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Spatial and Temporal Analysis of the Coastal Urban Occupation Line in The Municipality of Jaboatão dos Guararapes PE/Brazil, for the Period 1974-2016

Análise Espacial e Temporal da Linha de Ocupação Urbana Costeira no Município do Jaboatão dos Guararapes PE/Brasil no Período 1974-2016

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Abstract: Coastal erosion, a phenomenon affecting a large proportion of beaches around the world, has been increasing in line with population growth in coastal regions. The aim of this article is to study the influence of urban growth on the evolution of the building line along the Jaboatão dos Guararapes coastline. Due to changes in the direction of the coastline, the study area was divided into five sectors, in which spatial analyses were carried out. These show that the greatest advances in the building line occurred between 1974 and 1997 in sectors 5, 1 and 2, which advanced by 287. 27, 250.7 and 246.79 metres inland from the beach. The building line was extracted from aerial photographs and imagery. The evolution of the shoreline was calculated using the Digital Shoreline Analysis System (DSAS-USGS). The rates were calculated using Statistica. The shoreline, although formed by rigid structures, proved to be highly mobile over time, adapting to the constant changes in the coastline and the anthropogenic pressure exerted on the beach.

Keywords: Spatial analysis; Line of occupation; Displacement rate; Coastal zone.

Resumo: A erosão costeira, fenômeno que afeta grande parte das praias ao redor do mundo, tem aumentado com o crescimento populacional das regiões litorâneas. Este artigo tem como objetivo estudar a influência do crescimento urbano na evolução da linha de ocupação na orla de Jaboatão dos Guararapes. Por causa das mudanças de direção da linha de costa, a área de estudo foi dividida em cinco setores, nos quais foram realizadas análises espaciais que mostram que os maiores avanços da linha de ocupação ocorreram no período 1974 1997 nos setores 5,1 e 2 que avançaram respectivamente 287.27, 250.7 e 246,79 metros sobre a orla da praia. A linha de ocupação foi extraída de fotografias aéreas e imagens. O cálculo da evolução das linhas de ocupação foi realizado com o Digital Shoreline Analysis System – (DSAS-USGS). O cálculo das taxas foi realizado pelo *Statistica*. A linha de ocupação, mesmo formada por estruturas rígidas, mostrou-se bastante móvel com o passar do tempo, adaptando-se às constantes mudanças da linha de costa e a pressão antrópica exercida sobre a orla da praia.

Palavras-chave: Análise espacial; Linha de ocupação; Taxa de deslocamento; Zona costeira.

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1. Introduction

The Brazilian coastal zone is the geographical area where land, air and sea interact; the seashore – the strip within the coastal zone, of variable width, comprising a maritime strip and a terrestrial strip (BRAZIL, 2004) – extends for approximately 8,500 km along the Atlantic Ocean.

Coastal regions with recent geological formations (Pleistocene and Holocene), such as those in Brazil, are the most sensitive and dynamic. These include coastal plains and their sub-environments: lagoons, estuaries, fluvial-marine plains, beaches, and many other environments that are under pressure from the growth of large urban centres (MARINO and FREIRE, 2013).

Urban expansion and the encroachment on coastal areas fail to take into account the mobile, sensitive and dynamic nature of the coastline (BRASIL, 2016; MARINO and FREIRE, 2013; MMA, 2008). The development of the beach environment leads to changes in the coastal landscape, causing problems such as the destruction of structures built on the beach. The growing demand for space for activities such as tourism, housing, fishing, industrial and port activities, and, more recently, the installation of wind farms, has contributed to the degradation of coastal environments.

Coastal erosion occurs when the sediment balance is negative, that is, when the beach loses sediment. The causes of coastal erosion can be natural, such as rising sea levels, more intense storms, tectonic subsidence and changes in river basins; anthropogenic, such as land subsidence, the removal of sand for human activities, and the construction of dams and structures within the beach environment; or the result of the interaction between natural and anthropogenic factors (CAI et al., 2009; NICHOLLS and CAZENAVE, 2010).

Coastal retreat is a consequence of coastal erosion, as the beach morphology adapts to changing physical factors in order to better absorb wave energy. The beach environment, which should be a reserve area protected by law for future adaptations to the marine environment, should not be occupied by buildings, pavements, walls, dykes and roads, which cause waves to reflect, thereby carrying sand from the beach out to the seabed. When this happens, it leads to the destruction of existing coastal developments, as well as the waste of public funds on coastal engineering works, which, in most cases, end up accelerating the erosion process in adjacent areas.

The coastline of the state of Pernambuco is approximately 187 km long and consists mainly of sandy beaches; it is renowned in the global tourism sector for its unique beauty, but also features stretches along its coastline that are vulnerable to coastal erosion (GREGÓRIO et al., 2004). Studies conducted by ARAÚJO et al. (2007) found that the metropolitan area, comprising the municipalities of Recife, Olinda and Jaboatão dos Guararapes, is the most affected by human occupation of coastal environments and is particularly compromised by the presence of buildings or rigid structures designed to contain marine erosion.

MANSO et al. (2006) classified the beaches of Piedade, Candeias and Barra de Jangada in Jaboatão dos Guararapes as being severely affected by erosion processes. According to the authors, a reduction in the width of the foreshore, the destruction of buildings constructed close to the coast and a lowering of the beach profiles were observed at the site. SILVA and LIRA (2017), in their study entitled 'Spatial and Temporal Displacement of the Coastline' on the beaches belonging to Recife and Jaboatão dos Guararapes, Pernambuco, Brazil, found evidence of erosion to the south of the study area.

SANTOS JÚNIOR et al. (2020) found in their studies on coastline displacement on the beaches of Jaboatão dos Guararapes that Sector 1, located on Barra de Jangada beach, exhibited the highest average positive rate of coastline displacement during the period 1974–2013 due to beach nourishment carried out to counteract the erosion process.

2. Metodology

2.1 Study area

The municipality of Jaboatão dos Guararapes is situated in the Recife Metropolitan Region (RMR), in the state of Pernambuco, in north-eastern Brazil. It is bordered to the north by the municipalities of Recife and São Lourenço da Mata, to the south by the municipality of Cabo de Santo Agostinho, to the east by the Atlantic Ocean, and to the west by the municipality of Moreno. The study area comprises the beaches of the municipality of Jaboatão dos Guararapes (Barra de Jangada, Candeias and Piedade) and is approximately 8 km long (Figure 1).

