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An attempt to classify environmental aggressiveness in the city of Salvador - BA

Uma proposta de classificação da agressividade ambiental para a cidade de Salvador-BA


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Abstract

This paper presents a proposal for a classification of environmental aggressiveness in different areas of the city of Salvador, Bahia, Brazil. The work is based on the analysis of field data acquired in different areas of the city over the period of 2003 to 2007 and on the information obtained from designers and companies that perform mitigation actions in reinforced concrete structures. The occurrences of pathologies in reinforced concrete constructions which have suffered intervention in the city were used to identify the areas of the city with different degrees of environmental aggressiveness. Statistical analysis was carried out to identify the variables that most influence the intensity of the attack of the environmental agents on the reinforced concrete structures. Empirical equations are proposed and fitted to experimental results. Finally a map is drawn up considering the urban zone of the city of Salvador, classifying it into zones of different degrees of environmental aggressiveness. Despite being completely empirical work, whose derived equations are valid only to the specific case of Salvador-BA, the authors believe that this methodology could be used in other cities in Brazil with different characteristics, since it takes into account the particularities of each place.

Keywords: *environmental aggressiveness, classification, reinforced concrete, pathologies.*

Resumo

Este trabalho contém uma proposta de classificação da agressividade ambiental para a cidade de Salvador, a partir da análise dos resultados das pesquisas de campo efetuadas pelos autores em diversos bairros dessa capital, no período de 2003 a 2007, e de informações obtidas junto a projetistas e empresas de recuperação de concreto armado. Os estudos realizados visaram a identificar as regiões da cidade com maior número de ocorrência de patologias em edificações cujas estruturas sofreram intervenção. Os dados obtidos, após análise, foram utilizados como indicativos do grau de agressividade ambiental das diferentes áreas estudadas. Análises estatísticas foram realizadas no sentido de se avaliar as variáveis que mais influenciam na intensidade do ataque às estruturas de concreto armado pelos agentes ambientais em Salvador, e foram propostas equações empíricas para a previsão do grau de agressividade ambiental em diferentes pontos da cidade, em função das variáveis escolhidas. Como resultado final do trabalho, um mapeamento foi elaborado para a zona urbana da cidade, classificando-a em diferentes níveis de agressividade ambiental às estruturas de concreto armado. Apesar de se tratar de um trabalho empírico, cujos dados referem-se a uma cidade em particular, os autores acreditam que a metodologia empregada possa ser utilizada em outras cidades do Brasil, desde que sejam providenciadas as alterações pertinentes.

Palavras-chave: agressividade ambiental, classificação, concreto armado, patologias.

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1. Introduction

Environmental aggressiveness is normally the term utilized to describe the potential contribution of triggering substances of the oxidation processes (oxygen and chlorides, mainly) in reinforced concrete structures. On the other hand, the term corrosion, used until a short time ago to describe a specific type of metal deterioration, has been applied in a more wide-ranging form and nowadays it is understood as a degradation of materials (metallic and not metallic) by the action of the environment. In fact, certain types of decomposition of non metallic materials (for example, some problems that occur in concrete) follow mechanisms similar to those that occur in the corrosion of metals. (NUNES & DUTRA, 2006, p. 2).
Corrosion in concrete includes, specifically, the processes of deterioration that occur in the reinforcement components and some cases of the degradation of the cement paste itself. The steel parts are subject to the corrosion processes not only in structures exposed to the atmospheric conditions but also in the case of submerged and buried structures. Corrosive attack is in large scale facilitated by the transportation of the triggering substances of the corrosion process (ions of chlorides, for example) that are dissolved in the free interstitial water of the protective covering layer. Several phenomena are responsible for the transportation of these substances that finally reach the metal bars and the corrosive process is much facilitated the thinner the cement covering. Other characteristics of the covering layer concrete also play a prominent role, such as its permeability, water retention curve, its coefficient of diffusion and its absorption capacity. Besides this, sulphureous atmospheres can attack the cements rich in tri-calcium aluminato ($3CaO. Al_2O_3$) and, in this case, besides deteriorating the concrete these environments can expose the reinforcement to the atmosphere, intensifying the process of the degradation of the structure.
According to Silva (1995), the phenomenon of metallic corrosion was first observed in metal structures in marine environments. In the case of reinforced concrete, the conservation of the concrete alkalinity is one of the fundamental requirements for to the preservation of steel structures. It is accepted that the frontier for the beginning of the corrosion of the reinforcement is located approximately 8 mm more internally than the neutralization depth of the alkalinity, measured with the use of phenolphthalein. This would be, therefore, the limit of the penetration of the ions and of the substances that strengthen the process of corrosion during the lifetime of the structure.
It is important to point out that the occurrence of the phenomenon of the corrosion will be dependent of both concrete cover layer properties and environmental aggressiveness. Marine or sulphureous atmospheres for example, require the use of thicker concrete layers and/or the use of concretes of better quality concerning the protection against corrosion.
The NBR 6118 (ABNT, 2003) sets out in items 5,6 and 7 the general requirements of the structure quality and the evaluation of the project conformity, the guidelines for the durability of the concrete structures and the project criteria that aim to guarantee the minimum requirements of the cover layer. It is important to point out that the environmental influences should be foreseen and defined in consensus between the designer of the structural project and the owner of the construction. The referred standard defines the environmental aggressiveness as the physical and chemical actions

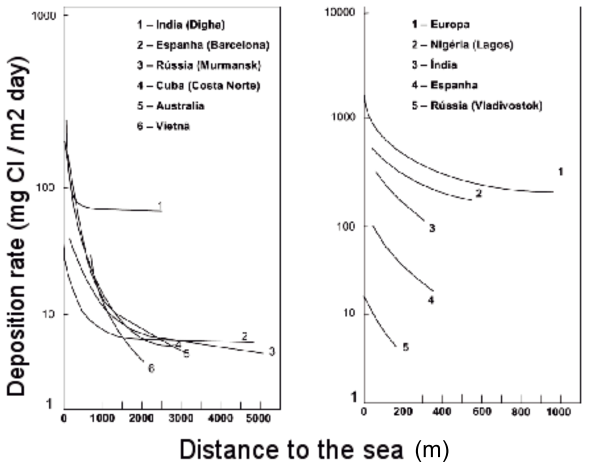
Table 1 – Levels of environment aggressiveness contemplated in NBR 6118

Level of environment aggressiveness	Aggressiveness	General classification of the type of environment for the purpose of the project	Risk of deterioration of the structure
I	Weak	Rural Submerged	Insignificant
II	Moderate	Urban 1), 2)	Little
III	Strong	Marine 1) Industrial 1), 2)	Big
IV	Very strong	Industrial 1), 3) Splash tide	Elevated

1) It is possible to have a micro environment with milder aggressiveness (a level above) for dry indoor rooms, bedrooms, bathrooms, kitchens, and service areas of residential apartments, and commercial suites or concrete covered rooms with plaster and painting.
2) It is possible to have a milder aggressiveness level (a level above) in constructions located in dry climate regions, with the relative humidity less than or equal to 65%, parts of the structure protected from rain in predominantly dry environments or areas where it rarely rains.
3) Chemically aggressive environments, industrial tanks, electroplating, industrial bleaching of pulp and paper, fertilizer warehouses, chemical industries.

