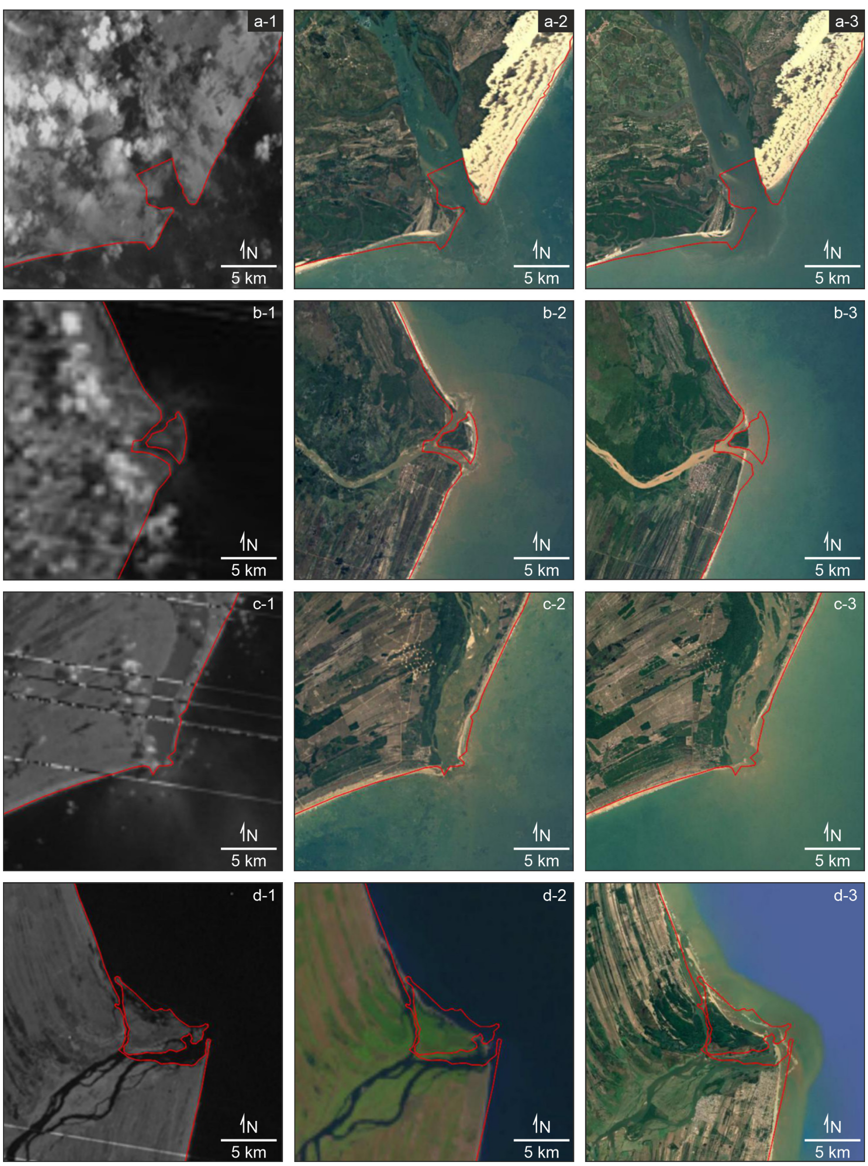

Figure 3. Changing morphology of the four deltas in the river mouth area (SF- a; JQ – b; DC – c; PS – d), in 1973 (1), 1997 (2) and 2020 (3). The red line shows the 1973 coastline for reference.

JQ and DC (Fig. 3b-2, c-2) the process seems more balanced, with some accretion and some erosion. When the comparison includes the 2020 images, more intense erosion is observed in the SF and JQ (Fig. 3a-1, a-2, a-3, b-1, b-2, b-3), whereas the DC shows a continuous balance (Fig. 3c-1, c-2, c-3) and the PS discrete erosion (Fig. 3b-1, b-2, b-3).

DISCUSSION

The data presented in Fig. 2 show a reduction in average flow volume after 2010 in the JQ, DC and PS, and since 1994 in the SF. Despite the inconsistency of the sediment data, the reduction of the average flow volume can be linked to a reduction of the sediment load, as has been shown by various other studies on deltas (Bussi et al. 2021, Maselli & Trincardi 2013, Yang et al. 2014, Besset et al. 2019). The São Francisco (SF) river shows a significant reduction in mean flow (Fig. 2) and increased erosion (Fig. 3a-2, a-3) after the construction of the Xingó dam in 1994, indicating that the building of a dam so close to this Atlantic-facing river mouth can modify the delta shoreline dynamics, as has been shown also in the case of the wave-dominated Volta river delta in West Africa dammed close to the Atlantic (Anthony et al. 2016). Similar situations can be noticed in the Jequitinhonha (JQ), following the conclusion of the Itapebi (1999) and Irapé (2002) dams, with a reduction of flow volume and increased erosion between 1997 and 2020 (Fig. 3b-2, b-3). In the Paraíba do Sul (PS), the reduction of mean flow volume is more evident after 2010, with the conclusion in 2015 of the water diversion system in São Paulo (Paiva et al. 2020), but the 12 dams in the major channels have had a constant influence on delta erosion since 1985 (Fig. 3d-1, d-2, d-3). The Doce (DC) river also presents a reduction of the average flow volume after 2012, but with discrete erosional response in the satellite images (Fig. 3c-1, c-2, c-3). The erosional patterns described for each delta can also be related to the number of dams and storage in the basins (Gamage & Smakhtin 2009), showing that the sediment regime in all four basins is sensitive to reservoir size and installation.