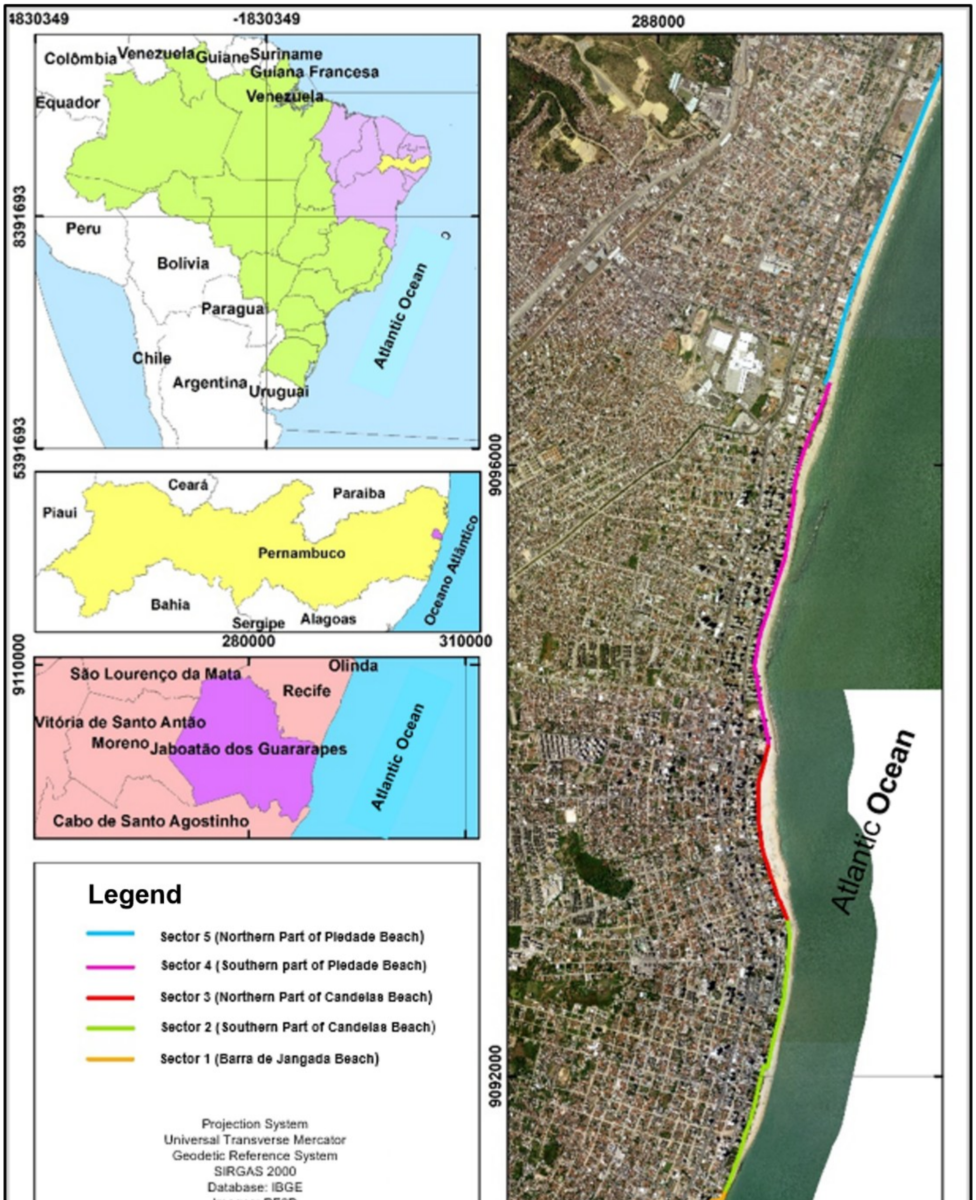

Figure 1 – Map showing the location of the study area and the division into sectors 1, 2, 3, 4 and 5.
Source: Authors (2025).

According to INMET (2009), the region's climate is characterised by high temperatures, with averages of 25°C, reaching a maximum of 32°C and a minimum of 18°C, and rainfall of up to 2,000 mm per year. Jaboatão dos Guararapes is situated within three major lithological units that were formed at different times 2,500 million years ago. According to Brito Neves (1975) and Amaral and Menor (1979), the lithology comprises lithotypes from the Pernambuco-Alagoas Massif and Tertiary and Quaternary overlying sediments. The Quaternary deposits are distributed across the lower-lying regions of the municipality, comprising sediments of marine, fluvial, lagune, fluvial-lagune, mangrove, reef, colluvial, alluvial and eluvial origin. These sediments consist of sands, silts, clays and peat-like sediments, covering a considerable area of the municipality (mainly along the coastline).

2.2. Materials and Methods

In this study, the line of development was defined as the line of existing urban infrastructure in the coastal environment that is closest to and runs parallel to the shoreline, comprising built urban structures such as walls and promenades. To determine the evolution of the built-up line, aerial photographs and laser-scanning images from 2016 were used, obtained from the Pernambuco State Planning and Research Agency (CONDEPE FIDEM), as this data was readily available, of high quality and clearly showed the evolution of development in the coastal zone. The images were georeferenced in the UTM (Universal Transverse Mercator) system within SIRGAS2000 (Geocentric Reference System for the Americas), using ArcGIS 10.1 software, onto a map with a scale of 1:1,000, which served as the cartographic base.

The study area was divided into sectors: sector 1, sector 2, sector 3, sector 4 and sector 5, arranged from south to north, due to the change in the direction of the coastline (Figure 1). The division of the study area into sectors was standardised in accordance with the division adopted by Santos Júnior et al. (2020), thereby assigning to the segments the current configuration of the coastline following the beach nourishment carried out in 2013. Consequently, the study area was divided into five sectors, each characterised by physical changes to the continuous coastline, as indicated by the curves present along the shoreline.

The lines were extracted for each year analysed, with the 1974 shoreline used as the baseline for calculating variations in the years 1981, 1997 and 2016. The rates of advance and retreat of the shoreline were calculated using the Digital Shoreline Analysis System (DSAS) and ArcGIS 10.1 software developed by the United States Geological Survey (USGS). The data obtained for each sector were grouped for analysis of the mean, median, maximum, minimum and standard deviation in Statistica, and presented in tables, graphs and maps.

3. Results and discussion

The results for the interaction rates (m/year) by occupation across the five sectors for the periods 1974–1981, 1974–1997 and 1974–2016 are shown in Table 1 and Figures 2 to 9.

3.1 Sector 1

Sector 1 comprises Barra de Jangada beach and extends for 1,688 metres. The variations in the shoreline position for Sector 1 are shown in Figures 2, 3 and 4, and the average rates are given in Table 1. The average rates of shoreline displacement ranged from –0.45 to 10.9 m/year. The median was similar to the mean, ranging from –0.46 to 10.9 m/year. The standard deviation ranged from 0.09 to 0.82, with values also consistent with the monitoring period (Table 1). The advance of the shoreline in Sector 1 was 7.91 m during the period 1974–1981, corresponding to an average rate of 1.18 m/year. The greatest advance observed occurred between 1974 and 1997, a period characterised by intense coastal development. The displacement reached 250.7 m offshore, at an average rate of 10.9 m/year. In contrast, during the period 1974–2016, the settlement line retreated, with a total displacement of –18.9 m and an average rate of –0.45 m/year (Table 1).

Figure 2 – Changes in the employment trend in Sector 1 for the years 1974, 1981, 1997 and 2016.
Source: Authors (2025).

Table 1 – Results of the shift in the line of occupation (m/year) between the periods 1974–1981, 1974–1997 and 1974–2016 for sectors 1, 2, 3, 4 and 5.

Sectors	Nº of Transects	Distances (m)	Average (m)	Mediana (m)	Minimum (m)	Maximum (m)	Standard Deviation
Setor_1_74_81	135	8,26	1,18	1,01	-0,13	3,16	0,82
Setor_1_74_97	192	250,7	10,9	10,9	10,47	11,28	0,25
Setor_1_74_16	192	-18,9	-0,45	-0,46	-0,62	-0,28	0,09
Setor_2_74_81	401	12,67	1,81	1,84	-4,68	6,04	2,21
Setor_2_74_97	401	246,79	10,73	10,97	7,87	11,53	0,84
Setor_2_74_16	401	9,24	0,22	0,1	-0,79	1,53	0,66
Setor_3_74_81	447	-6,65	-0,95	-0,15	-6,46	3,38	2,99
Setor_3_74_97	412	226,78	9,86	9,83	7,23	12,53	1,52
Setor_3_74_16	419	95,76	2,28	1,89	0,53	4,7	1,29
Setor`4_74_81	423	6,02	0,86	1,88	-10,83	7,11	4,24
Setor_4_74_97	410	156,63	6,81	6,57	5,63	9,37	0,88
Setor_4_74_16	423	37,8	0,9	0,39	-0,04	3,11	0,94
Setor_5_74_81	280	69,72	9,96	7,58	-11,48	38,72	9,9
Setor_5_74_97	280	287,27	12,49	10,89	6,66	19,98	3,88
Setor_5_74_16	280	76,44	1,82	1,27	-0,92	6,43	1,89

Source: Authors (2025).