Source: (ABNT, 2003)

Figure 1 – Behavior of the chloride deposition rate in function of the distance from the sea coast.



Source: Meira & Padaratz (2002)

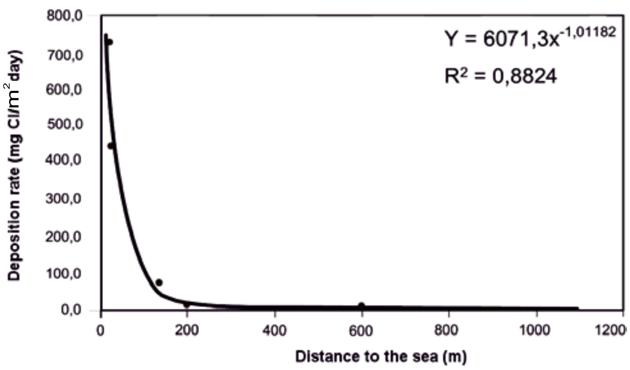
that impact concrete structures, independent of mechanical loads, thermal volumetric variations, or volume reduction due to hydration reactions. In the case of conventional structures, it is required that the environmental aggressiveness be classified according to Table 1. However, it is said that (item 6.4.3) if the professional responsible for the structural project detains enough knowledge about the environment in which the structure will be constructed, the classification can be considered more aggressive than the classification presented in Table 1.
Even though there are many papers in the specialized literature dealing with the problem of corrosion in reinforced concrete structures, it may said that one of the most difficult tasks faced by the designers after the publication of the NBR 6118 (ABNT, 2003) consists of defining the level of the environmental aggressiveness to which reinforced concrete is subjected and the correct thickness of the protection layer. This problem becomes more complex in the cases of coastline cities due to the formation and behavior of the marine aerosol. During the movement of marine aerosol toward the continent, its characteristics and its relation with atmospheric salinity are strongly influenced by several aspects, such as direction and speed of predominant winds, distance from the coast, local topography, altitude, etc. (MORCILLO, 1998). All these variables influence the deposition rate and consequently the decay curve of chloride concentration in function of the distance from the coast (MEIRA & PADARATZ, 2002).
Deposition of the saline particles is stronger in the first hundred meters away from coast and decreases with the distance from the sea. The deposition processes is caused mainly by the gravitational effects and by the impact of the particles in suspension with the soil surface and obstacles to the movement of the marine aerosol (FELIU & MORCILLO, 1999). Therefore it can be said that this behavior is peculiar to each region, with fluctuations over time. However, accordingly to Feliu & Morcillo, (1999) "*the influence of the distance to the sea constitutes the most important aspect in the study of corrosion in marine environments*". Meira & Padaratz (2002) came to similar conclusions. Figure 1 illustrates the experimental results obtained by Meira & Padaratz (2002).
Costa (2001) presents results obtained in an experimental study carried out in Salvador, Bahia. It was observed that the average chloride deposition rate in the first three stations used in his research (maximum distance of 500 m) is approximately 8 times higher than the obtained results in the other six stations located more than 500 meters from coast. Table 2 shows the chloride deposition rates obtained by the author. The wet candle method was adopted and the sampling period was five months. The chloride contents were obtained by ionic chromatography.

Table 2 – Chloride deposition rates obtained in Salvador, Bahia

Neighborhood	Distance to the sea (m)	Deposition rate (mg C l/ m² day)	
		Average	Standard Deviation
Flamengo	71,60	46,20	18,80
Flamengo	137,60	9,30	3,80
Itapuã	143,40	21,10	23,50
Itapuã	531,90	4,20	1,50
Placaford	787,70	2,90	1,40
Arembepe	1165,40	2,60	1,50
Stela Mares	2225,50	4,60	1,00
Buraquinho	2645,00	1,80	0,80
Piatã	4704,70	3,70	5,80

Source: Costa (2001)

Figure 2 – Experimental profile obtained for the chloride deposition rate in function of the distance from the sea shore in João Pessoa - PB



Source: Meira & Padaratz (2002)

Figure 2 shows the chloride deposition rates obtained by Meira & Padaratz (2002) in the marine atmospheric zone of João Pessoa. The experimental procedures were based on ASTM G140, (1996). The experimental period was from November 2001 to March 2002. The results indicate a sharp decrease in the chloride deposition rate with distance from the coast. After one kilometer the experimental values are very low compared to the points located less than 100 meters from the sea. Table 3 presents data of chloride deposition rates obtained in João Pessoa by the same authors.

This paper presents the main findings of the field research campaign performed by Vilasboas (2004) in various neighborhoods of Salvador, Bahia. The regions of the city with the highest number of performed repair activities in reinforced concrete structures were identified. The obtained data was analyzed and used as an indication of the level of environmental aggressiveness of each area studied. Statistical analysis was performed in order to identify the main variables affecting the chloride deposition rates. These variables were used in the development of empirical equations to predict the level of environmental aggressiveness in different points of the city.

2. Materials and methods

The experimental work consisted of a field investigation of the reinforced concrete structures which presented pathological manifestations due to corrosion processes and which had been effectively submitted to repair. It must be therefore emphasized that this work is not based on the total number of pathological manifestations in one specific area, rather it considers only the cases where the pathological manifestations in the structures were sufficiently serious to motivate their owners to contract mitigation activities. The authors believe that the real number of pathologies in the field is by far superior to the numbers presented in this paper.

