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Improved Ecosystem Services and Environmental Gentrification after Rehabilitating Brazilian Urban Streams

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Abstract: The high levels of environmental pollution observed in urban freshwater ecosystems result in losses of ecosystem goods and services, reducing the well-being of human populations in densely populated tropical cities. The Belo Horizonte Metropolitan Region (BHMR) resembles other megacities in the Global South, with inadequate collection and treatment of domestic sewage being an important source of environmental degradation. However, urban stream rehabilitation can improve ecosystem quality and the physical and mental well-being of local citizens. Therefore, the objective of this study was to assess whether the rehabilitation of three BHMR streams and the increased provision of ecosystem goods and services for local residents were associated with environmental gentrification and public health issues. To achieve this objective, we asked three questions. (i) Was there socioeconomic improvement in the households located near the rehabilitated streams? (ii) Did property values appreciate near the rehabilitated streams? (iii) Was the relative incidence of diseases decreased in the residents living near the rehabilitated streams? We tested three hypotheses. (H1) The socioeconomic profile of the households in the areas neighboring the rehabilitated streams improved. (H2) The property values of residences in the areas neighboring the rehabilitated streams increased. (H3) The incidence of waterborne and other types of diseases in the areas neighboring the rehabilitated streams decreased. To answer the first question and hypothesis, we compared 2000 to 2010 census tracts in the areas neighboring the rehabilitated streams with others in the municipality of Belo Horizonte (BH). We observed non-significant socioeconomic and demographic differences. To answer the second question and hypothesis, we used real estate transactions between 2009 and 2018 using hedonic models. After controlling for multiple interacting variables, we observed real estate appreciation after stream rehabilitation. To answer the third question and hypothesis, we analyzed the association between the prevalence of waterborne diseases, vector-borne diseases, and other diseases in the residents living near the rehabilitated streams. To do so, we analyzed hospitalization data from 2005 to 2016 for residents neighboring the streams versus BH. We observed a significant increase in the prevalence of waterborne and vector-transmitted diseases until two years after the stream rehabilitation, followed by a decrease until 2010. Trends for other types of diseases differed from these and mostly followed the general tendencies of BH, indicating different temporal variations. Our results highlight that ecosystem goods and services fostered by urban stream rehabilitation have potential contributions to the well-being of urban populations. The economic analyses applied in the paper have clear policy implications in support of urban stream rehabilitation. Although South American countries lack mandatory rehabilitation investments, Belo Horizonte's example can inspire other interventions in tropical megacities.

Keywords: Belo Horizonte; waterborne diseases; real estate appreciation; ecosystem services

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1. Introduction

Water as a resource for multiple human uses is commonly studied with a multidisciplinary approach, including historical, political, social, economic, cultural, and ecological perspectives [1]. Analyses of the provision of ecosystem goods and services offered by urban freshwater ecosystems to human populations living in their catchments are currently being used in such assessments [2].

Aquatic ecosystems can provide many ecosystem goods and services. Anderson et al. (2019) [1] emphasized the importance of good water quality for multiple uses. Direct physical benefits include fishing and food supply, as well as transportation and cleaning. Socio-cultural benefits include human well-being, therapeutic effects associated with recreation, promoting local identity, cultural transmission, family and group cohesion, and promoting a sense of place and time. Similarly, Parker and Oates (2016) [3] list ecosystem services associated with aesthetics, recreation, spirituality and culture, promoting social relations, education and science, and improved health and hygiene.

The growing recognition of the mutual association between freshwater and human society has influenced the implementation of practices that seek to conserve freshwater ecosystems and address social challenges related to the management of urban stream basins [4,5]. Among the United Nation's 17 Sustainable Development Goals (SDGs), SDG-3 seeks to ensure a healthy life and promote well-being for all human beings of all ages. SDG-6 seeks to ensure the availability and sustainable management of water and sanitation for all [6].

The development of tropical cities is directly related to the provision of ecosystem goods and services to populations living around freshwater ecosystems [7]. However, the growing demand for water for multiple urban uses and the occurrence of anthropogenic disturbances have caused widespread degradation of freshwater ecosystems in large cities worldwide [8]. Urban streams, in general, usually carry high levels of sediments and pollutants and drain extensive areas of impermeable surfaces, which foster flash flooding [5,8].

Stream rehabilitation and increased provisions of ecosystem goods and services by aquatic ecosystems can influence the socioeconomic levels of riverine populations, potentially causing local gentrification. Because such gentrification is related to environmental quality improvements, it has been named environmental gentrification [9].

Associated with this process, previous studies associated freshwater ecosystem rehabilitation with the real estate appreciation of nearby neighborhoods [7]. Sander and Haight (2012) [10] reported that housing prices in areas bordering freshwater ecosystems with intervention sites were greater the closer they were to the rehabilitation areas. Thus, one way of indirectly evaluating the monetary value of ecosystem goods and services, including outdoor recreation and scenic quality potentials, is the real estate price appreciation of neighboring properties.

Urban stream rehabilitation and the implementation of linear riparian parks can also provide ecosystem goods and services that reduce the prevalence of waterborne diseases [2,11]. Such diseases are prevalent in tropical nations throughout the Global South. Hammer et al. (2006) [12] associated the use of contaminated water and the prevalence of waterborne diseases in Varanasi, India. Nwidu et al. (2008) [13] correlated poor water quality in the Niger Delta, Nigeria, with the prevalence of waterborne diseases. Qureshi et al. (2011) [14] linked the levels of microbiological contamination of drinking water in Lahore, Pakistan, with the prevalence of diseases. Again, in the BHMR, Matta-Machado (2007) [15] reported decreased rates of hospitalization for infectious diarrhea in children and of infant mortality with improved water supply quality, sanitation, and socioeconomic level.

Freshwater ecosystem rehabilitation and increased provision of ecosystem goods and services can also positively influence the prevalence of other types of human diseases. For example, increased recreation opportunities in newly created urban parks can reduce the incidence of diseases caused by a sedentary lifestyle, such as diabetes mellitus and cardiovascular diseases [16].

Urban stream rehabilitation has been applied for decades in several developed countries [8,17]; however, examples are still rare in Brazil [2,18]. In Brazil, it is common to channelize urban streams to prioritize road systems, maximizing urban transport while inadequately treating domestic effluents [17,19]. However, the Brazilian National Congress approved two Regulatory Frameworks for Basic Sanitation Laws (4162/2019 and 14.026/2020) that may change this perspective. These new Sanitation Regulatory Frameworks seek to promote further interventions with the goal of spreading potable water supply and sewage treatment throughout Brazil in the future [20].