In Sector 1, the variation in the line of occupation during the period 1974–1981 ranged from –0.5 to 3.5 m/year, with most shifts occurring between 0 and 1.5 m/year (Figures 3 and 4). During this period, the shoreline advanced towards the foreshore, associated with the presence of buildings and urban infrastructure close to the coastline. In the period 1974–1997, an even more significant advance was recorded in the same area. The displacement rates for this period ranged between 10 and 11.4 m/year, which were higher than those observed in the period 1974–1981, as shown in Figures 3 and 4. In contrast, during the period 1974–2016, a slight retreat of the building line was observed. Displacements ranged from -0.70 to -0.20 m/year, with the majority falling between -0.50 and -0.30 m/year.

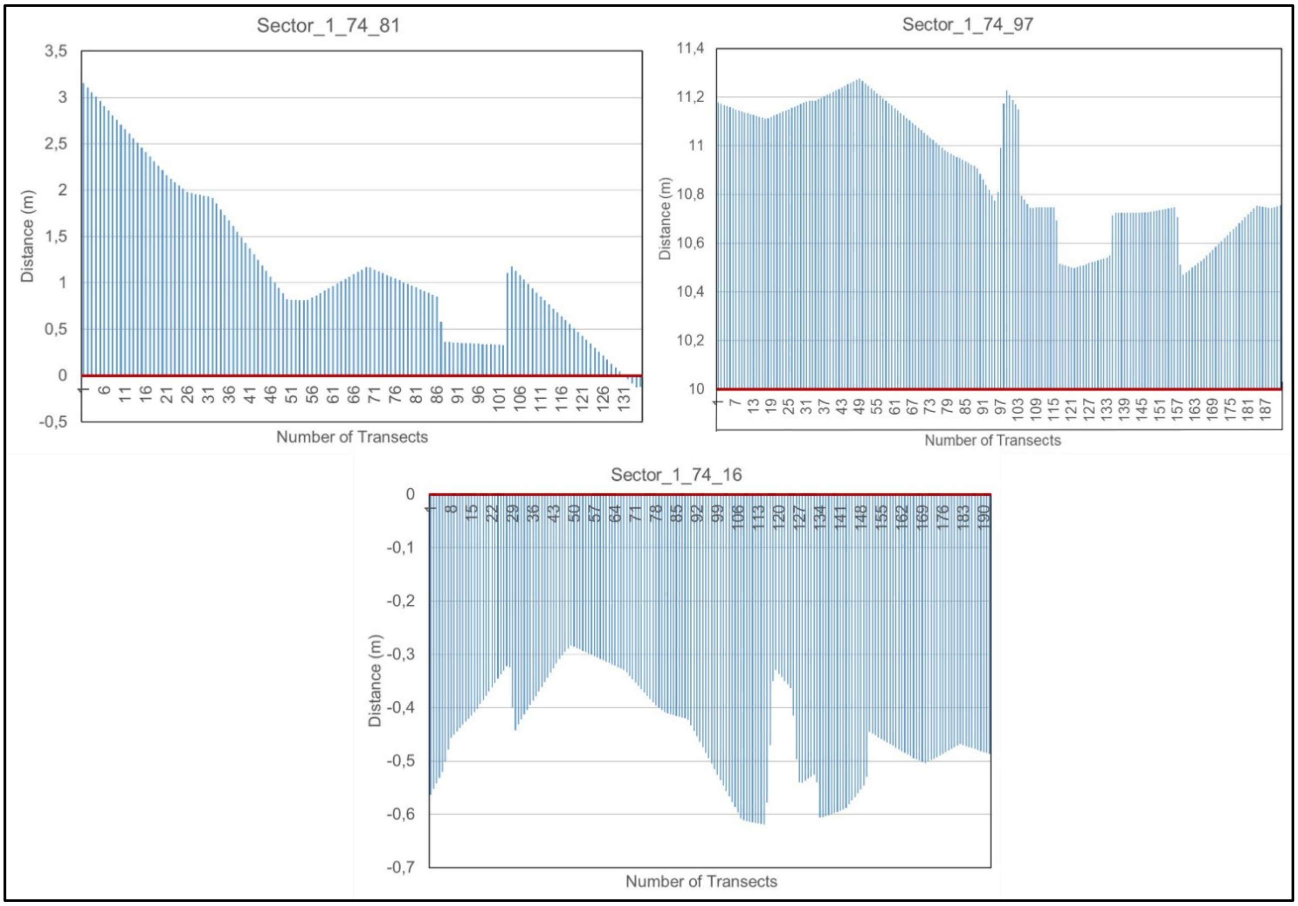

Figure 3 – Graph showing the distribution of shifts in the sector's employment trend for the periods 1974–1981, 1974–1997 and 1974–2016.
Source: Authors (2025).