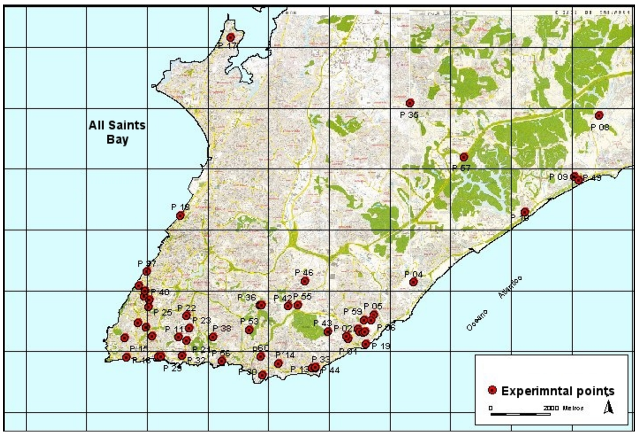
The the first step of the methodology used was to improve the database obtained by Villasboas (2004). These improvements included not only the increase in the numbers of pathology cases but also improved the quality of the previous information: new cases of structural repair were catalogued, and all the case studied had their UTM coordinates, elevation and distance from the sea measured. Attention was also given to the relative position of the building with regard to the All Saints Bay and the North coast. Other information such as the quantity of houses, number of inhabitants and the average family income of each area of the city were obtained from the census carried out in 2000 by the Brazilian Institute of Geography and

Table 3 – Some values of chloride deposition rate obtained in João Pessoa-PB

Distance	Deposition rate (mg Cl/m² day)					
Distance (m)	November	December	January	February	March	Average
10	639,92	729,16	483,56	412,45	438,61	540,74
100	187,95	213,51	74,48	69,70	80,68	125,26
200	13,16	13,27	9,85	12,60	20,59	13,89
500		9,85	8,92	13,04	15,17	11,74
1100				5,88	6,02	5,95

Source: Meira & Padaratz (2002)

Figure 3 – Location of the buildings used in this research. Salvador - BA



Statistic (IBGE). During the data analysis and classification of environmental aggressiveness stage, it was also necessary to ascertain the total superficial area of each region used in the work. This was done with the aid of the Company of Urban Development of the State of Bahia (CONDER).

Figure 3 presents all the registered points (cases of mitigation activities performed) used in this study. After preliminary statistical treatment of the obtained (use of correlation coefficients and fitting of multivariable functions), the following variables were chosen as those most directly related to the cases of pathology in reinforced concrete structures in Salvador: the altitude of the construction, its distance from the coast and its relative position to the coast/All Saints Bay. The value of +1 was given to the buildings next to the North coast as they are more exposed to the SE-NW wind coming from sea. A value of 0 was given to the buildings located half way from North coast and All Saints Bay. A value of -1 was attributed to the buildings located near to All Saints Bay .

Besides the variables listed above the average income or the income ratio of the region (see Table 4) was take into account in the performed analysis. The income ratio was defined as the ratio between the average family income of the area and the average family income of The Metropolitan Region of Salvador (R$ 1,220.00 according to the IBGE 2000 Census). This variable, while not associated to the phenomenon in question, was used in order to consider the fact that the wealthier population is more inclined to perform repair activities on their buildings.

The altitude and the distance from the coast were normalized by the maximum elevation (119 meters) of the city of Salvador. Table 4 presents a summary of the geographical and social characteristics of each region used in this research. Table 5 presents the original data obtained for each building catalogued.

The data presented in Figure 3 was treated in order to obtain the density of pathologies around each experimental point. In order to do this, the number of buildings found in a radius of 2 km was calculated, which is equivalent to an area of 4π km². The obtained values are also presented in Table 5. The calculated densities of pathologies were normalized using the data presented in Table 4 (neighborhood area and number of residences). The normalized values are presented in Table 6. For a better visualization, the obtained values were multiplied by 1,000 in such a way that the presented data correspond to the number of cases for each thousand homes. Figure 4 shows the location of the main regions of the city.

Table 4 – Data for the neighbourhoods with the occurrence of mitigation actions catalogued

Neighborhood	Área km²	Residences	Average income R$	Average income (-)
Amaralina	1,14	7514	1576,00	1,29
Armação	3,09	8530	3263,00	2,68
Barra	1,07	5299	3805,00	3,12
Brotas	3,22	14150	1830,00	1,50
Canela	0,91	4283	4752,00	3,90
Federação	0,83	5381	888,00	0,73
Imbuí	2,31	5918	2948,00	2,42
Itaigara	3,77	6854	7241,00	5,94
Jardim Apipéma	0,75	4099	4784,00	3,92
Ondina	2,68	6008	2468,00	2,02
Piatã, Patamares, Jaguaribe	17,41	7085	2996,00	2,46
Pituba	4,28	14615	4511,00	3,70
Ribeira	0,91	4283	950,00	0,78
Rio Vermelho	1,38	8899	3110,00	2,55
Sussuarana	7,12	12979	719,00	0,59
Vitória	0,91	4283	4752,00	3,90

Source: Modified data from IBGE (2000) and from the database of SICAR/CONDER

Table 5 – Primary data obtained for the analysis

Neighborhood	UTM Coordinates		Density of Pathologies (un/km²)	Elevation (m)	Distance to the sea (m)	Wind direction
Amaralina	557454	8561444	1,19	12	209	1
Amaralina	557566	8561482	1,35	20	217	1
Amaralina	557571	8561468	1,35	22	164	1
Amaralina	557572	8561482	1,35	19	217	1
Armação	560800	8564278	0,40	20	495	1
Av. Sete - Vitoria	551717	8562948	1,59	27	683	-1
Barra	551338	8561812	0,95	10	30	0
Barra	551275	8562437	1,27	45	247	0
Brotas	555792	8563528	0,88	57	2992	0
Brotas	557209	8564318	0,64	62	2970	0
Brotas	555739	8563518	0,80	57	3028	0
Brotas	555391	8562716	1,03	48	1300	0
Cais - Baia de Todos os Santos	553109	8566473	0,24	5	1	-1
Campo Grande - Vitória	551950	8563986	1,19	62	436	-1
Campo Grande - Vitória	551745	8564176	1,03	55	88	-1
Candeal - Brotas	556653	8563498	0,88	32	2333	0
Canela	552088	8563700	1,43	65	738	-1
Canela-Ufba Belas Artes	551926	8563809	1,19	67	400	-1
Canela-Ufba Instituo de Ciências da Sáude	552061	8563455	1,59	35	791	-1
Cardeal Da Silva - Federação	554197	8562483	1,19	50	92	1
Centenário	551982	8562786	1,59	18	1010	1
Federação	553045	8562464	1,59	45	1576	1
Itaigara	556974	8563538	0,80	32	2202	0
Itaigara / Pituba	557963	8562660	1,67	20	940	1
Jaguaribe*	566247	8567639	0,32	10	109	1
Jardim Namorados - Pituba	559226	8562251	1,35	5	20	1
Ondina	552455	8561850	1,35	10	112	1
Ondina	555815	8561236	0,88	7	109	1
Ondina	552369	8561848	1,35	10	126	1
Ondina	553159	8561866	1,35	5	77	1
Ondina- Ufba CPD	553394	8562768	1,51	19	1146	1
Ondina- Ufba Veterinária	553317	8562346	1,27	10	712	1
Paralela - Imbuí	562453	8568388	0,24	35	2876	0
Patamares	564472	8566582	0,32	5	135	1
Piatã	566901	8569746	0,24	5	1910	1
Piatã	566094	8567739	0,40	10	94	1
Pituba	559173	8563036	1,03	15	761	1
Pituba	559187	8562646	1,27	15	365	1
Pituba	559402	8563033	1,11	15	227	1
Pituba	558962	8562727	1,35	15	605	1
Pituba	559025	8562638	1,35	16	500	1
Pituba	558648	8562422	1,35	29	297	1
Pituba	558567	8562506	1,43	10	461	1
Pituba	559132	8562608	1,27	28	397	1
Pituba	559476	8563209	1,11	15	383	1
Ribeira (Igreja)*	554754	8572324	0,24	3	30	-1
Rio Vermelho*	555759	8561846	1,19	5	706	1
Rio Vermelho	556339	8561610	1,11	15	393	1
Rio Vermelho	554463	8561682	1,03	22	60	1
Sussuarana	560671	8570152	0,24	78	4835	0
Viaduto do Contorno	552009	8564630	0,88	15	10	-1
Jardim Apipéma	552164	8562499	1,51	30	630	0
Federação- Ufba Arquitetura	553321	8563174	1,59	57	1806	1