While areas of erosion and deposition change, the overall estimated (based on satellite image analysis) tendency for the SF and PS is retrogressional (Fig. 4a-2, d-2). Despite in the fact that the JQ and DC show a positive estimated annual rate of loss/gain (Fig. 4b-2, c-2), they also show a generalized erosion in the river mouth sector.

The retroggression observed in the four deltas mouths (Fig. 4) cannot be explained by the regional sea-level rise, as there is only a mild trend of increase for the South Atlantic (Frederikse et al. 2021). The erosion in these deltas is most plausibly explained by the reduced sediment supply, which is directly related to upstream flow regulation (dams building). Since the 1980’s, all four rivers have been subjected to the building of several reservoirs that have led to the reversal of the typical progradation pattern of the deltas (Fig. 4). Despite erosion being a dominant process close to the river’s mouth, deposition still occurs in limited sections of the coastline, far from the river mouth. This is a typical pattern observed in wave-dominated deltas wherein erosion at the mouth results from weakening of the river outflow jet by water discharge relative to the ambient waves (Anthony 2015, Zăinescu et al. 2021). Bedload reworked in the wake of this erosion of the river mouth is commonly redistributed alongshore by wave-induced longshore transport, leading to reduction of the delta protrusion (Besset et al. 2017). An extreme case of such a plan-view modification of the delta protrusion is that of

Figure 4. Images from 2020 of the four deltas in the river mouth area (SF- a; JQ – b; DC – c; PS – d), with 1973 highlighted coastline (1) and with erosion (red) / accretion (green) balance (2) in between 1973 and 2020.

the Moulouya delta in Morocco (Snoussi et al. 2002).

This change in the deltas sedimentation pattern is especially relevant in the light of the generalized erosive trend currently prevailing along the Brazilian coast (Muehe 2018). These deltas are not only redistributing sediments in an attempt to maintain their stability but are contributing to the general sediment load on the Brazilian eastern coast through this longshore redistribution.

This study can be improved with longer series of sediment loads and the use of higher resolution remote sensing images, but even with the existing limited data, the results of the study are consistent with the affirmation of Gamage & Smakhtin (2009), that upstream basin storage development leads to the retreat of deltas. In the SF, the situation is critical, because the mean flow has dropped by half in the last ten years. A similar situation can be observed in the PS, with an almost "closed basin" case, with twelve dams and two diversions regulating the river flow. The situation in the JQ and DC is also likely to deteriorate with the construction of dams that lead to additional storage.

Sedimentation modeling of the major Brazilian rivers would be useful in understanding the relationship between upstream runoff reduction, sediment discharge reduction, upstream reservoir storage increase and their impacts on deltas. These studies could lead to the specification of environmental flow releases in the reservoirs, to compensate for delta sediment regimes, and the planning of new types of dams that are designed to preserve the sediment load characteristics of the rivers (Gamage & Smakhtin 2009).

CONCLUSIONS

"Starving" deltas are now an increasingly more common feature of the world's coasts, and the eastern Brazilian coast and its deltas are no exception. We identified four wave-dominated deltas on this coast that are now vulnerable to erosion as a result of sequestration of sediments in upstream reservoirs. A consequence of this is that the eastern Brazilian coast is not only receiving less sediment, but this situation is leading to erosion of distant stretches of coast that are not directly related to these deltas.

The building of reservoirs for water storage and electricity generation is leading to a significant decrease in sediment supply, especially bedload to deltas. This study demonstrated that the São Francisco (SF), Jequitinhonha (JQ), Doce (DC) and Paraíba do Sul (PS) deltas have been in retreat for the last 35 years, with erosion at the mouths and some deposition along adjacent deltaic shorelines that is related to redistribution of sediments eroded at the mouth. The reduced water and sediment inflow is the main cause of this retreat and is closely related to the building of reservoir storage and dams.