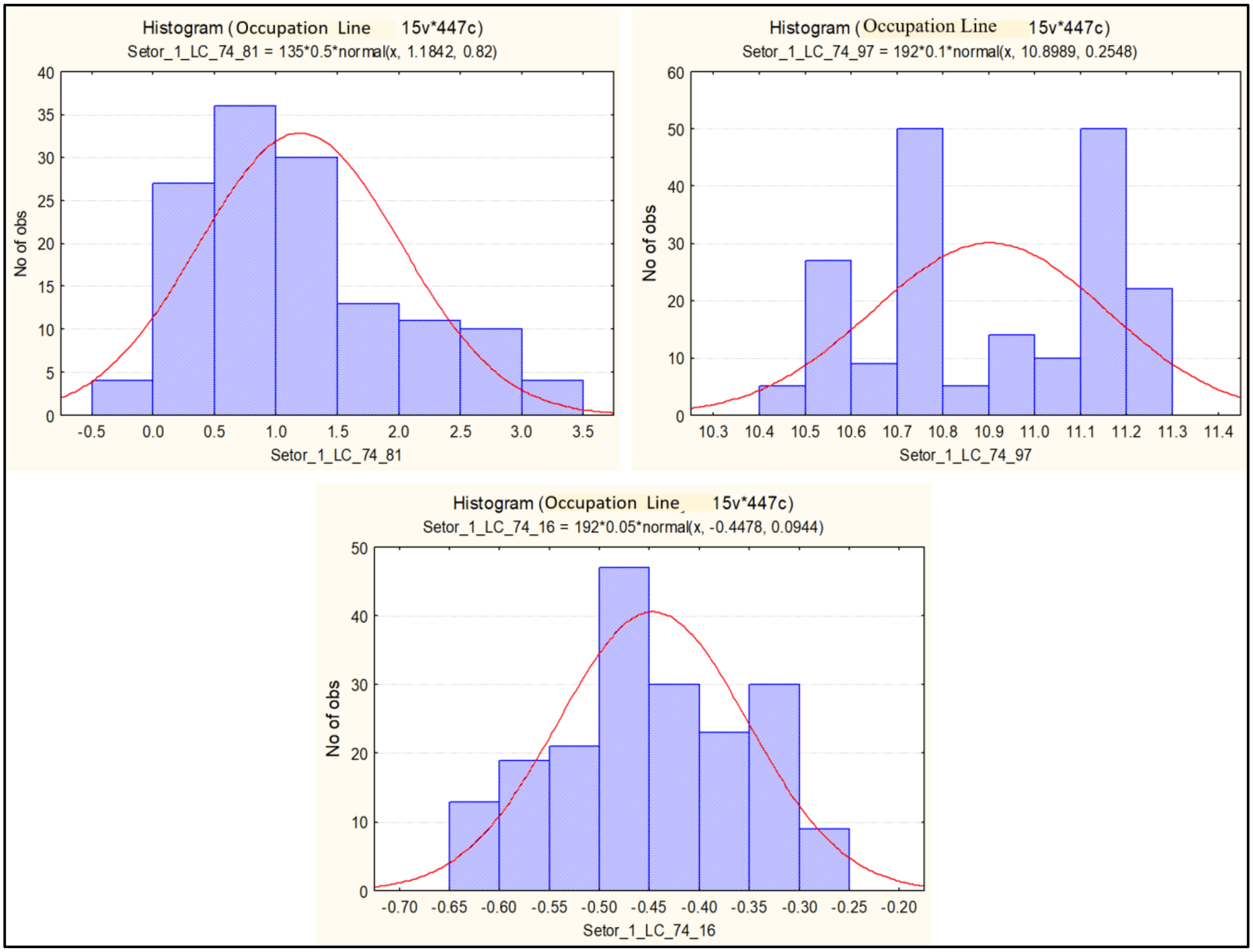

Figure 4 – Histogram of the rates of displacement of the occupation line in Sector 1 for the periods 1974–1981, 1974–1997 and 1974–2016.
Source: Authors (2025).

3.2. Sectors 2 and 3

Sector 2 is situated at the southernmost end of Candeias beach and extends for 1845 m. The results and average displacement distances are presented in Table 1 and Figures 5, 6 and 7.

During the period 1974–1981 (Figures 5a and 6a), there was a slight retreat of the building line in the northern part of the sector. As in Sector 1, the greatest average advance in Sector 2 was recorded during the period 1974–1997, at a rate of 10.97 m/year (Figures 5a and 6b). At the southern end of the sector, there was a slight retreat of the occupation line during the period 1974–2016, as shown in Figures 5a and 6c. In the central region, variations were observed, with both retreats and advances, in both onshore (retreat towards the mainland) and offshore (advance towards the sea) directions.

Analysis of the histogram (Figure 7a) indicates that the shifts in the occupation line for Sector 2 during the period 1974–1981 ranged from –6 m to 8 m/year, with the greatest concentration in two intervals: from -6 to -1 m/year and from -1 to 6 m/year, the latter being more indicative of the advance of the occupation. During the period 1974–1997, shifts in the occupation line ranged from 7 to 12 m/year, with rates predominantly between 9.5 and 12 m/year (Figure 7b), indicating a greater advance than in the previous period. Between 1974 and 2016, the variation in the occupation line ranged from -1.2 to 1.6 m/year (Figure 7c), with two clusters: the first between -0.8 and 0.4 m/year; the second between 0.4 and 1.6 m/year. These results indicate the coexistence of retreats and advances in the shoreline during this period, as shown in

Figure 7c, in contrast to what was observed in Sector 1, where no such variation was recorded, as the accretion of the exposed beach in Sector 1, which occurred between 2013 and 2015, allowed the shoreline to remain more stable.

Sector 3 is situated to the north of Candeias Beach (Figure 5c) and is 1,152.04 m long. The variation in the shift of the settlement line and the averages are shown in Table 1 and in Figures 5c, 6 (d, e, f) and 7 (d, e, f). Sector 3 showed a retreat of the shoreline to the south during the period 1974–1981, followed by advances in beach encroachment during the periods 1974–1997 and 1974–2016.

The average shift in the shoreline of Sector 3 over the period 1974–2016 ranged from –0.95 to 9.86 m/year, with extreme values ranging from –6.46 m to 12.53 m/year (Table 1). During the period 1974–1981, the average was –0.95 m/year, with retreats observed between –6.46 and 4 m/year (Figure 6d). The displacement rates fall into two groups: the first ranging from -7 to -1 m/year and the second from -1 to 4 m/year (Figure 7d), representing both retreat and advance in onshore and offshore directions.

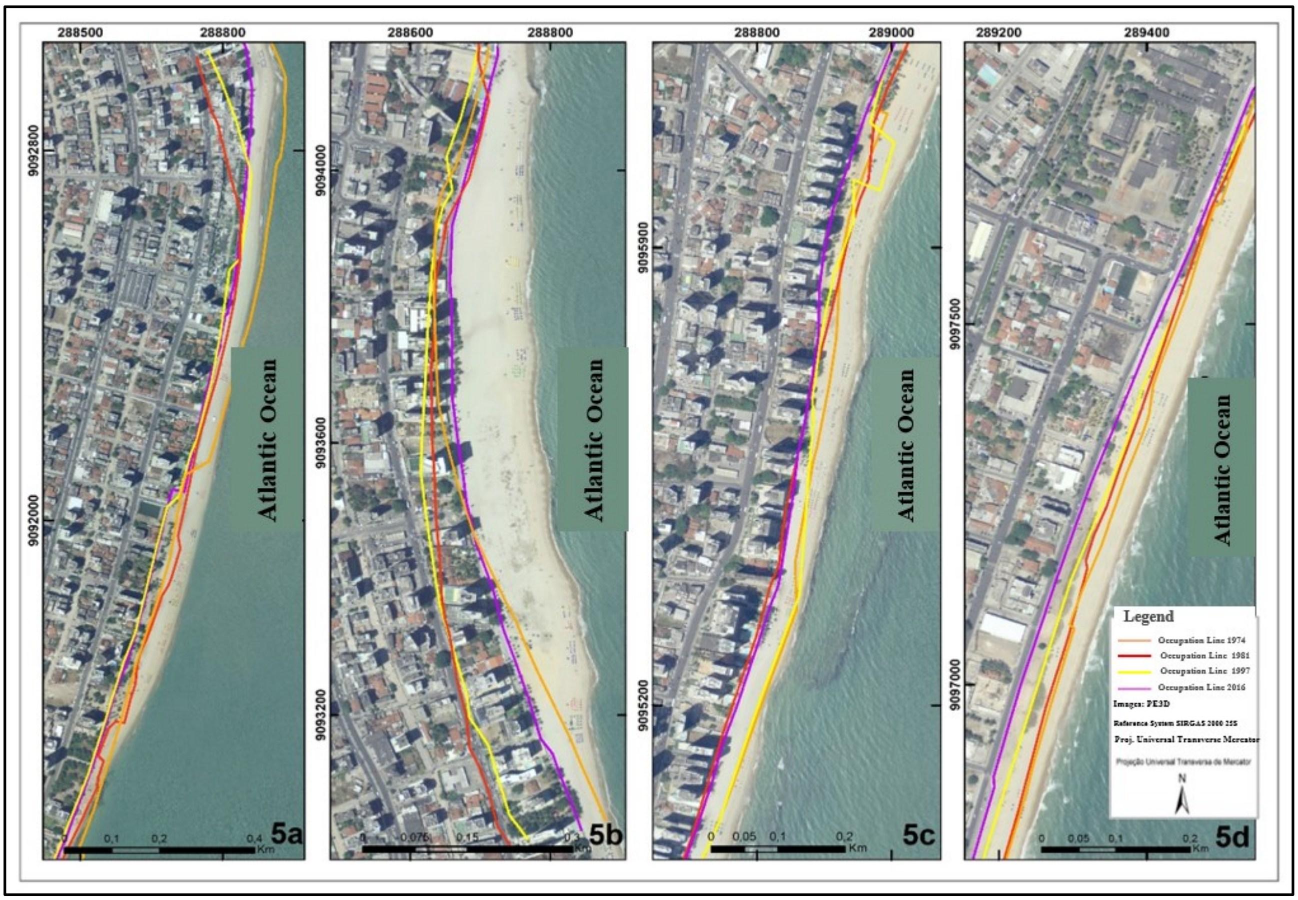

Figure 5 – Map of sectors 2 (5a), 3 (5b), 4 (5c) and 5 (5d) of the study area in 2016.
Source: Authors (2025).