Source: Data obtained by the authors with the aid of the database from SICAR/CONDER

Table 6 – Table 5 data after normalization

Neighborhood	UTM Coordinates		Density of Pathologies X 10^{-3} (-)	Elevation (-)	Distance to the sea (-)	Wind direction
Amaralina	557454	8561444	0,181	0,101	1,378	1
Amaralina	557566	8561482	0,205	0,168	1,824	1
Amaralina	557571	8561468	0,205	0,185	1,756	1
Amaralina	557572	8561482	0,205	0,160	1,824	1
Armação	560800	8564278	0,144	0,168	4,160	1
Av. Sete - Vitoria	551717	8562948	0,338	0,227	5,739	-1
Barra	551338	8561812	0,193	0,084	0,252	0
Barra	551275	8562437	0,257	0,378	2,076	0
Brotas	555792	8563528	0,199	0,479	25,143	0
Brotas	557209	8564318	0,145	0,403	10,924	0
Brotas	555739	8563518	0,181	0,479	25,445	0
Brotas	555391	8562716	0,235	0,521	24,958	0
Cais - Baia de Todos os Santos	553109	8566473	0,067	0,042	0,008	-1
Campo Grande - Vitória	551950	8563986	0,254	0,521	3,664	-1
Campo Grande - Vitória	551745	8564176	0,220	0,462	0,739	-1
Candeal - Brotas	556653	8563498	0,199	0,269	19,605	0
Canela	552088	8563700	0,304	0,546	6,202	-1
Canela-Ufba Belas Artes	551926	8563809	0,254	0,563	3,361	-1
Canela-Ufba Instituto de Ciências da Sáude	552061	8563455	0,338	0,294	6,647	-1
Cardeal Da Silva - Federação	554197	8562483	0,184	0,420	0,773	1
Centenário	551982	8562786	0,321	0,151	8,487	1
Federação	553045	8562464	0,245	0,378	13,244	1
Itaigara	556974	8563538	0,438	0,269	18,504	0
Itaigara / Pituba	557963	8562660	0,919	0,168	7,899	1
Jaguaribe*	566247	8567639	0,782	0,084	0,916	1
Jardim Namorados - Pituba	559226	8562251	0,396	0,042	0,168	1
Ondina	552455	8561850	0,603	0,042	0,647	1
Ondina	555815	8561236	0,390	0,084	0,941	1
Ondina	552369	8561848	0,603	0,059	0,916	1
Ondina	553159	8561866	0,603	0,084	1,059	1
Ondina- Ufba CPD	553394	8562768	0,674	0,160	9,630	1
Ondina- Ufba Veterinária	553317	8562346	0,568	0,084	5,983	1
Paralela - Imbuí	562453	8568388	0,093	0,294	24,168	0
Patamares	564472	8566582	0,782	0,042	1,134	1
Piatã	566901	8569746	0,587	0,084	0,790	1
Piatã	566094	8567739	0,978	0,042	16,050	1
Pituba	559173	8563036	0,303	0,126	1,908	1
Pituba	559187	8562646	0,373	0,126	6,395	1
Pituba	559402	8563033	0,326	0,126	3,067	1
Pituba	558962	8562727	0,396	0,244	2,496	1
Pituba	559025	8562638	0,396	0,134	4,202	1
Pituba	558648	8562422	0,396	0,126	5,084	1
Pituba	558567	8562506	0,419	0,084	3,874	1
Pituba	559132	8562608	0,373	0,235	3,336	1
Pituba	559476	8563209	0,326	0,126	3,218	1
Ribeira (Igreja)*	554754	8572324	0,051	0,025	0,252	-1
Rio Vermelho*	555759	8561846	0,185	0,042	5,933	1
Rio Vermelho	556339	8561610	0,173	0,126	3,303	1
Rio Vermelho	554463	8561682	0,160	0,185	0,504	1
Sussuarana	560671	8570152	0,131	0,655	40,630	0
Viaduto do Contorno	552009	8564630	0,186	0,126	0,084	-1
Jardim Apipéma	552164	8562499	0,277	0,252	5,294	0
Federação- Ufba Arquitetura	553321	8563174	0,245	0,479	15,176	1

Source: Data obtained by the authors with the aid of the database from SICAR/CONDER and from the results of the IBGE census (2000)

3. Results and analysis

3.1 Choice of the polynomial function

When analyzing Figure 3 it is possible to observe that most of the repair activities were performed near the coast. Only a few cases are located near the All Saints Bay. It is believed that two factors contributed to this: the location of the buildings themselves and the different social characteristics of these areas (coastal residences are normally inhabited by people with a higher income)

The areas with a higher incidence of repair are areas with high incomes, such as Barra, Vitória, Pituba, etc. The authors believe that in such areas if there is a pathology the motivation of the owner to fix the problem, considering similar cases, will be higher than that of owners living in lower income neighbourhoods. As said before, the number of buildings which have carried out repairs should be much smaller than the number of pathological manifestations that actually exist in the field. In the case of high income areas, this

Figure 4 – Location of the main neighborhoods of the city of Salvador – BA

Source: Modified from <http://pt.wikipedia.org/wiki/ File: Bairros_de_Salvador.png>

$$N = a_0 + a_1.x_1 + a_2.x_2^{1/3} + a_3.x_3^{-1/10} + a_4.x_4^{1/2} + a_5.x_2^{1/3}.x_3^{1/10} + a_6.x_2^{1/3}.x_4^{-1/2} + a_7.x_3^{1/10}.x_4^{-1/2} \quad (1)$$

distortion tends to be smaller and the number of repair services and pathological manifestations tends to be closer. However, if the average income of the area is low, just the opposite may occur. Therefore, even though the average income of the area does not influence the corrosion process of the reinforced concrete structures, it can influence the analysis of the experimental data and its influence should not be ignored.