Among these interventions, the Drenurbs program in the BHMR stands out [2,19]. The Drenurbs has focused on watercourses degraded by domestic pollution but not yet channelized. The Drenurbs has five main goals: (a) the collection and treatment of sewage; (b) reducing flood and bank erosion risks; (c) the revegetation of riparian zones; (d) the removal of people living in riparian zones; and (e) the creation of protected areas with riparian parklands [2,4,21]. The Drenurbs used financial support from the Inter-American Development Bank of USD 14.5 million in 2008 to rehabilitate three urban streams: Baleares, Primeiro de Maio, and Nossa Senhora da Piedade [2,18].

To date, the Drenurbs has had several positive results, improving the provision of ecosystem services and being one of the most successful rehabilitation programs of urban streams thus far implemented in Brazil [22]. Macedo et al. (2011) [18] and Macedo et al. (2022) [2] reported significantly improved water quality and macroinvertebrate assemblages. Macedo and Magalhães Junior (2011) [21] reported that local residents appreciated the improvements soon after they were implemented, as well as in the following decade [2].

The BHMR is the third most populous urban center in Brazil, after the metropolitan regions of São Paulo and Rio de Janeiro, with an estimated population of approximately 6 million in 2020. It resembles other Global South megacities, with inadequate sewage collection and treatment. South American countries lack mandatory rehabilitation investments, and Belo Horizonte's example can inspire interventions in other tropical megacities, where half of the population has no sewage collection or treatment [8].

Therefore, the objective of this study was to evaluate the relationship between the rehabilitation of three BHMR streams and the social, economic, and public health aspects of their nearby neighborhoods. To achieve this objective, we asked three questions. (i) Was there socioeconomic improvement in the households located near the rehabilitated streams? (ii) Did property values appreciate near the rehabilitated streams? (iii) Did the relative incidence of diseases decrease in the residents living near the rehabilitated streams? We tested three hypotheses.

H1. *The socioeconomic profile of the households in the areas neighboring the rehabilitated streams improved.*

H2. *The property values of residences in the areas neighboring the rehabilitated streams increased.*

H3. *The incidence of waterborne and other types of diseases in the areas neighboring the rehabilitated streams decreased. Those first two hypotheses are directly linked with the environmental gentrification process.*

Considering urban stream rehabilitation, Sander and Haight (2012) [10] argued that the population directly benefited from ecosystem goods and services value them but that their economic value, reflecting the gains in the well-being of the local population, is often poorly recognized. In general, the multiple results of stream rehabilitation projects are poorly monitored and assessed [17]. Consequently, ecosystem goods and services are usually not properly valued and, in general, their provision tends to decline with urbanization, with a loss of watershed and stream quality in cities. We believe that the improvement of well-being and quality of life of human populations neighboring interventions should be better quantified, appreciated and valued because freshwater ecosystem rehabilitation can provide ecosystem goods and services. Thus, the analysis proposed here provides empirical findings that help to overcome this lack of knowledge. To the best of our knowledge, studies addressing these topics, including demographic, socioeconomic, real estate and epidemiological aspects, with similar approaches are still missing in the Global South [23]. We seek to contribute to the knowledge gap relating to specific interventions in sanitation and ecology associated with the rehabilitation of urban rivers and public health impacts.

2. Materials and Methods

2.1. Study Area

BHMR is composed of several municipalities, with its metropolitan nucleus (BH) being the most populous, with a population of around 2.5 million (Figure 1). We evaluated three rehabilitated BHMR streams in the Drenurbs program [2]: Baleares, Primeiro de Maio, and Nossa Senhora da Piedade (Figure 1). Their total catchment areas were 0.73, 0.48, and 0.43 km^2, respectively.

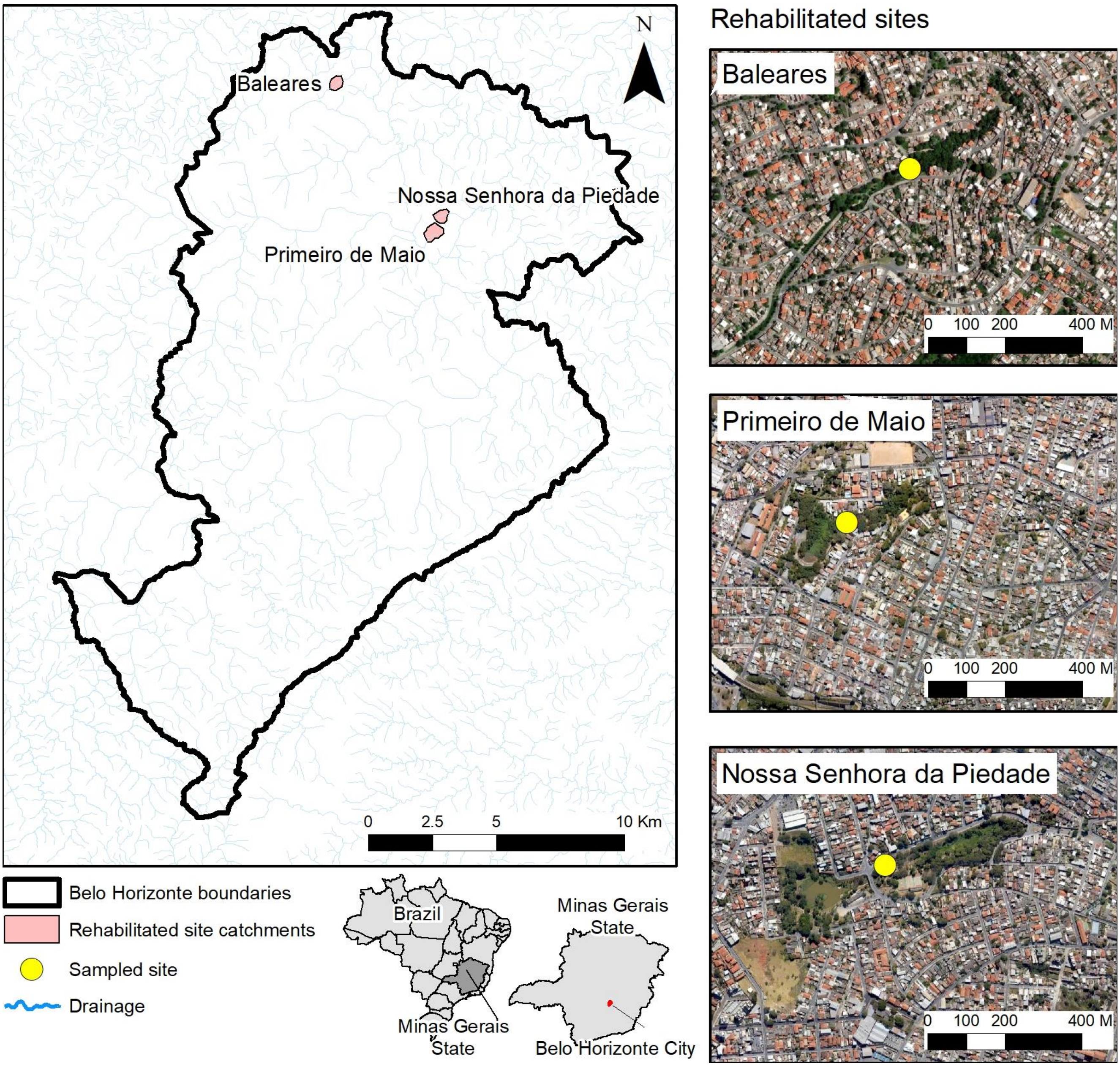

Figure 1. Locations of Baleares, Primeiro de Maio, and Nossa Senhora da Piedade streams.