During the period 1974–1997, the average rate of displacement of the occupation line was 9.86 m/year, with values ranging from 7 to 13 m/year (Table 1 and Figures 6e and 7e). A concentration was observed between 8 and 9.5 m/year, as well as between 9.5 and 12.5 m/year, confirming a significant advance, similar to that observed in the previous sectors. The period 1974–2016 also showed a positive average (2.28 m/year). The rates of displacement of the occupation line were concentrated between 0.5 and 5 m/year, with a concentration of average values between 0.5 and 2 m/year, and from 3 to 4.5 m/year (Figure 7f).

The average displacement of the occupation line in sector 3 during the period 1974–2016 ranged from –0.95 to 9.86 m/year, with extreme values ranging from –6.46 m to 12.53 m/year (Table 1). During the period 1974–1981, the average was –0.95 m/year, with retreats observed between –6.46 and 4 m/year (Figure 6d). The rates of displacement are concentrated in two groups: the first ranging from -7 to -1 m/year and the second from -1 to 4 m/year (Figure 7d), representing both retreat and advance in onshore and offshore directions. These data suggest that Sector 3 was not significantly influenced by the beach accretion at Jaboatão dos Guararapes that occurred in 2013, showing a less pronounced advance of the shoreline during the period 1974–2016, compared with the previous period.

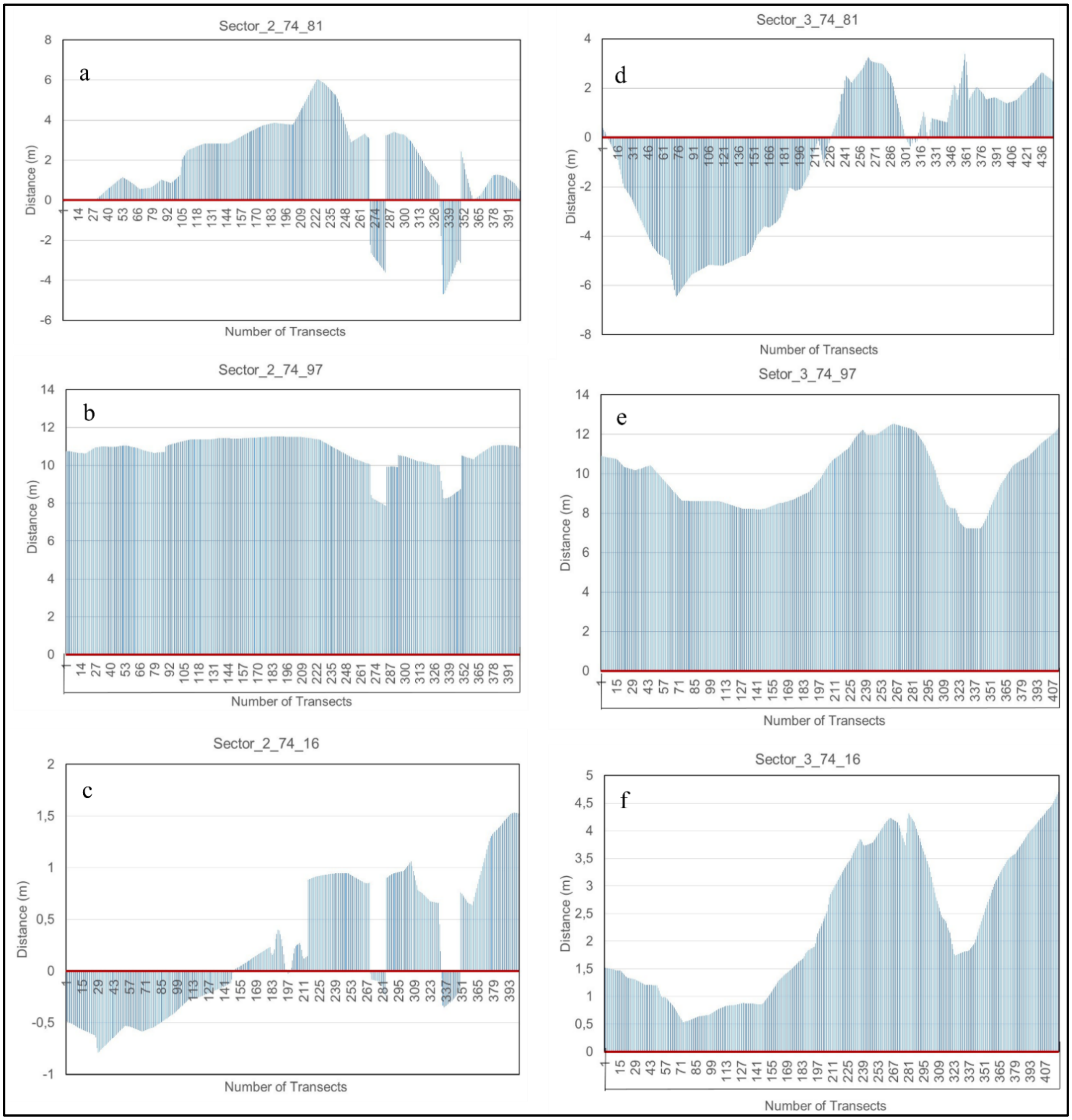

Figure 6 – Graph showing the distribution of the shift in the occupation line for sectors 2 (a, b, c) and 3 (d, e, f) for the periods 1974–1981, 1974–1997 and 1974–2016.
Source: Authors (2025)