The SE-NW winds in the region under study also play an important role in the occurrence of corrosion problems in reinforced concrete structures. Residences located near the coast suffer more intensely from the action of marine *spray* than those near the Bay of All Saints. Figure 5 shows the density of pathologies results of Table 6 interpolated in the urban space of Salvador. The obtained values were represented by a transition of colors ranging from blue, representing a density of pathologies of zero, to the red: the highest density of occurrences found (1.67 un/km²).

The obtained values of density of pathologies were used to find an empirical function able to reproduce the field behavior presented in Figure 5. The minimum squares method was used to fit the trial equations. The following variables were used: the normalized income of the area, the normalized elevation and distance from the sea and the relative position of the building considering the north coast and the All Saints Bay. After several attempts at using different types of functions, equation 1 was selected to reproduce the data obtained in the field. It is a highly nonlinear empirical function, and the validity of the obtained fitting coefficients are restricted to the area studied. Thus, although it is believed that equation 1 is very useful, its use requires attention and precaution by the designers as the obtained values in this paper are influenced by a great number of variables that modify the environmental aggressiveness of the area.

Other variables, such as wind speed or even the concentration of chlorides in the marine spray were not incorporated into the analysis

Figure 5 – Contours of density occurrence of the pathologies for the cases studied in the area of Salvador-BA

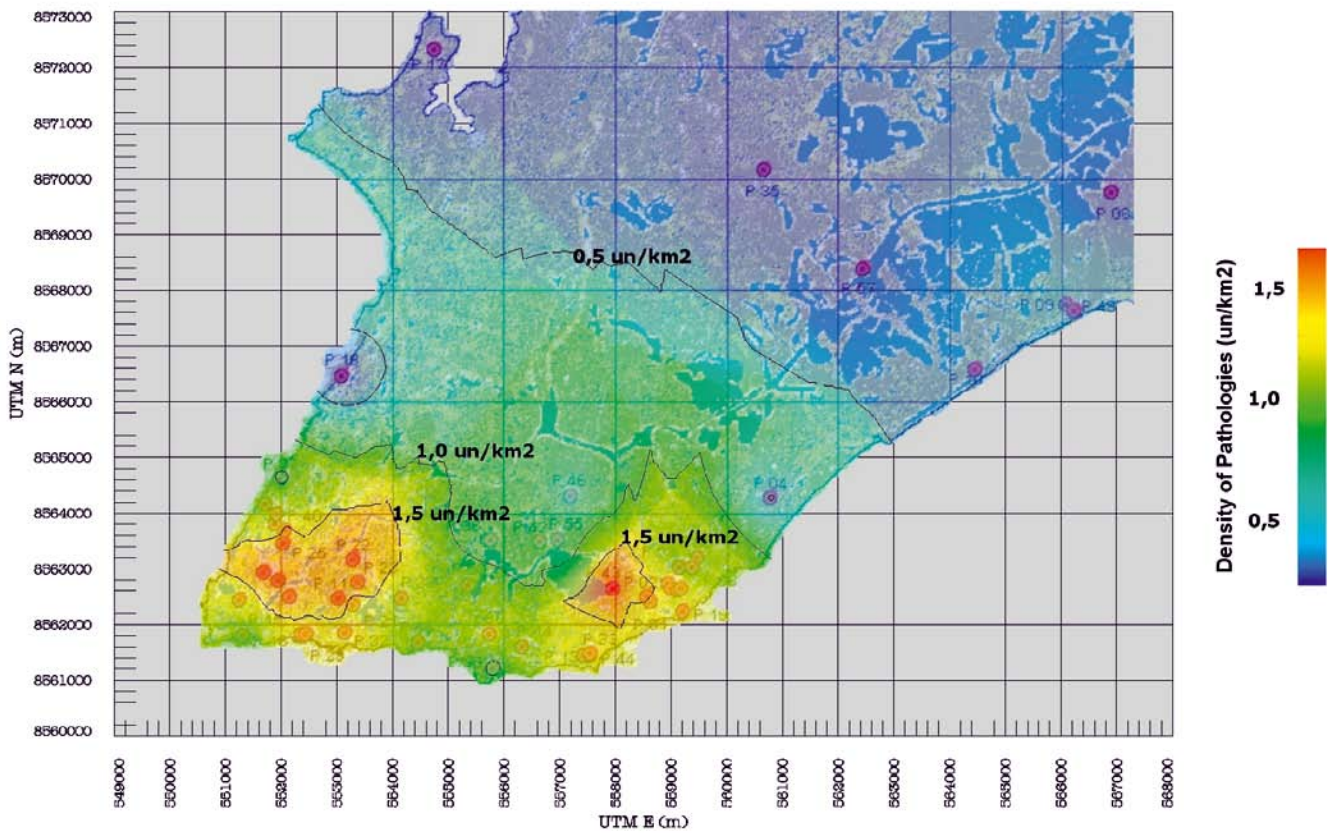


Figure 6 – Obtained and predicted results with the use of equation 1, considering all the points studied

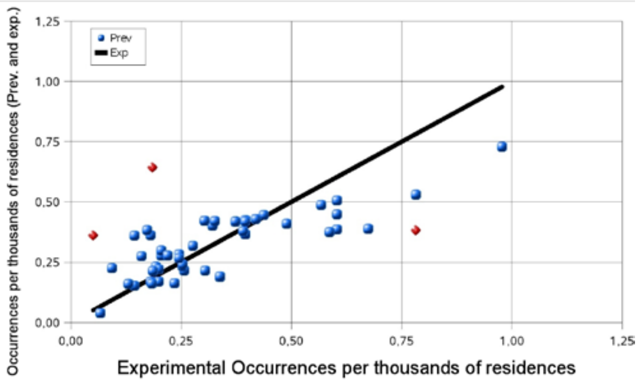
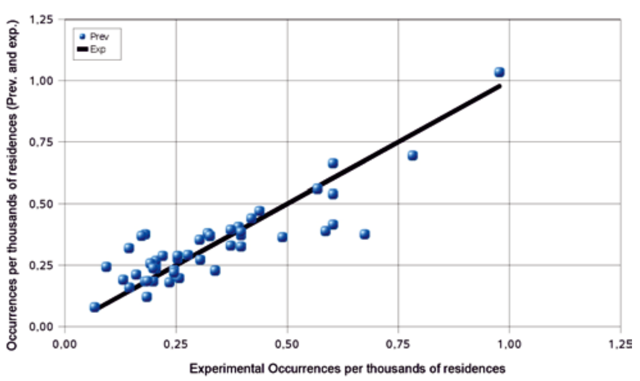


Figure 7 – Obtained and predicted results with the use of equation 1, after removing the points highlighted in Tables 5 and 6



because of the difficulties in obtaining experimental data and/or its little influence on the experimental results obtained (Equation 1).