These stream catchments had deficient drainage infrastructure, human occupation of riparian zones, untreated sewage discharges, uncollected garbage disposal, riparian deforestation, and seriously eroded streambanks before the rehabilitation. The interventions were implemented from 2006 to 2007 and improved all those deleterious pressures, removed preexisting households, and created protected riparian parklands [2].

The rehabilitated areas, when compared with other areas of BH, had households with higher resident densities, lower income levels, larger proportions of women as household heads, and higher proportions of children. These characteristics indicated lower socioeconomic conditions in the rehabilitated areas than elsewhere in BH.

2.2. Methodology

To test the three hypotheses of the paper, we analyzed databases for socioeconomic improvement, real estate prices, and disease prevalence. All statistical analyses were performed using Stata software version 12.

2.2.1. Demographic and Socioeconomic Aspects

To test H1, we obtained data from the 2000 and 2010 Brazilian Demographic Censuses, the last census data available. Census tracts were used as a proxy for communities [24]. A census tract is established by operational criteria for data collection, being the most disaggregated territorial level that has population data collected periodically in Brazil [25]. Census data were obtained from the Brazilian Institute of Geography and Statistics (IBGE) sites: https://biblioteca.ibge.gov.br/biblioteca-catalogo.html?id=25581&view=detalhes, accessed on 15 January 2022 and https://ftp.ibge.gov.br/Censos/Censo_Demografico_2010/Resultados_do_Universo/Agregados_por_Setores_Censitarios/, accessed on 15 January 2022.

Belo Horizonte was divided into 2564 and 3936 census tracts in 2000 and 2010, respectively. Because the number of census tracts differed in the two censuses and we needed the same areas in both censuses to draw comparisons [25], we grouped some of the areas in both censuses using a file provided by IBGE.

There are two types of census tracts: common and special. The latter includes types such as orphanages or penitentiaries, which were discarded from our analysis. Subnormal agglomerations (favelas or slums), also considered special, were retained. A few census tracts lacked complete data in either census and were discarded. The final sample had 2537 census tracts for both 2000 and 2010.

We assessed several variables for each census tract, shown in Box 1. These variables were used for analyzing demographic, socioeconomic, and infrastructure data associated with local gentrification.

Box 1. Variables used for comparing census tracts.

For household: mean density of dwellers, proportion of houses, proportion of apartments, proportion owned, proportion rented, proportion with water, proportion with sewage, proportion with garbage collection, proportion with spouse, and proportion with children
For the person of reference in the household: real income, proportion literate, proportion women, proportion aged 10 to 24, and proportion aged 65 years or more
For population: sex ratio, proportion aged 0 to 4, proportion aged 5 to 9, and proportion aged 70 years or more

Regarding the determination of the census tracts belonging to each of the rehabilitated stream catchments, there is a trade-off between proximity and the number of selected census tracts, as the closer the residence is to the intervention site, the greater the expected effects are [10]. We selected as belonging to the vicinities of the rehabilitation areas all census tracts whose formal neighborhoods in 2010 were located within the borders of the rehabilitation areas. Of the 2537 tracts in the sample, 41 were in one of the three rehabilitation catchments.

The census tracts located in the catchments of the rehabilitated streams were compared with others in BH using propensity score matching [26]. This technique makes it possible to obtain an adequate counterfactual (control) group to perform comparisons using observational data.

We performed two comparisons. First, we obtained a group of 41 census tracts located outside the catchments with observed characteristics a priori similar to the census tracts located in the catchments of the rehabilitated streams in all variables of Box 1 (both with 2000 data). These same groups were compared for the 2010 data to observe whether there existed any difference at the end of the period in any of the variables.

Then, we obtained a group of 41 census tracts located outside the catchments with characteristics a posteriori similar to the census tracts located in the catchments (both with 2010 data). These same groups were compared for the 2000 data to observe whether any difference existed at the beginning of the analyzed period.

2.2.2. Real Estate Prices

To assess (H2), we compared the prices of transactions in the rehabilitation-neighboring areas with other areas in BH. To do so, we used the BH Tax on Transmission of Goods (ITBI) from 2009 to 2019, obtained at: https://prefeitura.pbh.gov.br/fazenda/tributos/ITBI, accessed on 15 January 2022. This database also includes the address and neighborhood of the real estate, some characteristics of the real estate, and the transaction date.

Initially, the database contained transactions between 2009 and 2021, but those in the COVID epidemic years, 2020 and 2021, were discarded because they may present idiosyncrasies. The resulting database contained 294,282 property transactions classified as residential, non-residential, territorial, and null value. To homogenize the data, only residential transactions of houses and apartments were kept, resulting in 226,860 transactions.

Following Sander and Haight (2012) [10], we used hedonic models to compare real estate values. Our hedonic model was:

$$\ln P = \alpha + \beta L + \delta T + \nu(T * L) + \theta X + \phi Z + \varepsilon \tag{1}$$

where P is the real estate price, L are location dummies, T is a categorical variable with the year of the transaction, $(T * L)$ are the interactions between the temporal variable and the location dummy, X are real estate variables, Z are neighborhood variables, and ε is the stochastic error.

Dummies were created to indicate whether the property was located in one of the catchments or not (1—yes, 0—no). To create these dummies, we used the transaction neighborhood and address. Of the 226,860 transactions, 1134 were close to Baleares, 487 were close to Nossa Senhora da Piedade, and 400 were close to Primeiro de Maio, with all transactions in the rehabilitated catchments summing to 1651 (0.73% of the total).

A categorical variable was created for the year of the transaction, which is important to eliminate general upward price trends. The interactions between location and transaction year were also included in the hedonic models to address the potential relative appreciation of rehabilitation-neighboring areas.

Real estate appreciation near the rehabilitated streams may have resulted from different factors, for example, the relative distribution of houses and apartments, the relative increase in the size of properties, the relative increase in the finishing standards and/or the increase in the price per area of properties with similar finishing standards. We created some variables to address these aspects. A dummy was created to indicate whether the property was a house or an apartment (1—apartment, 0—house). Houses and apartments are expected to have different prices, even if they are similar in other parameters. Real estate property values may vary because of their level of finishing, and a categorical variable was built (1—poor standard to 5—excellent standard). The database also includes property size in square meters, and this variable was treated as continuous. Moreover, the various areas of Belo Horizonte were classified into 11 types for urban development purposes, and a categorical variable was constructed with these types. The type of area can affect the price of the property.