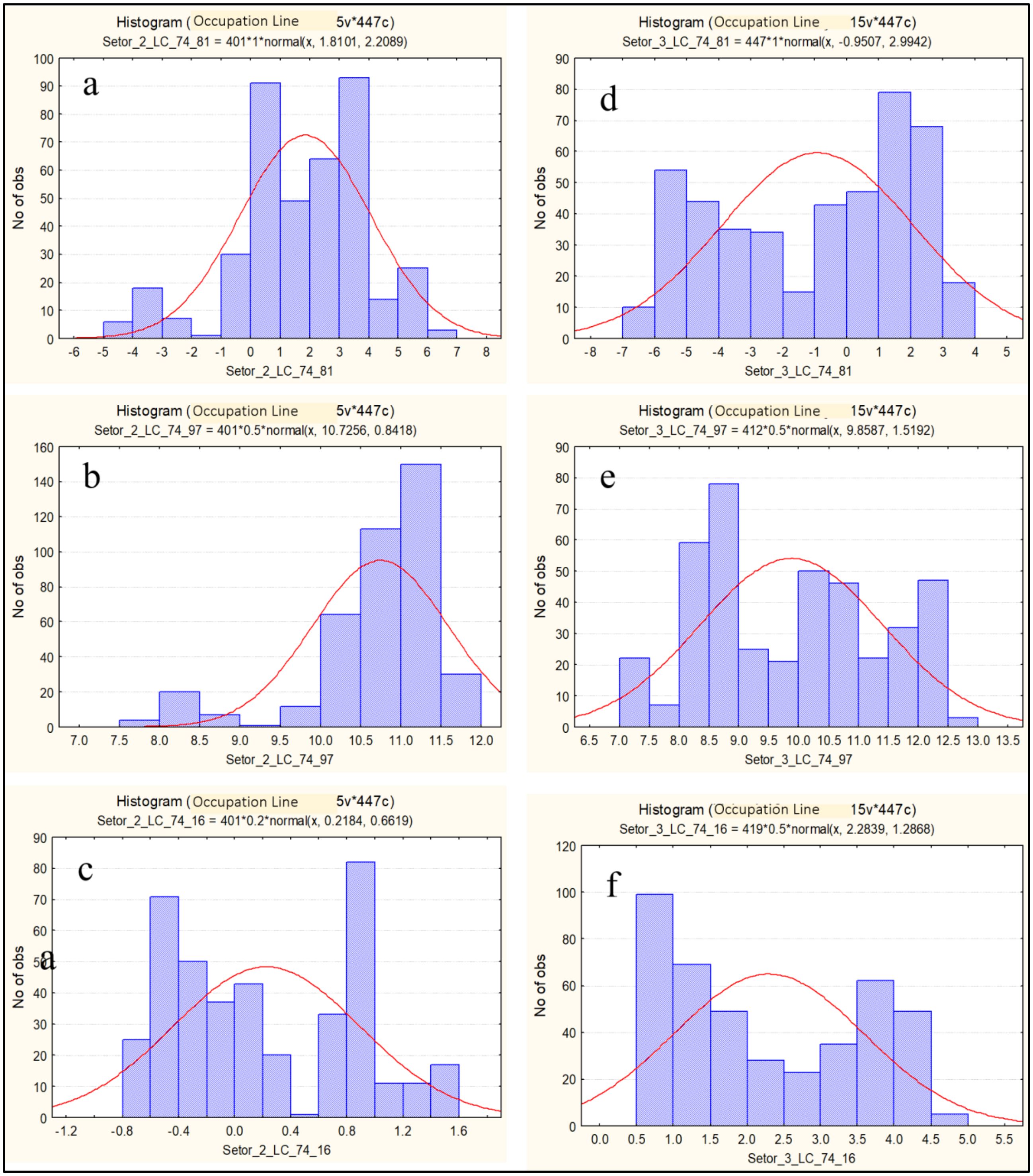

Figure 7 – Histogram of the average shift in the line of occupation for sectors 2 (a, b, c) and 3 (d, e, f) over the periods 1974–1981, 1974–1997 and 1974–2016.
Source: Authors (2025).

3.3 Sectors 4 and 5

Sector 4, located in the Piedade neighbourhood, corresponds to the southernmost part of Piedade Beach and extends for 2,379 m (Figure 5c). The distribution of the displacements of the shoreline is shown in Figure 8 (a, b, c), whilst the average rates of displacement are shown in Table 1 and Figure 9 (a, b, c).

The period 1974–1981, as in sectors 1, 3 and 5, showed the smallest displacement recorded during the monitoring period (6.02 metres). The highest average rate of shoreline displacement in this sector was recorded, as in all other sectors, during the period 1974–1997 (6.81 m/year). Research carried out by Santos Júnior (2017) and Santos Júnior et al (2020) on shoreline displacement in the study area, Sector 4, during the period 1974–1997, showed little variation between the average values of the shoreline displacement rates analysed. The authors observed positive average values, thus indicating a certain stability of the coastline, which may well have influenced and contributed to the advance of the building line.

According to the data in Figure 8a, there was a retreat of the building line in the southern part of Sector 4 between 1974 and 1981. However, during the period 1974–1997, there was a significant advance of buildings towards the beach environment (Figure 8b). During the period 1974–2016, a slight advance of buildings was observed in the southern part (Figure 8c).

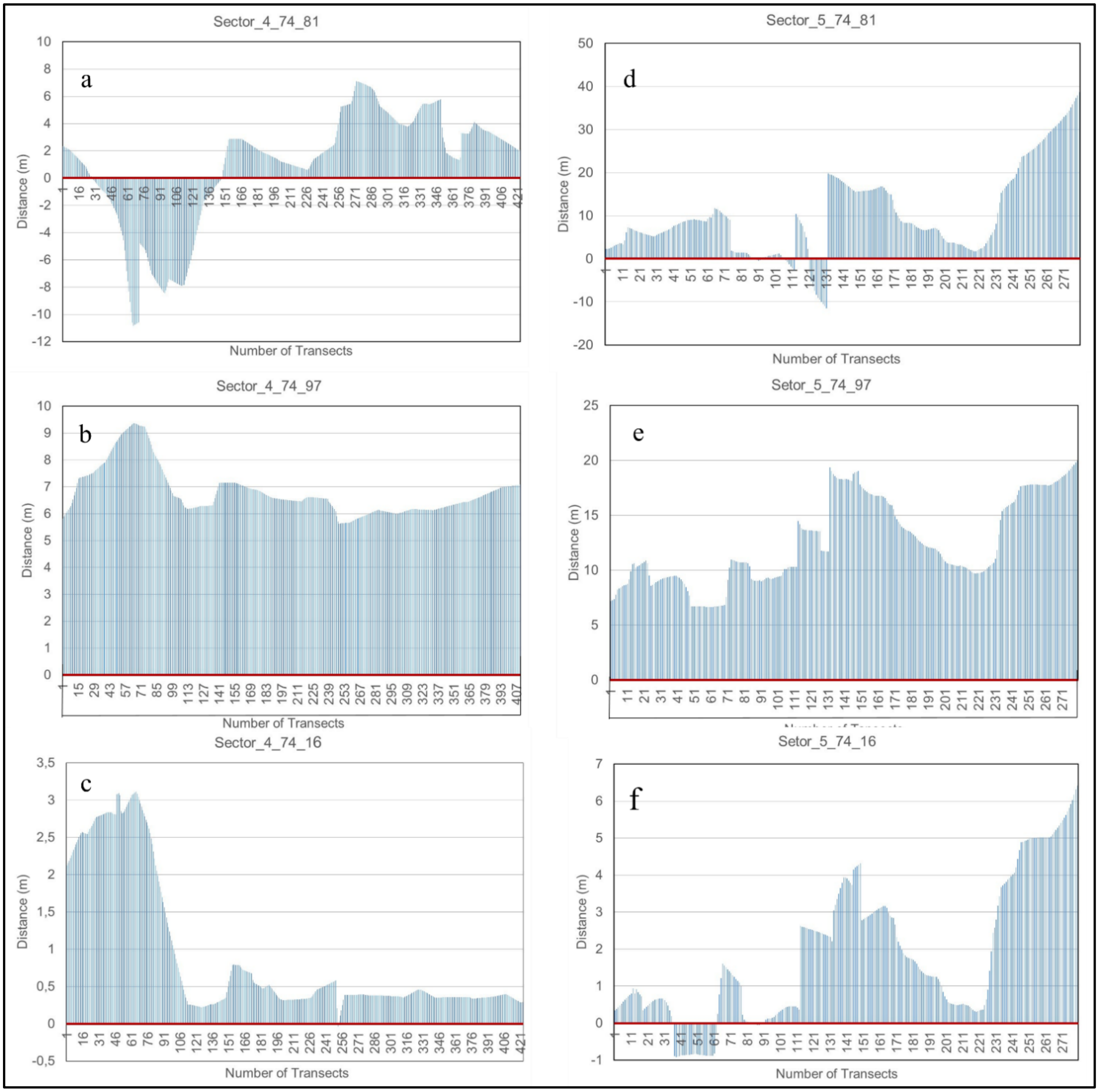

Figure 8 – Graph showing the distribution of the shift in the occupation line for sectors 4 (a, b, c) and 5 (d, e, f) over the periods 1974–1981, 1974–1997 and 1974–2016.
Source: Authors (2025).