Where:

N is the number of occurrences per thousand of residences, x_1 corresponds to the variable relative position of the construction with regard to the coast and All Saints Bay, x_2 corresponds to the variable income ratio, x_3 corresponds to the normalized distance from the sea, x_4 corresponds to the normalized elevation and a_0, a_1, a_2, a_3, a_4, a_5, a_6, a_7 are fitting coefficients.

Figure 6 shows the results obtained by the use of equation 1 to predict the density of pathologies. As can be observed in Figure 6 the points denote the values predicted by equation 1, and the 45 degrees line indicates what value would be obtained if the predicted values were equal to the experimental ones. In this case, the parameters used in the adjustment were: a_0 = -7,16 x 10^{-2}, a_1 = 1,21 x 10^{-1}, a_2 = 1,32 x 10^{-2}, a_3 = -1,78 x 10^{-1}, a_4 = 1,40 x 10^{-1}, a_5 = -7,05 x 10^{-3}, a_6 = -1,62 x 10^{-3}, a_7 = 1,35 x 10^{-1}.

As can be seen, there are some points (corresponding to the neighborhoods of Jaguaribe, Rio Vermelho and Ribeira), highlighted in red, that presented errors by far superior to the typical scattering, reducing the fitting coefficient of determination (R^2 = 0.45). Based on this erratic behavior, these points were eliminated from the performed analysis. These points were also highlighted with an asterisk in Tables 5 and 6. The results of the analysis performed after the exclusion of the cited points are shown in Figure 7.

As can be observed from Figure 7, there is a substantial gain in the quality of the adjustment, with the coefficient of determination reaching a value of R^2 = 0.76, assumed as satisfactory, considering all the uncertainties embedded in the performed analysis. In this case, the parameters used in the adjustment were: a_0 = -8,45 x 10^{-1}, a_1 = 6,21 x 10^{-2}, a_2 = 1,02 x 10^{-2}, a_3 = 1,16 x 10^{-1}, a_4 = 5,96 x 10^{-1}, a_5 = -4,61 x 10^{-3}, a_6 = -1,78 x 10^{-3}, a_7 = 2,63 x 10^{-1}.

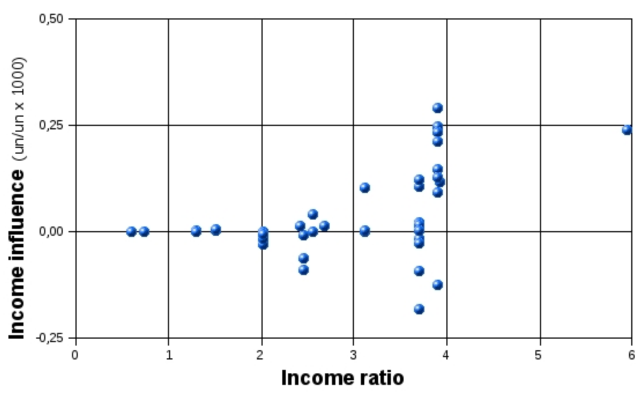
Some analyses were performed in order to evaluate the influence of the socioeconomic factor, the income ratio. This was done by removing the items associated to income variable from equation 1 and calculating the differences between the experimental and predicted values now using equation 2, according to the procedures adopted by Vilasboas (2004). In this equation, Nr corresponds to the motivation caused by the increase in the purchasing power to carry out the restoration works and Nprev corresponds to the number of experimental cases predicted and using all the variables (equation 1).

Figure 8 shows the values of Nr obtained in function of the income ratio. As can be seen, the average income of the neighborhood did not have a significant influence on the experimental results, although for values above 2.5, there seems to be an increase in the number of cases of repair of the structures due to the higher income of the population. Still, there is a significant number of cases with "a negative influence of the income", in contrast to what can be observed in the work of Vilasboas (2004). The authors believe that the change in the equation used in the fitting process in comparison with the work of Vilasboas (2004) and the fact that this equation is combined with other variables, have limited its influence on the experimental results.

Based on the results presented in Figure 8, no corrections were applied to the calculated values and Equation 1 was used without any modification to predict the number of occurrences of repair cases in reinforced concrete structures in the city of Salvador. As this paper describes essentially an empirical research, it is important to note that the need for correction of the obtained values in function of the average income ratio of the area may vary

$$N_r = N_{prev} - [a_0 + a_1.x_1 + a_3.x_3^{-1/10} + a_4.x_4^{1/2} + a_5.x_2^{1/3}.x_3^{1/10} + a_7.x_3^{1/10}.x_4^{-1/2}] \quad (2)$$

Figure 8 - Influence of the income ratio on the experimental results



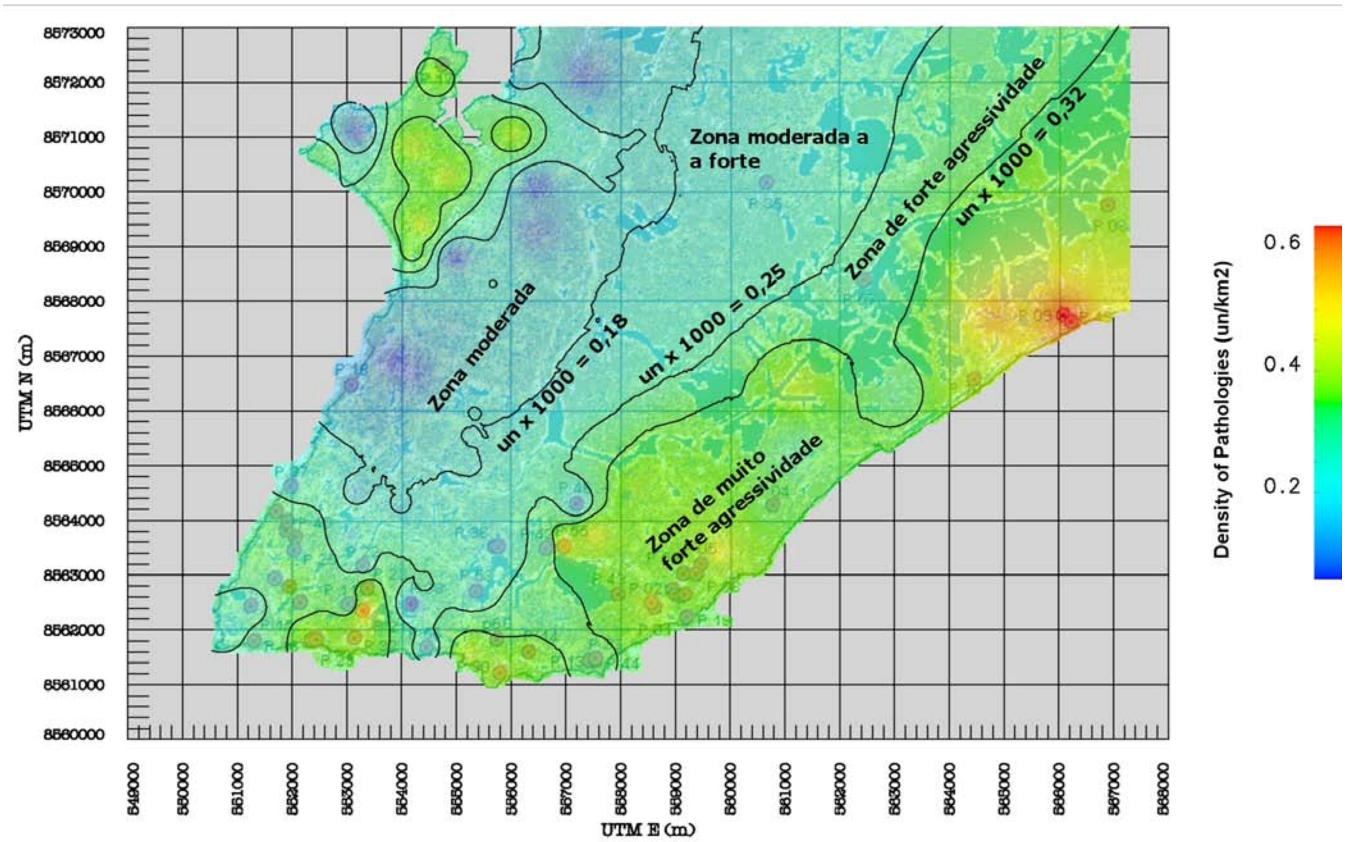
from city to city. Further details on how to proceed to correct the influence of income on the experimental values can be obtained in Vilasboas (2004).