The hedonic models estimated with ordinary least squares (OLS) might have limitations because of the spatial features of the data, so we estimated the models with errors robust to heteroscedasticity and errors clustered by neighborhood [27]. We estimated four models for houses and apartments together, four only for houses and four only for apartments. Among these four models, for each group of observations, two analyzed the rehabilitation efforts together, and two analyzed them separately. Among each group of two models, one contained only the zone type as a control (model 1), whereas the other also included the finishing standard and property size (model 2).

2.2.3. Disease Prevalence

To test (H3), we used hospitalization authorization (AIH) data for the period between 2005 and 2016 obtained directly from the DATASUS website: DataSus/tabnet: https://datasus.saude.gov.br/transferencia-de-arquivos/#, accessed on 15 January 2022.

The databases include the patient's zip code, which was used to determine whether the patient lived in one of the catchments of the three rehabilitated streams or in another region of BH. The final database had a total of 1,567,691 observations, and a small proportion, 28,003 or 1.78%, lived in one of the three catchments (Table 1). Given this small number, all rehabilitation areas were analyzed together, and a location dummy was created (1—catchments, 0—other areas).

Table 1. Distribution of AIH by disease type and residence area.

Disease Type	**Area** **Other Areas**	**Stream Areas**	**Total**
Waterborne	13,252	272	13,524
Vectors	5965	113	6078
Vascular and related	97,722	1807	99,529
Mental disorders	13,883	146	14,029
Total of selected diseases	130,822	2338	133,160
Other diseases	1,408,866	25,665	1,434,531
Total	1,539,688	28,003	1,567,691

The database also has the main cause of the AIH classified according to the 10th revision of the International Classification of Diseases and Related Health Problems of the World Health Organization (ICD-10) (details in Appendix A Box A1). A small proportion of the AIH, 133,160 (8.49%), were due to waterborne diseases, vector-transmitted diseases, vascular-related diseases, and mental disorders, and a much smaller number of them was for residents in one of the catchments, 2338 (0.15%). Thus, we analyzed the diseases in three groups (1—waterborne diseases or diseases transmitted by vectors, 2—vascular-related diseases or mental disorders, 3—other diseases).

The data are for individuals, and the response variable is whether the individual's AIH was classified in one of the three categories. Because the response variable is categorical, we used multinomial models [27].

The multinomial models included as explanatory variables of interest a dummy for location (1—catchments, 0—other areas), dummies for years (2006 to 2016) and the interactions between the location dummy and the year dummies. Moreover, the models included the age and sex of the patient as controls.

3. Results

3.1. Demographic and Socioeconomic Aspects

The first comparison was between the demographic tracts neighboring the rehabilitated streams and the counterfactual similar a priori census tracts. They were similar in 2000 in all variables presented in Box 1 by construction and did not differ significantly in 2010 in any of them. The second comparison was between these first tracts and the counterfactual similar a posteriori census tracts. Similarly, they were similar in 2010 in all variables by construction, and the analyzed period also started as similar in all of them in 2000.

In either comparison, the trends in the demographic tracts neighboring the rehabilitated streams did not differ from the counterfactual groups in any of the variables presented in Box 1. There may have been too few years after the rehabilitation efforts were completed to reflect significant demographic changes. Nevertheless, these results indicate the non-existence of a previous gentrification process in the neighboring areas before the rehabilitation, rendering the following results more robust.

3.2. Real Estate Prices

We observed a clear relative increase in real estate prices for the rehabilitated stream catchments versus other areas of BH between 2009 and 2019 (Figure 2).

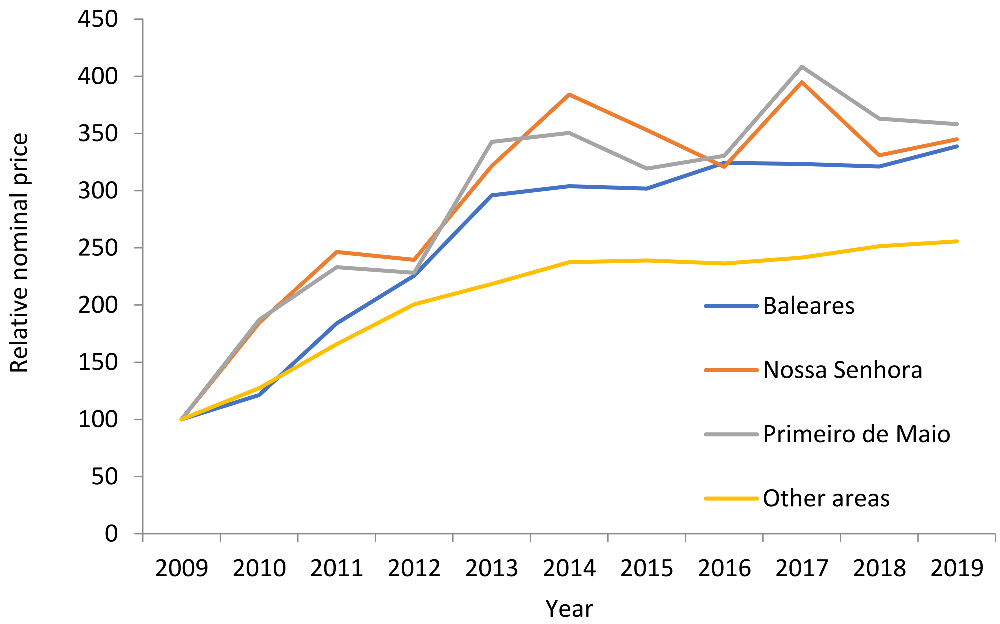

Figure 2. Real estate prices in the rehabilitated stream catchments versus other areas in BH between 2009 and 2019.

The proportion of transactions that were apartments in each area per year increased slightly in BH (Table 2). However, the Primeiro de Maio and Nossa Senhora da Piedade catchments showed an increasing share of apartments, suggesting that apartment buildings were being built in larger numbers in these areas after the rehabilitation efforts had been completed. We did not observe this trend for Baleares.

Concerning the hedonic models (Table 3), we observed negative and significant coefficients for the dummy representing the catchments (1—catchment areas, 0—otherwise), indicating that real estate prices near the rehabilitated streams were lower than in other BH areas. The negative coefficients decreased in magnitude in model 2 when compared to model 1. The lower prices near the rehabilitated streams versus other areas in the BH can be partially explained because of the smaller sizes of houses and apartments and lower finishing standards near the streams.

Table 2. Percentage of apartment transactions around the rehabilitated streams and other areas in the BH.