Sector 5 is situated in the northern part of Piedade Beach and extends for 2,148 metres, as shown in Figure 5d. The average rates of displacement of the foreshore are shown in Table 1 and in Figures 8 (d, e, f) and 9 (d, e, f). This sector showed positive averages in all three periods analysed: 1974–1981, 1974–1997 and 1974–2016. The variation in occupation line displacements for the period 1974–1981 ranged from –12 m to 10 m/year (Figure 9a), with values predominantly between –2 and 8 m/year, indicating a higher frequency of advances than retreats. During the period 1974–1997, displacement rates were predominantly positive, ranging between 5 and 10 m/year, with most values falling between 5.5 and 7.5 m/year (Figure 9b).

For the period 1974–2016, displacement rates ranged from –0.5 to 3.5 m/year (Figure 9c), showing a narrower range and a higher concentration of values at 0 and 1 m/year. During this period, this sector showed a lower rate of advance of the shoreline compared with the previous period. It should be noted that this sector was also not included in the beach nourishment works.

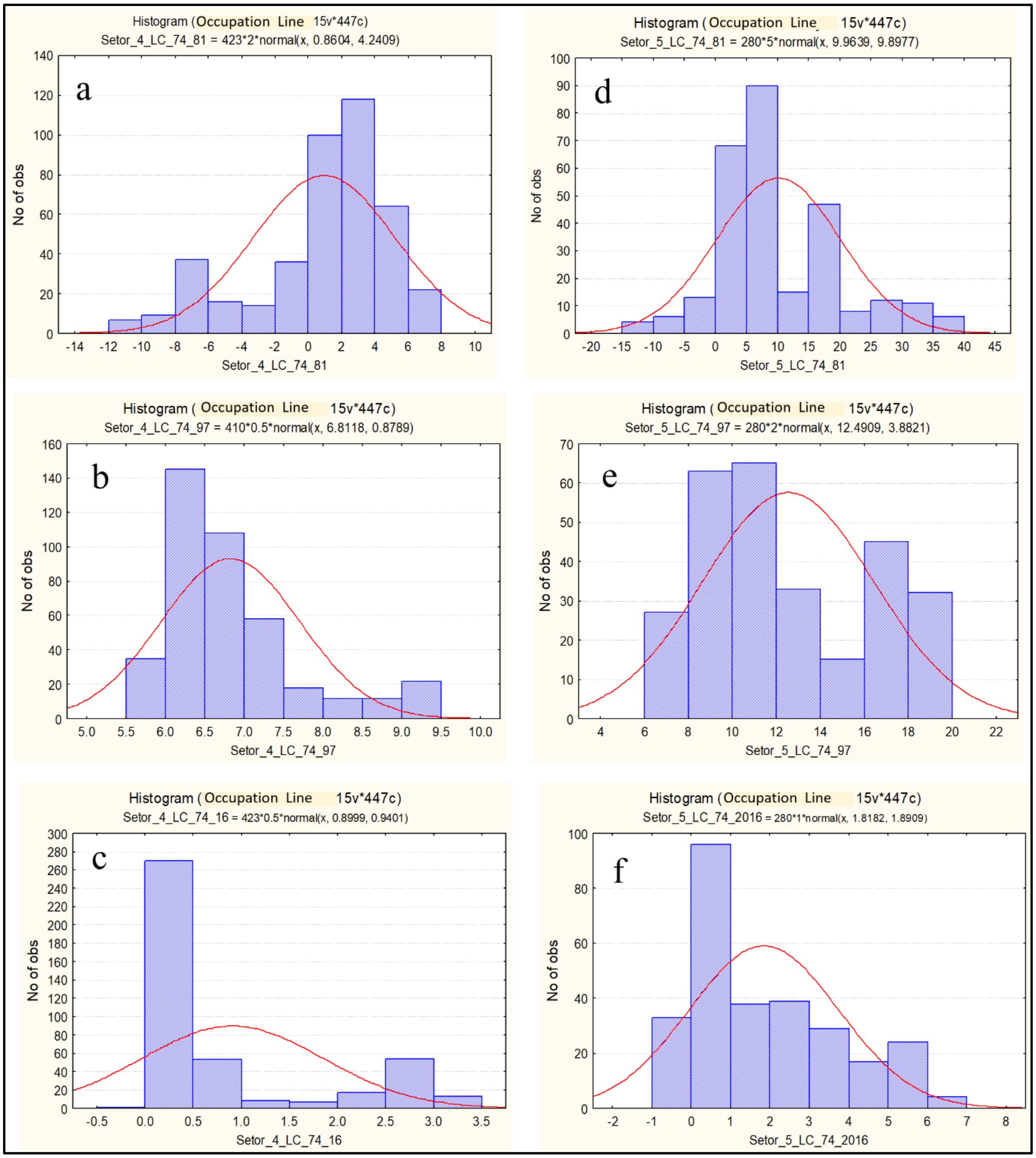

Figure 9 – Histogram of the rates of displacement of the occupation line in sectors 4 (a, b, c) and 5 (d, e, f) for the periods 1974–1981, 1974–1997 and 1974–2016.
Source: Authors (2025).

During the period 1974–1981, the minimum and maximum values observed were –11.48 and 38.72 m/year, with values predominantly concentrated between 0 and 20 m/year, as shown in Table 1. These data generally indicate an advance of the shoreline in the beach environment (Figures 8d and 9d). Nevertheless, in Figure 8d, isolated retreats were observed between transects 82 to 100 and 120 to 128, whilst the greatest advances were recorded from transect 244 onwards, at the southern end of the sector.

During the period 1974–1997, the average displacement of the shoreline was 6 to 22 m/year (Figures 8e and 9e), with the highest concentration of rates between 8 and 12 m/year (Figure 9e). During this period, all records indicated an advance of the occupation line, particularly in the central and northern regions of this sector. For all monitored periods, the most significant values were recorded, on a recurring basis, at the northern end, as shown in Figure 8 (d, e, f).

During the period 1974–2016, a retreat of the occupation line was observed between transects 37 and 63, whilst the greatest advances occurred from transect 244 onwards (Figure 8f). The average rates of shift in the settlement boundary ranged from –1 to 7 m/year, with the majority falling between –1 and 0 m/year (Figure 9f), revealing more modest advances in the settlement boundary compared with the period 1974–1997.

Following the 1930 revolution, the process of urbanisation and industrialisation gained new momentum in Brazil's coastal cities, promoting a pattern of settlement that triggered various environmental impacts, including the progressive reclamation of mangroves (MARICATO, 2001). According to data from the IBGE (2010), of the 45,731,614 inhabitants living in coastal areas in Brazil, just over 20 million were concentrated along the coast of the North-East region.