3.2 *Estimating the classes of environmental aggressiveness*

In order to extend the use of equation 1, extra geographical data were collected always making reference to the center of gravity of the various districts of the city, including areas that were not covered by this experimental work. Table 7 presents a summary of these data. For each new point presented in Table 7, equation 1 was used to calculate the density of pathologies. These values are also shown in Table 7. During the application of equation 1 to the points presented in Table 7, it was observed that areas with very low elevation presented an overestimation of the density of pathologies compared to the experimental results. To correct this problem, the elevation was truncated to a value of 10 meters (in other words, when using equation 1, elevation values lower than 10 meters were assumed to be equal to 10 meters).

The results presented in Table 7 are more easily analyzed when geo-referenced. Figure 9 shows the obtained results for the whole area of Salvador. In this figure, contour lines were drawn for the predicted densities of 0.2, 0.3 and 0.4 un per thousand of residences. As can be observed, there is a good agreement between the predicted data and the experimental. Two aspects should be

Figure 9 – Proposed Classification of the different zones of environmental aggressiveness for Salvador



Note: According to NBR 6118 (ABNT, 2007), all areas with splash tide should be considered as zones of very strong environmental aggressiveness.

Table 7 – Estimate of the density of pathologies in different districts of Salvador

Neighborhood	Distance to the sea (-)	Income ratio (-)	Elevation (-)	Wind direction	UTM (m)		Density of Pathologies X 10^{-3} (-)
AGUAS CLARAS	40,96	0,36	0,69	0	561370	8575589	0,19
ALTO DA SANTA TEREZINHA	5,82	0,45	0,48	-1	556410	8575554	0,06
AMARALINA	1,66	1,29	0,18	1	557252	8561483	0,24
ARMAÇAO	5,80	2,68	0,32	1	560385	8564072	0,25
BARBALHO	8,22	1,15	0,5	-1	554214	8566693	0,07
BARRA	1,63	3,12	0,27	0	550860	8562092	0,20
BARRIS	5,75	1,25	0,59	-1	552645	8564496	0,06
BOCA DO RIO	9,72	0,77	0,27	1	561153	8565175	0,26
BONFIM	3,57	1,23	0,3	-1	553161	8571099	0,07
BROTAS	17,04	1,5	0,32	0	555500	8564224	0,20
CABULA	32,11	0,98	0,53	0	557440	8566897	0,18
CAIXA D'AGUA	9,84	0,78	0,63	0	554849	8567500	0,14
CAJAZEIRA	58,11	0,36	0,67	0	562608	8575003	0,20
CALÇADA	1,97	0,63	0,08	-1	554210	8568909	0,35
CAMINHO DAS ARVORES	20,77	5,45	0,25	0	558257	8564623	0,38
CAMPINAS	11,18	0,42	0,53	0	557434	8571844	0,14
CANABRAVA	43,05	0,77	0,53	0	562802	8571340	0,20
CAPELINHA	3,64	0,47	0,09	-1	556041	8571044	0,39
CASTELO BRANCO	42,83	0,57	0,71	0	560366	8573509	0,19
CIDADE NOVA	18,15	0,61	0,48	0	555607	8566806	0,16
COSME DE FARIAS	25,74	0,51	0,5	0	555250	8564995	0,18
COSTA AZUL	4,56	2,49	0,09	1	559776	8563401	0,48
COUTOS	4,18	0,43	0,41	-1	557414	8578991	0,05
DOM AVELAR	26,35	0,56	0,69	0	559737	8573587	0,17
ENGENHO VELHO DA FEDERAÇAO	10,06	0,54	0,27	1	554388	8562818	0,26
ENGENHO VELHO DE BROTAS	22,05	1,00	0,5	0	553972	8564293	0,17
ENGOMADEIRA	40,73	0,52	0,57	0	558746	8568326	0,19
ESCADA	1,08	0,53	0,09	-1	555973	8575722	0,29
FAZENDA COUTOS	11,88	0,32	0,59	-1	558672	8579872	0,08
FAZENDA GRANDE	13,06	0,48	0,6	-1	556468	8569259	0,09
FEDERAÇAO	13,30	0,73	0,25	0	553057	8563207	0,22
GARCIA	13,83	1,48	0,36	0	553054	8563715	0,18
GRAÇA	7,23	3,82	0,54	0	551920	8563181	0,32
IAPI	20,12	0,87	0,5	0	556303	8568060	0,17
IMBUI	20,24	2,42	0,17	1	561205	8566448	0,41
ITACARANHA	1,46	0,53	0,11	-1	555775	8575152	0,24
ITAIGARA	17,02	5,94	0,25	0	557544	8563732	0,46
ITAPAGIPE	2,51	0,73	0	-1	554657	8572155	0,37
ITAPUÃ	2,89	1,35	0,17	1	568617	8568603	0,28
ITINGA	43,17	0,52	0,17	1	570886	8574118	0,48
JARDIM NOVA ESPERANÇA	56,72	0,45	0,47	0	562909	8572688	0,22
LAPINHA	2,98	0,78	0,18	-1	554162	8567930	0,14
LIBERDADE	7,95	0,62	0,5	-1	554981	8568795	0,07
LOBATO	0,76	0,41	0,12	-1	556183	8572094	0,16
LUIZ ANSELMO	22,82	1,88	0,5	0	555221	8565565	0,18
MARECHAL RONDON	10,62	0,42	0,49	-1	557343	8572136	0,08
MARES	4,62	0,63	0,08	-1	554340	8569405	0,43
MASSARANDUBA	4,03	0,67	0,08	-1	554214	8570836	0,41
MATA ESCURA	24,80	0,54	0,58	0	558435	8569994	0,17
MATATU	17,81	1,52	0,43	0	554832	8565766	0,17
MONTE SERRAT	0,93	1,23	0,08	-1	552545	8570629	0,29
MUSSURUNGA	31,33	0,63	0,25	1	568368	8571995	0,34