Year	Area			
	Baleares (%)	**Nossa Senhora (%)**	**Primeiro de Maio (%)**	**Other Areas of BH (%)**
2009	68.2	33.3	0.0	79.3
2010	68.3	29.7	24.2	81.5
2011	76.1	20.0	12.5	82.7
2012	52.4	28.6	25.0	84.6
2013	78.5	41.7	40.0	85.6
2014	91.2	54.5	42.9	87.5
2015	78.7	71.4	65.5	87.2
2016	72.0	82.9	80.6	87.2
2017	71.1	78.4	78.4	86.4
2018	53.0	90.0	80.7	86.2
2019	65.8	84.4	80.0	86.9

Table 3. Hedonic model results for houses and apartments in all three stream rehabilitation areas together versus BH as a whole.

Variable	**Model 1**	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
	Apartments & Houses		**Houses**		**Apartments**	
Catchments	−0.591 **	−0.296 **	−0.502 **	−0.358 **	−0.618 **	−0.230 **
	(0.0890)	(0.0369)	(0.0596)	(0.0651)	(0.123)	(0.0694)
Years						
2009	Reference					
2010	0.283 **	0.255 **	0.294 **	0.303 **	0.277 **	0.243 **
	(0.0178)	(0.0125)	(0.0186)	(0.0161)	(0.0211)	(0.0153)
2011	0.534 **	0.483 **	0.530 **	0.546 **	0.526 **	0.462 **
	(0.0208)	(0.0150)	(0.0245)	(0.0194)	(0.0216)	(0.0173)
2012	0.731 **	0.655 **	0.722 **	0.707 **	0.723 **	0.639 **
	(0.0183)	(0.0124)	(0.0278)	(0.0226)	(0.0208)	(0.0140)
2013	0.881 **	0.803 **	0.889 **	0.881 **	0.868 **	0.783 **
	(0.0221)	(0.0155)	(0.0296)	(0.0236)	(0.0275)	(0.0178)
2014	0.975 **	0.871 **	0.979 **	0.962 **	0.958 **	0.847 **
	(0.0247)	(0.0178)	(0.0289)	(0.0228)	(0.0319)	(0.0206)
2015	0.978 **	0.884 **	1.012 **	0.979 **	0.959 **	0.859 **
	(0.0230)	(0.0167)	(0.0272)	(0.0217)	(0.0292)	(0.0196)
2016	0.966 **	0.865 **	0.995 **	0.978 **	0.948 **	0.836 **
	(0.0263)	(0.0192)	(0.0314)	(0.0243)	(0.0326)	(0.0215)
2017	0.984 **	0.887 **	1.114 **	1.041 **	0.949 **	0.848 **
	(0.0271)	(0.0212)	(0.0289)	(0.0231)	(0.0330)	(0.0238)
2018	0.997 *	0.862 *	1.121 *	0.945 *	0.965 *	0.834 **
	(0.0305)	(0.0174)	(0.0295)	(0.0249)	(0.0358)	(0.0200)
2019	1.016 **	0.880 **	1.245 **	0.938 **	0.970 **	0.852 **
	(0.0301)	(0.0159)	(0.0376)	(0.0307)	(0.0358)	(0.0184)
Year x catchment interactions						
2009	Reference					
2010	0.0608	0.0927 *	0.141	0.144 *	−0.00461	0.0593 **
	(0.0810)	(0.0400)	(0.0764)	(0.0725)	(0.0900)	(0.0227)
2011	0.195 **	0.251 **	0.299 **	0.216	0.128	0.252 **
	(0.0700)	(0.0877)	(0.0891)	(0.181)	(0.0963)	(0.0448)
2012	0.103 *	0.130 **	0.275 **	0.226 **	−0.0546	0.0499
	(0.0514)	(0.0440)	(0.0925)	(0.0848)	(0.0693)	(0.0276)
2013	0.261 **	0.168 **	0.287 **	0.171 **	0.264	0.125 *
	(0.0859)	(0.0405)	(0.0507)	(0.0579)	(0.138)	(0.0627)

Table 3. *Cont.*

Variable	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
	Apartments & Houses		**Houses**		**Apartments**	
2014	0.202 **	0.0720 *	0.194 *	0.148	0.232 *	0.00490
	(0.0708)	(0.0325)	(0.0871)	(0.0877)	(0.112)	(0.0484)
2015	0.167 *	0.0719	0.158	0.136	0.177	−0.00725
	(0.0781)	(0.0438)	(0.216)	(0.173)	(0.103)	(0.0439)
2016	0.270 **	0.169 **	0.347 **	0.307 **	0.264 **	0.0598
	(0.0451)	(0.0302)	(0.0669)	(0.0707)	(0.0963)	(0.0509)
2017	0.278 **	0.159 **	0.400 **	0.251	0.230 *	0.0567
	(0.0733)	(0.0241)	(0.127)	(0.133)	(0.109)	(0.0460)
2018	0.259 **	0.168 **	0.297 **	0.292 **	0.241 **	0.0657
	(0.0449)	(0.0262)	(0.0710)	(0.0535)	(0.0891)	(0.0495)
2019	0.248 **	0.163 **	0.276 **	0.254 **	0.211 *	0.0714
	(0.0426)	(0.0316)	(0.0951)	(0.0649)	(0.105)	(0.0377)
Constant	11.12 **	10.61 **	10.71 **	10.22 **	11.51 **	10.79 **
	(0.152)	(0.0879)	(0.0652)	(0.0510)	(0.319)	(0.151)
Observations	226,860	226,860	34,894	34,894	191,966	191,966
R^2	0.361	0.649	0.362	0.573	0.362	0.679

Model 1 includes zoning type as a predictor; model 2 includes zoning type, finishing standard, and property size. ** $p < 0.01$, * $p < 0.05$.

The positive and significant coefficients for the year dummies indicate a general appreciation of real estate in BH. The coefficients of the interactions between the location dummy and the transaction year offer some patterns of relative appreciation of the rehabilitation-neighboring areas. For houses, most of the coefficients were positive and significant in models 1 and 2, indicating that there was an appreciation of house values in the rehabilitated stream catchments relative to BH. For apartments, model 1 has several positive and significant coefficients, indicating the increased values of apartments in the rehabilitated stream catchments relative to BH as a whole. However, in model 2, the coefficients were mostly non-significant. That is, the finishing standards and size controls explained the relative appreciation of the apartments, as they improved their quality according to these two variables in the stream catchments. The R^2 values indicate that model 2 explained 57–68% of the variation in property values after controlling for zoning type, finishing standard, and property size.

We also assessed the interactions for similar models, but with each stream rehabilitation analyzed separately (Appendix B). For Baleares and Nossa Senhora, the coefficients for houses were mostly positive and significant, indicating the relative real estate price appreciation of both areas. On the other hand, the results for Primeiro de Maio showed no such pattern. Those results indicate a gentrification process in two neighboring areas that did not exist before implementing the rehabilitation efforts.