This situation can get worse considering the ongoing global sea-level rise, which can accelerate the erosion process in these deltas. The rivers that reach the Brazilian coast must be studied with detailed sedimentation models that are capable of analyzing the relationship between water and sediment flow throughout the river reaches and their reservoirs, and how this affects the deltas and the coastline. This could lead to better river flow control, with environmental flow releases for the maintenance of deltas and the coastline.

Acknowledgments

We would like to thank Agência Nacional de Águas (ANA) and United States Geological Service (USGS) for the data and Gustavo Seichi Inouye Shintate for the English language revision. We also thank the two anonymous reviewers for their valuable comments

REFERENCES

ALI EM & EL-MAGD IA. 2016. Impact of human interventions and coastal processes along the Nile Delta coast, Egypt during the past twenty-five years. Egypt J Aquat Res 42: 1-10.

ANA - AGÊNCIA NACIONAL DE ÁGUAS. 2021. Gestão das águas. URL https://www.gov.br/ana/pt-br/assuntos/gestao-das-aguas.

ANTHONY EJ. 2015. Wave influence in the construction, shaping and destruction of river deltas: A review. Marine Geol 361: 53-78.

ANTHONY EJ, ALMAR R & AAGAARD T. 2016. Recent shoreline changes in the Volta River delta, West Africa: the roles of natural processes and human impacts. Afr J Aqua Sci 41: 81-87.

ANTHONY EJ, BRUNIER G, BESSET M, GOICHOT M, DUSSOUILLEZ P & NGUYEN VL. 2015. Linking rapid erosion of the Mekong River delta to human activities. Sci Rep 5: 1-12.

ANTHONY EJ, MARRINER N & MORHANGE C. 2014. Human influence and the changing geomorphology of Mediterranean deltas and coasts over the last 6000 years: from progradation to destruction phase? Earth Sci Rev 139: 336-361.

BESSET M, ANTHONY EJ & BOUCHETTE F. 2019. Multi-decadal variations in delta shorelines and their relationship to river sediment supply: An assessment and review. Earth Sci Rev 193: 199-219.

BESSET M, ANTHONY EJ & SABATIER F. 2017. River delta shoreline reworking and erosion in the Mediterranean and Black Seas: the potential roles of fluvial sediment starvation and other factors. Elementa Sci Anthropocene 5: 54.

BIANCHI TS & ALLISON MA. 2009. Large-river delta-front estuaries as natural "recorders" of global environmental change. Proc Natl Acad Sci 106(20): 8085-8092.

BUSSI G ET AL. 2021. Impact of dams and climate change on suspended sediment flux to the Mekong delta. Sci Total Environ 755(1): 142468.

DAVIS RA & DAVIS JR RA. 1983. Depositional Systems: A Genetic Approach to Sedimentary Geology. New Jersey: Prentice-Hall, 506 p.

DOMINGUEZ JML. 1996. The São Francisco strandplain: a paradigm for wave-dominated deltas? In: DE BAPTIST M & JACOBS P (Eds), Geology of Siliciclastic Shelf Seas. Geol Soc London Special Publication 117: 217-231.

DOMINGUEZ JML. 2004. The coastal zone of Brazil: An overview. J Coast Res Special Issue 39: 16-20.

DOMINGUEZ JML. 2009. The coastal zone of Brazil. In: DILLENBURG SR & HESP PA (Eds), Geology and Geomorphology of Holocene Coastal Barriers of Brazil. Berlin: Springer, 380 p.

EVANS G. 2012. Deltas: The Fertile dustbins of the continents. Proc Geol Assoc 123(3): 397-418.

FERREIRA VO & SILVA MM. 2012. O Clima da Bacia do Rio Jequitinhonha, em Minas Gerais: Subsídios para a Gestão de Recursos Hídricos. Rev Bras Geogr Fis 2: 302-319.

FREDERIKSE T ET AL. 2021. Constraining 20th-Century Sea-Level Rise in the South Atlantic Ocean. J Geophys Res Ocean 126(3): 016970.

GAMAGE N & SMAKHTIN V. 2009. Do river deltas in east India retreat? A case of the Krishna Delta. Geomorphol 103(4): 533-540.

GAO S & WANG YP. 2008. Changes in material fluxes from the Changjiang River and their implications on the adjoining continental shelf ecosystem. Cont Shelf Research 28(19): 1490-1500.

GHORAI D & MAHAPATRA M. 2020. Extracting Shoreline from Satellite Imagery for GIS Analysis. Remote Sens Earth Syst Sci 3: 13-22.

HEREHER ME. 2011. Mapping coastal erosion at the Nile Delta western promontory using Landsat imagery. Environ Earth Sci 64: 1117-1125.

LATRUBESSE E ET AL. 2017. Damming the rivers of the Amazon basin. Nature 546: 363-369.

LI X, LIU JP, SAITO Y & NGUYEN VL. 2017. Recent evolution of the Mekong Delta and the impacts of dams. Earth-Science Reviews 175: 1-17.