Table 7 – Estimate of the density of pathologies in different districts in Salvador (continued)

Neighborhood	Distance to the sea (-)	Income ratio (-)	Elevation (-)	Wind direction	UTM (m)		Density of Pathologies X 10³ (-)
NARANDIBA	36,01	1,03	0,42	0	558782	8567613	0,20
NAZARE	10,08	1,52	0,5	0	553890	8565825	0,15
NOGUEIRAS	31,71	0,52	0,82	0	560321	8574838	0,19
NORDESTE	8,25	0,41	0,25	1	556828	8562258	0,26
NOVA BRASILIA	45,52	0,73	0,37	1	563890	8572089	0,29
NOVA SUSSUARANA	43,03	0,59	0,5	0	560861	8570025	0,20
ONDINA	3,93	2,02	0,17	1	553109	8562070	0,31
PARIPE	5,76	0,47	0,08	-1	557829	8580673	0,45
PATAMARES	7,45	2,46	0,08	1	564856	8567728	0,57
PAU DA LIMA	34,35	0,43	0,64	0	560207	8571429	0,18
PAU MIUDO	20,77	0,61	0,51	0	555973	8567036	0,17
PERIPERI	4,27	0,53	0,08	-1	557074	8577672	0,42
PERNAMBUES	30,75	0,62	0,35	0	558270	8566100	0,22
PIATA	2,96	2,46	0,08	1	567305	8568191	0,49
PIRAJA	10,87	0,51	0,59	0	557949	8574024	0,14
PITUAÇU	7,75	2,46	0,25	1	563038	8566380	0,28
PITUBA	7,31	3,7	0,25	1	558756	8562867	0,34
PLATAFORMA	1,78	0,42	0,31	-1	555390	8574037	0,04
PRAIA GRANDE	2,11	0,53	0,21	-1	556880	8576694	0,10
RIBEIRA	1,07	0,78	0	-1	554865	8572437	0,30
RIO VERMELHO	1,20	2,55	0,08	1	555250	8561587	0,42
ROMA	2,96	0,63	0,08	-1	553695	8569874	0,38
SANTA CRUZ	8,70	0,51	0,24	1	556216	8562264	0,27
SANTA MONICA	13,20	0,87	0,33	0	555668	8568319	0,18
SANTO ANTONIO	4,49	1,15	0,41	-1	553890	8566926	0,06
SAO CAETANO	8,97	0,58	0,67	-1	556459	8570082	0,08
SAO CRISTOVAO	35,93	0,50	0,21	1	569745	8572559	0,39
SAO GONÇALO DO RETIRO	28,45	0,53	0,58	0	558020	8568235	0,18
SAO MARCOS	53,81	0,77	0,66	0	560657	8571072	0,20
SAUDE	7,31	1,52	0,5	0	553562	8565837	0,14
SE	3,01	1,63	0,37	-1	553054	8565792	0,05
SETE DE ABRIL	59,17	0,44	0,47	0	561597	8572565	0,22
STIEP	11,67	2,49	0,25	0	560107	8564486	0,23
SUSSUARANA	35,33	0,59	0,59	0	560129	8570435	0,18
TANCREDO NEVES	35,17	0,52	0,49	0	559371	8568802	0,19
TORORO	10,09	1,52	0,46	0	553164	8564516	0,15
URUGUAI	4,04	0,63	0,07	-1	554839	8570292	0,41
VALERIA	42,13	0,42	0,84	0	561659	8577342	0,20
VILA CANARIA	33,58	0,45	0,76	0	560249	8572729	0,19
VILA LAURA	22,53	1,88	0,5	0	555322	8565964	0,18
VILA RUI BARBOSA	8,22	0,67	0,08	-1	553974	8570564	0,48
VITORIA	1,31	3,9	0,49	-1	551372	8563573	0,29

highlighted here a) for the areas from Patamares to Itapuã and for the areas close to Ribeira, the predicted aggressiveness is higher than the observed number of cases and b) there is an apparent underestimation of the environmental aggressiveness for the area of Barra.

Regarding these two aspects, it is noteworthy that although the number of cases of pathological manifestations identified for the areas from Patamares to Itapuã is relatively small, the environmental aggressiveness of this area is easily visible, as the rapid degradation of the buildings located there is very apparent. Thus, the values predicted by equation 1 are believed to be compatible with reality. For the areas of Barra, Graça and surrounding areas, the income factor should play an important role (income ratio superior to 2.5) on the contracting of restoration works, a reason for which a relatively lower prediction of density by equation 1 is also quite plausible.

Concerning the predicted data for Ribeira, a more detailed study is required. As can be seen in Figure 9, the area of the city of Salvador was divided into 4 areas of environmental aggressiveness a) zone of moderate aggressiveness: this corresponds to the sites with a density of pathologies lower than 0.18 per thousand units of residence. This includes, except for the areas close to Ribeira, the areas located near All Saints Bay b) zone of moderate to strong aggressiveness: this corresponds to places with a density of pathologies between 0.18 and 0.25. It covers mainly areas located on the dividing axis of the North coast / Bay of All Saints c) zone of strong environmental aggressiveness: this corresponds to sites with a density of pathologies between 0.25 and 0.32. It covers the pre-coastal areas and most of Barra, Ondina and Graça d) zone of very strong environmental aggressiveness: this corresponds to sites with a density of pathologies superior to 0.32. It covers most of the coastal areas. It is noteworthy that the areas that have direct contact with the marine spray should be considered as zone of very strong environmental aggressiveness, according to NBR 6118 (ABNT, 2007).

4. Final considerations

The results obtained in this study contribute to the elaboration of structural designs of buildings located in the Urban Region of Salvador as the obtained results have made it possible to propose a classification of the environmental aggressiveness of different areas in the city. In this sense, it is believed that this study provides a contribution not only to those who work directly with civil construction, but also to all those interested in this subject.

The current article aims to collaborate with the design engineers especially in the task of defining of the degree of aggressiveness of the environment in which the structure will be built, allowing them to differentiate environments of moderate aggressiveness from those with strong or very strong aggressiveness.

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