3.3. Disease Prevalence

Initially, we descriptively compare the rehabilitated neighboring areas versus other areas of BH. We determined the proportion of each type of disease incurred by residents near the rehabilitation areas using the moving mean of three years to minimize small sample fluctuations. To increase comparability, we normalized the results in 2006 for all types of diseases. Given the results of the two first studies and the slight upward trend of relative socioeconomic levels observed in the rehabilitation-neighboring areas, a slight negative tendency is expected for overall disease prevalence. This trend was observed for other diseases, including cardiovascular diseases and mental disorders (Figure 3). Rather differently, we observed increased waterborne and vector-transmitted diseases in the years immediately following the stream rehabilitation because of increased vector-transmitted diseases, among them dengue, but an acute decline was observed after five years.

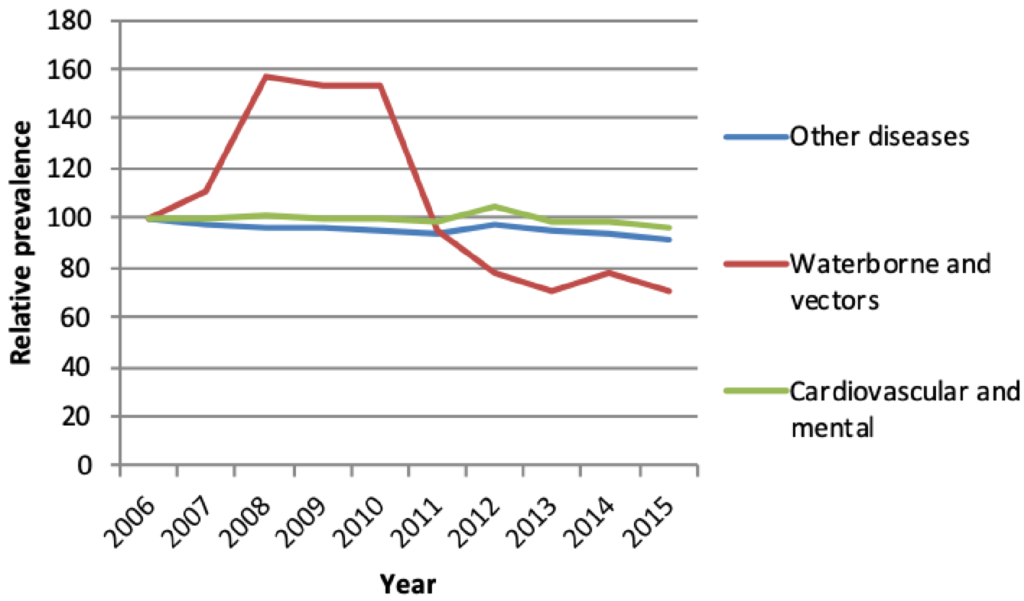

Figure 3. Levels of hospitalization authorizations for different types of diseases in Belo Horizonte between 2006 and 2015.

Concerning the multinomial model´s results, the group Other Diseases was used as the basis of comparisons. The prevalence of cardiovascular diseases and mental disorders, when compared to other diseases, did not change significantly regarding location (non-significant coefficient). Furthermore, the coefficients for the interactions between location and years were non-significant (Table 4). In conclusion, the results for cardiovascular and mental diseases and for other diseases did not differ significantly due to the rehabilitation efforts and followed temporal expectations associated with a slight upward trend of socioeconomic levels observed in the previous studies.

Table 4. Multinomial models for different disease types (standard errors in parentheses).

Variables	Basis of Comparison: Other Diseases	
	Waterborne and Vector	**Cardiovascular and Mental**
Stream catchment	−0.336 * (0.162)	−0.0505 (0.0851)
Year & location interaction		
2005	0.140 (0.240)	0.0716 (0.117)
2006	0.487 * (0.233)	−0.0770 (0.120)
2007	0.541 * (0.235)	−0.00743 (0.122)
2008	0.503 * (0.237)	0.0662 (0.116)
2009	1.411 ** (0.203)	−0.0782 (0.120)
2010	0.576 * (0.224)	−0.104 (0.124)
2011	0.211 (0.301)	0.130 (0.118)
2012	0.156 (0.315)	0.00372 (0.121)
2013	0.161 (0.260)	−0.0256 (0.119)
2014	−0.139 (0.345)	0.0171 (0.122)
2015	0.461 (0.275)	0.0875 (0.121)
Observations	1,567,691	1,567,691

Controls for year, sex and age are included in the models. ** $p < 0.01$, * $p < 0.05$.

Differently, we observed a generally reduced prevalence of waterborne and vector-transmitted diseases for the rehabilitated stream catchments because the coefficient for catchment was negative and significant (Table 4). The interactions of location and year in 2005 and after 2010 showed non-significant coefficients, indicating that only the general trend was significant. However, between 2006 and 2010, the coefficients for the interactions were positive and significant with a greater magnitude than that for the catchment dummy, suggesting that the prevalence of waterborne and vector-transmitted diseases actually relatively increased at rehabilitated stream catchments in these years. Thus, tendencies for waterborne and vector diseases differed substantially with clear temporal associations with the rehabilitation efforts.

4. Discussion

We first evaluated whether urban stream rehabilitation efforts may have contributed to gentrification. When an urban ecosystem is degraded, residents of higher socioeconomic classes tend to move to other locations, allowing economically disadvantaged classes to occupy local housing. The opposite is expected when the environment is improved, i.e., by stream rehabilitation [12]. Neighborhoods can experience demographic and social improvements in the process of environmental gentrification [28].

Our results indicated that the rehabilitated stream catchments followed the general trends of BH for demographic and socioeconomic variables, as we did not observe significant associations with the rehabilitation efforts. This same non-significant result was observed by Eckerd (2011) [9], who found no evidence of environmental gentrification in a study in Portland, Oregon, USA. Greenstone and Gallagher (2008) [29] also found no statistically significant changes in populations living near rehabilitated Superfund sites across the USA.

Nonetheless, all our demographic and socioeconomic analyses depended on data from the 2000 and 2010 Brazilian Demographic Censuses. Because the streams were rehabilitated in 2008, our results are limited by the two-year period following the rehabilitation efforts to be reflected in demographic and socioeconomic changes. However, the results indicate the absence of a prior gentrification process in the neighborhoods before the implementation of the rehabilitation efforts when compared with other areas in BH.

Nonetheless, we observed a significant upward relative trend in real estate prices between 2009 and 2019, mainly for houses and for the Baleares and Nossa Senhora da Piedade catchments, when compared to the rest of BH. That is, the rehabilitation efforts were associated with a relative increase in real estate prices in the rehabilitation neighborhoods after the implementation of the rehabilitation efforts. Hence, stream rehabilitation and increased provision of ecosystem goods and services, such as increased recreational uses and aesthetic features, were associated with an increase in real estate prices. This led to local environmental gentrification.