MARENGO JA & ALVES LM. 2005. Tendências hidrológicas da bacia do rio Paraíba do Sul. Rev Bras Meteorol 20(2): 215-226.

MASELLI V & TRINCARDI F. 2013. Man made deltas Sci Rep 3: 1-7.

MENTASCHI L, VOUSDOUKAS MI, PEKEL JF, VOUKOUVALAS E & FEYEN L. 2018. Global long-term observations of coastal erosion and accretion. Sci Rep 8: 1-11.

MUEHE D. 2006. Erosion in the Brazilian coastal zone: an overview. J Coast Res 39: 43-48.

MUEHE D. 2018. Panorama da erosão costeira no Brasil. Brasília: Ministério do Meio Ambiente, 759 p.

PAIVA ACE, NASCIMENTO N, RODRIGUEZ DA, TOMASELLA J, CARRIELLO F & REZENDE FS. 2020. Urban expansion and its impact on water security: The case of the Paraíba do Sul River Basin, São Paulo, Brazil. Sci Total Environ 720: 137509.

QUARESMA VS, BASTOS AC, LEITE MD, COSTA A, CAGNIN RC, GRILO CF, ZOGHEIB LF & SANTOS OLIVEIRA KS. 2020. The effects of a tailing dam failure on the sedimentation of the eastern Brazilian inner shelf. Cont Shelf Res 205: 104172.

SNOUSSI M, HAIDA S & IMASSI S. 2002. Effects of the construction of dams on the Moulouya and the Sebou rivers (Morocco). Reg Environ Change 3: 5-12.

SYVITSKI J, KETTNER A, OVEREEM I, HUTTON EWH, HANNON MT, BRAKENRIDGE JD, VÖRÖSMARTY C, SAITO Y, GIOSAN L & NICHOLLS RJ. 2009. Sinking deltas due to human activities. Nature Geosci. 2: 681-686.

SYVITSKI JPM. 2008. Deltas at risk. Sustain Sci 3: 23-32.

SYVITSKI JPM & SAITO Y. 2007. Morphodynamics of deltas under the influence of humans. Glob Planet Change 57(3-4): 261-282.

VÖRÖSMARTY CJ, MEYBECK M, FEKETE B, SHARMA K, GREEN P & SYVITSKI JPM. 2003. Anthropogenic sediment retention: major global impact from registered river impoundments. Glob Planet Chang 39(1-2): 169-190.

YANG SL, MILLIMAN JD, XU KH, DENG B, ZHANG XY & LUO XX. 2014. Downstream sedimentary and geomorphic impacts of the Three Gorges Dam on the Yangtze River. Earth Sci Rev 138: 469-486.

ZĂINESCU F, ANTHONY E & VESPREMEANU-STROE A. 2021. River jets versus wave-drive longshore currents at river mouths. Front Mar Sci 8: 708258.

ZARFL C, LUMSDON AE, BERLEKAMP J, TYDECKS L & TOCKNER K. 2015. A global boom in hydropower dam construction. Aquat Sci 77: 161-170.

How to cite

OLIVEIRA EC, BARBOZA RD, SILVA BGG & DIAZ FILHO MC. 2023. Erosion of four Brazilian coastal deltas: how dam construction is changing the natural pattern of coastal sedimentary systems. An Acad Bras Cienc 95: e20220576. DOI: 10.1590/0001-3765202320220576.

Manuscritp received on July 6, 2022;
accepted for publication on November 16, 2022

EMILIANO C. OLIVEIRA[1]
https://orcid.org/0000-0002-7980-8138

RAUL D. BARBOZA[2]
https://orcid.org/0009-0000-4877-7335

BEATRIZ G.G. SILVA[2]
https://orcid.org/0009-0006-0168-9518

MAURICIO C. DIAZ FILHO[2]
https://orcid.org/0009-0004-5932-1025

[1]Universidade Federal de São Paulo, Departamento de Ciências do Mar, Instituto do Mar, Rua Doutor Carvalho de Mendonça, 144, 11070-100 Santos, SP, Brazil

[2]Universidade Federal de São Paulo, Bacharelado Interdisciplinar em Ciência e Tecnologia do Mar, Instituto do Mar, Rua Doutor Carvalho de Mendonça, 144, 11070-100 Santos, SP, Brazil

Correspondence to: **Emiliano Castro de Oliveira**
E-mail: emiliano.oliveira@unifesp.br

Author contributions

Emiliano Castro de Oliveira: Writing – review & editing; Investigation; Methodology; Software; Validation; Visualization; Supervision. Raul Dias Barboza: Methodology; Software; Validation; Visualization. Beatriz Gabriella Gomes da Silva: Software; Validation; Visualization. Mauricio de Castro Diaz Filho: Software; Validation; Visualization.