The Pernambuco coastline was, historically, one of the first in Brazil to be developed, having experienced rapid urban growth and a sharp rise in property values in recent decades. In the municipality of Jaboatão dos Guararapes, the development of the waterfront has been heavily influenced by the property market. The marked expansion of construction along the beachfront intensified with the rising value of coastal areas, a result of public policies that equated urbanisation with development, without taking into account the significant impacts such changes had on coastal ecosystems (SOUZA, 1996).

The evolution of land use in the study area is intrinsically linked to the increasing value of the coastal zone; after all, the more these urban spaces were valued, the more attractive they became, and consequently the more they were developed. NETO and BARBOSA (2020) analysed the changes in land cover within the Jaboatão River Water Bodies Conservation Zone in the Jardim Barra de Jangada housing estate (Sector 1) and found that in 1974, there were only natural features, such as vegetation and exposed soil, indicating that during this period, the region had not undergone significant human intervention. By 1981, there was occupation along the Barra de Jangada beachfront, but this occupation was still of low intensity when compared to the 1974 occupation line.

Between 1974 and 1981, Jaboatão dos Guararapes was one of the municipalities attracting the most people in the Recife metropolitan area, as a result of a series of government investments and the scarcity of available land for new developments along Recife's waterfront (SILVA, 2010). The Jaboatão dos Guararapes waterfront was already benefiting from Recife's extended infrastructure and attracting a clientele with greater purchasing power, with hotels, guesthouses and high-end residential properties.

Sectors 1, 2 and 4 showed, for the period 1974–1981, only a slight advance in the building line along the beachfront. This may indicate that anthropogenic pressure was less intense during this period; after all, much of the development that came to characterise the southernmost areas of the municipality was still in its early stages. Sector 5, located at the northernmost end of the study area, recorded the greatest average displacement, at 69.72 metres during this period. This phenomenon can be explained in part by the influence exerted on this sector by the neighbouring neighbourhood, Boa Viagem. Sector 5 came under significant pressure from construction companies and property developers during this period, as space for new developments was scarce in Recife, making the Piedade neighbourhood an extremely attractive location for new projects.

During the period 1974–1997, the socio-spatial configuration of the region already exhibited a much more complex urban morphology, distinct from that observed in 1974 (SILVA, 2017). The data for the period 1974–1997 revealed that the situation changed between the early 1980s and the late 1990s. There is no longer any retreat from the building line, when compared with the 1974 line. The trend towards encroachment became established in sectors 1, 2, 4 and 5, which had shown evidence of retreat in the previous period, and in sector 3, which showed the first signs of encroachment. Sector 5 exhibited the greatest average encroachment of the building line, continuing the trend observed in the previous period.

The significant increase in the data on the advance of the occupation line demonstrates that there was significant anthropogenic pressure on the coastal environment, coming from the south (sector 1) and the north (sectors 5 and 4). To the south of the study area, the main drivers of activity in these sectors were the port of Suape and the tourist attractions that had undergone redevelopment. To the north of the study area, the property market saw excellent profit opportunities in coastal developments in the neighbourhoods of Piedade and Candeias. The greatest encroachment was recorded in Sector 5, in the centre and at the northern end.

With regard to the period 1974–2016, it was possible to observe that the situation changed between the late 1990s and the end of the first decade of the 2000s. In sectors 1, 2 and 3, the process of humanisation is mainly linked to the construction of the road providing access to the Wilson Campos Bridge (Paiva Bridge), which has made access to the SUAPE complex easier by reducing the distance between it and the Recife Metropolitan Area by 40 km. According to NOGUEIRA (2015), the developments planned for high-income groups brought about a new configuration of the space along the Barra de Jangada waterfront, filling it with high-rise towers and intensive land use.

The dynamics of Jaboatão's beaches are characterised by constant transformation, and the intensification of coastal development is causing major changes to the municipality's coastal zone. SANTOS JÚNIOR et al. (2020), who studied the dynamics of the coastline over the last 42 years, showed that the erosion process had worsened on the beaches of Jaboatão dos Guararapes. Their findings revealed that, even following sediment transfer or beach nourishment, sediment was lost in sector 1 (Barra de Jangada beach) between 1974 and 1981 due to natural processes. These shifts in the coastline at Jaboatão dos Guararapes demonstrated that the solutions proposed to curb erosion in the region have so far been unsuccessful, as beach nourishment was carried out only on the emergent beach, without including the submerged zone of the profile. According to COSTA (2020), compared with 2013, the years 2015, 2016 and 2018 saw rates of retreat that were almost half the rate of advance compared to the period 1974–2013, at 199.901 m², 203.274 m² and 208.009 m² respectively. Each year, progradation decreased when compared to retrogradation, showing that the municipality's three beaches continue to suffer from constant sediment loss, even after beach nourishment.

Measures to tackle the impacts of coastal erosion are varied and can be categorised in terms of prevention or mitigation. Most mitigation measures consist of rigid structures built close to the shoreline, which are used to meet different needs and budgets. The major problem with most of these mitigation measures that use rigid structures is that they are built to solve a local problem and may even induce erosion in neighbouring areas, forcing public authorities and the affected communities to implement costly emergency measures (PAULA, 2015).

To tackle the effects of coastal erosion, one of the most widely adopted solutions internationally is beach restoration, which involves increasing sand reserves and restoring the balance of the beach environment, as this reduces the energy of storm waves and restores this habitat (NORDSTROM, 2010). Measures aimed at restoring the coastline and the natural conditions of beach ecosystems – such as the removal of buildings on the shoreline and the restoration of vegetation – can prevent coastal erosion from worsening or even occurring in the first place. Sustainable urban development in coastal areas also depends on maintaining a stabilised shoreline. To this end, public policies better suited to the integrated management of the coastal zone are required. Understanding the evolution of coastlines and land use is essential to support more efficient environmental management in the municipality of Jaboatão dos Guararapes.

4. Concluding remarks

Coastal erosion along the beaches of Jaboatão dos Guararapes has been exacerbated by population growth and the expansion of urban development in the coastal region. The results of this study showed that, amongst the periods analysed, the period from 1974 to 1997 saw the greatest encroachment of the built-up area onto the beach environment, a trend observed in all five sectors studied. Some of these impacts were subsequently mitigated by the artificial beach nourishment carried out in 2013.

The results highlight the need to incorporate the risks associated with beachfront development into coastal planning and management, in order to reduce socio-environmental vulnerability and prevent material losses resulting from erosion processes.

The use of geotechnologies proved effective in the spatiotemporal analysis of the evolution of the development boundary. The DSAS (Digital Shoreline Analysis System) tool, integrated with ArcGIS 10.1 software and developed by the United States Geological Survey (USGS), traditionally used for monitoring the shoreline, proved equally effective in identifying and analysing the line of occupation represented by urban infrastructure closest to and running parallel to the coast, thereby expanding its potential for application in coastal dynamics studies.

Despite the limitations relating to the quality of the older historical images, the methodology employed yielded satisfactory results. It is recommended that future research explore in greater depth the interaction between the coastline and the settlement line, with a view to informing more effective strategies for the planning, management and conservation of this complex coastal ecosystem.

In conclusion, the coastal zone is a complex, dynamic system with a variable morphology, and human settlement in this region is a factor contributing to its imbalance. Understanding changes to the coastline is essential for better management and demarcation of the coastal development boundary.

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