Other authors in the USA and Australia observed similar valuations. For example, Sander and Haight (2012) [10] found real estate appreciation of properties located within 600 m of a rehabilitated stream park in Dakota County, MN, USA. Polyakov et al. (2017) [30] analyzed an aquatic ecosystem rehabilitation in Perth, Australia, and observed an appreciation of home values located within a 200 m radius of the site.

Improved living conditions are associated with decreased overall disease prevalence. We observed this trend for other diseases, cardiovascular diseases, and mental disorders. Initially, we observed increased hospitalizations in waterborne and vector-transmitted diseases relative to the BH shortly after the implementation of the linear parks but a decrease afterwards. Speldewinde et al. (2015) [31] discussed how the incidence of diseases is multifaceted and how ecosystem rehabilitation can increase or decrease disease incidence, depending on a myriad of factors. We observed a relative increase in the prevalence of dengue around the streams in 2009, possibly because of changing environmental factors, including more small standing water reservoirs, where dengue-transmitting *Aedes aegypti* larvae develop. However, over time, the expected results of an improvement in sanitary conditions following the epidemiological transition were observed. In other words, the positive effects of stream rehabilitation were observed a few years after implementation, when a new balance between environmental factors and public health was achieved.

5. Conclusions

The three approaches that we used to quantify the ecosystem service benefits of urban stream rehabilitation in the BHMR can be included in analyses in other countries. Relative to the entire BH, we observed an increase in real estate prices and a delayed decline in waterborne and vector-transmitted diseases, indicating environmental gentrification and lower levels of specific disease prevalence.

Sander and Haight (2012) [10] argued that the economic value of rehabilitation, reflecting the gains in the well-being of the local population due to increases in ecosystem services provision, is often poorly recognized. Our analyses provide empirical findings that help overcome this lack of knowledge.

We did not perform a rigorous economic evaluation of the rehabilitation efforts [32] because it was beyond the scope of this study. However, we can offer a simple illustrative estimate based only on real estate prices that does not include health issues directly. Figure 2 shows the relative values of catchment areas compared to the rest of BH. Therefore, we estimated the total real estate value of all the 1651 transactions in the rehabilitation catchments if the price evolution was similar to the rest of BH. That value is >USD 50 million or a mean value of more than USD 25 thousand per transaction, which is much higher than the USD 14.5 million cost of the rehabilitation efforts.

Our findings have clear policy implications for the future. The quantifiable improvements in real estate values and community health that we presented may be associated with the economic viability of similar proposals for urban stream rehabilitation, particularly in large urban cities in the Global South. Finally, on a planet undergoing intense global change, rehabilitating urban streams and rivers to improve water quality and stream landscapes is an urgent and useful goal for a sustainable future and life improvement in highly populated tropical cities.

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Appendix A

Box A1. Waterborne diseases, vector-transmitted diseases, diabetes mellitus, cardiovascular and related diseases and mental disorders as classified by ICD-10.

Waterborne diseases
A00—Cholera, A01—Typhoid and Paratyphoid Fever, A02—Other Salmonella Infections, A03—Shigellosis, A04—Other Bacterial Intestinal Infections, A05—Other Bacterial Food Poisoning, Not Elsewhere Classified, A06—Amoebiasis, A07—Other Diseases Protozoan Intestinal Infections, A08—Viral, Other and Unspecified Intestinal Infections, A09—Diarrhea and Gastroenteritis of Presumed Infectious Origin, B15—Acute Hepatitis A, B65—Schistosomiasis (bilharzia) (Schistosomiasis), B66—Other Trematode Infestations, B67—Echinococcosis, B68—Taenia Infestation, B69—Cysticercosis, B70—Diphyllobothriasis and Sparganosis, B71—Other Cestoid Infestations, B72—Dracontiasis, B73—Onchocerciasis, B74—Filariasis, B75—Trichinosis, B76—Hookworm, B77—Ascariasis, B78—Strongyloidiasis, B79—Tricuriasis, B80—Oxyuriasis, B81—Other Intestinal Helminthiasis, Not Elsewhere Classified, B82—Intestinal Parasitosis, Unspecified, B8 3—Other Helminthiases and B99—Infectious, Other and Unspecified Diseases.

Diseases transmitted by vectors
A90—Dengue (Classical dengue), A91—Hemorrhagic Fever Due to Dengue Virus, A92—Other Mosquito-Transmitted Viral Fever, A93—Other Arthropod-Transmitted Virus Fever Not Elsewhere Classified, A94—Arthropod-Transmitted Viral Fever, Unspecified, A95—Yellow Fever, A96—Arenavirus Hemorrhagic Fever and B57—Chagas Disease.

Diabetes Mellitus and Obesity
E10—Insulin-dependent Diabetes Mellitus, E11—Non-insulin-dependent Diabetes Mellitus, E12—Malnutrition-Related Diabetes Mellitus, E13—Other Specified Types of Diabetes Mellitus, E14—Unspecified Diabetes Mellitus, E66—Obesity, E78—Disorders of Lipoprotein Metabolism and Other Lipidemias, E88—Other Metabolic Disorders and R73—Increase in Blood Glucose

Strokes and cardiovascular disease
G45—Transient Ischemic Strokes and Related Syndromes, G46—Cerebral Vascular Syndromes Occurring in Cerebrovascular Diseases, I10—Essential Hypertension (primary), I11—Hypertensive Heart Disease, I12—Hypertensive Kidney Disease, I13—Hypertensive Heart and Kidney Disease, I15—Secondary Hypertension, I20—Angina Pectoris, I21—Acute Myocardial Infarction, I22—Recurrent Myocardial Infarction, I23—Some Current Complications Following Acute Myocardial Infarction, I24—Other Acute Ischemic Heart Diseases, I25—Chronic Ischemic Disease I64—Stroke, not specified as hemorrhagic or ischemic, I69.4—Sequelae of stroke not specified as hemorrhagic or ischemic, I70—Atherosclerosis, I71—Aneurysm and Aortic Dissection, I72—Other Aneurysms, I73—Other Peripheral Vascular Diseases, I74—Arterial Embolism and Thrombosis and I77—Other Air Disorders and arterioles.

Mental disorders
F10—Mental and Behavioral Disorders Due to Use of Alcohol, F11—Mental and Behavioral Disorders Due to Use of Opiates, F12—Mental and Behavioral Disorders Due to Use of Cannabinoids, F13—Mental and Behavioral Disorders Due to Use of Sedatives and Hypnotics, F14—Mental and Behavioral Disorders Due to Use of Cocaine, F15—Mental and Behavioral Disorders Due to Use of Other Stimulants, Including Caffeine, F16—Mental and Behavioral Disorders Due to Use of Hallucinogens, F17—Mental and Behavioral Disorders Due to Use Smoking, F18—Mental and Behavioral Disorders Due to the Use of Volatile Solvents, F19—Mental and Behavioral Disorders Due to the Use of Multiple Drugs and the Use of Other Psychoactive Substances, F32—Depressive Episodes, F33—Recurrent Depressive Disorder, F34—Disorders Persistent Mood Disorders (affective), F38—Other Mood Disorders (affective), F39—Mood Disorder (affective) Unspecified, F40—Phobic Anxiety Disorders, F41—Other Anxiety Disorders and G47—Sleep Disorders.

Appendix B

Table A1. Results of the hedonic models for houses and apartments for each stream rehabilitation separately.

Variables	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
	All		**Houses**		**Apartments**	
Year * Location Interactions						
Baleares						
2009	Reference					
2010	−0.0248	0.0502	0.0754	0.0781	−0.0701	0.0449 **
	(0.0379)	(0.0295)	(0.0694)	(0.0827)	(0.0919)	(0.0171)
2011	0.167	0.288 **	0.279 *	0.307	0.124	0.278 **
	(0.0920)	(0.0740)	(0.138)	(0.191)	(0.104)	(0.0266)
2012	0.105	0.151 **	0.398 **	0.326 **	−0.109	0.0482
	(0.0607)	(0.0389)	(0.0285)	(0.0332)	(0.0789)	(0.0319)
2013	0.235 *	0.170 **	0.281 **	0.217 **	0.235	0.122
	(0.110)	(0.0490)	(0.0703)	(0.0485)	(0.158)	(0.0642)
2014	0.187 *	0.0570	0.173	0.139	0.213 *	−0.00823
	(0.0854)	(0.0356)	(0.144)	(0.146)	(0.124)	(0.0521)
2015	0.179 **	0.0796 *	0.399 **	0.340 **	0.130	−0.0416
	(0.0637)	(0.0310)	(0.0447)	(0.0995)	(0.128)	(0.0393)
2016	0.258 **	0.171 **	0.415 **	0.401 **	0.225	0.0363
	(0.0650)	(0.0498)	(0.0587)	(0.0271)	(0.148)	(0.0526)
2017	0.215 *	0.152 **	0.403 *	0.371 *	0.139	0.0184
	(0.0907)	(0.0334)	(0.188)	(0.178)	(0.152)	(0.0375)
2018	0.207 **	0.196 **	0.298 **	0.326 **	0.0724	0.0411
	(0.0540)	(0.0439)	(0.0750)	(0.0683)	(0.136)	(0.0344)
2019	0.246 **	0.186 **	0.374 **	0.331 **	0.126	0.0668 **
	(0.0359)	(0.0458)	(0.0801)	(0.0433)	(0.114)	(0.0239)
Nossa Senhora						
2009	Reference					
2010	0.487 **	0.394 **	0.649 **	0.536 **	0.0818 **	0.170 **
	(0.188)	(0.132)	(0.157)	(0.164)	(0.0211)	(0.0151)
2011	0.390 **	0.344	0.493 **	0.417	−0.175 **	−0.300 **
	(0.0769)	(0.185)	(0.186)	(0.381)	(0.0216)	(0.0225)
2012	0.376 **	0.352 **	0.346 **	0.298 **	0.219 **	0.114 **
	(0.0939)	(0.0356)	(0.126)	(0.0974)	(0.0208)	(0.0173)
2013	0.259 **	−0.0328	0.132	−0.433 **	0.345 **	0.484 **
	(0.0255)	(0.0862)	(0.0790)	(0.127)	(0.0275)	(0.0192)
2014	0.816 **	0.409 *	0.503 *	0.254	0.373 **	0.255 **
	(0.213)	(0.203)	(0.227)	(0.284)	(0.0316)	(0.0296)
2015	1.490 **	1.068 **	1.337 **	0.962 **	0.192 **	0.345 **
	(0.502)	(0.287)	(0.355)	(0.236)	(0.0292)	(0.0213)
2016	0.744 **	0.493 **	0.409 **	0.361	0.260 *	0.216 **
	(0.0951)	(0.175)	(0.0841)	(0.190)	(0.118)	(0.0571)
2017	0.854 **	0.403 **	0.693 **	0.120	0.309 **	0.240 **
	(0.104)	(0.0718)	(0.0743)	(0.0770)	(0.100)	(0.0547)
2018	0.208	0.0842	0.375 *	0.161 *	0.363 **	0.126 *
	(0.114)	(0.0977)	(0.149)	(0.0729)	(0.0959)	(0.0599)
2019	0.620 *	0.451 **	1.061 **	0.801 **	0.284 **	0.205 **
	(0.310)	(0.155)	(0.0854)	(0.177)	(0.0491)	(0.0281)
Primeiro de Maio						
2009	Reference					
2010	−0.0417	−0.132	−0.308 *	−0.284	0.379 **	0.0799 *
	(0.178)	(0.122)	(0.156)	(0.171)	(0.0398)	(0.0467)
2011	−0.0289	−0.281	−0.142	−0.438	0.513 **	0.422 **
	(0.124)	(0.254)	(0.230)	(0.432)	(0.0398)	(0.0377)

Table A1. *Cont.*

Variables	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
	All		**Houses**		**Apartments**	
Year * Location Interactions						
2012	−0.218 * (0.0969)	−0.356 ** (0.0804)	−0.371 ** (0.139)	−0.367 ** (0.123)	0.0931 * (0.0398)	0.0206 (0.0327)
2013	0.227 ** (0.0722)	0.256 * (0.117)	0.285 ** (0.109)	0.581 ** (0.137)	0.00142 (0.0398)	−0.257 ** (0.0287)
2014	−0.318 (0.225)	−0.155 (0.236)	−0.158 (0.211)	−0.0883 (0.284)		
2015	−1.121 * (0.461)	−0.905 ** (0.251)	−1.336 ** (0.265)	−0.995 ** (0.152)	0.127 (0.121)	−0.104 (0.0626)
2016	−0.285 ** (0.0829)	−0.269 (0.164)	−0.0232 (0.0712)	−0.162 (0.161)		
2017	−0.320 * (0.152)	−0.180 (0.119)	−0.164 (0.0976)	−0.0606 (0.118)		
2018	0.261 (0.138)	0.147 (0.137)	0.0487 (0.158)	0.141 (0.0995)	−0.0692 (0.0449)	0.107 ** (0.0331)
2019	−0.193 (0.286)	−0.265 (0.142)	−0.779 ** (0.118)	−0.561 ** (0.213)		
Controls for zone type	Yes	Yes	Yes	Yes	Yes	Yes
Controls for size and finishing standards	No	Yes	No	Yes	No	Yes
Observations	226,860	226,860	34,894	34,894	191,966	191,966
R-squared	0.361	0.649	0.362	0.573	0.362	0.679

Controls for year, catchment area, sex and age are included in the models. ** $p < 0.01$, * $p < 0.05$.

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