Universität Augsburg

Fakultät für Angewandte Informatik

Institut für Geographie

Deutsches Zentrum für Luft- und Raumfahrt e.V.

Earth Observation Center

Deutsches Fernerkundungsdatenzentrum

Slums in Rio de Janeiro

Spatial and morphologic analyses of slums derived from remote sensing data based on visual image interpretation

Bachelor Thesis

Author
Fricke, Jonas
Matriculation No.: 1296388
B.Sc. Geography
Mail: jonas_fricke@web.de

Adviser
Dr. Michael Wurm
Deutsches Zentrum für
Luft- und Raumfahrt (DLR)
Deutsches Fernerkundungszentrum (DFD)

Reviser
Dr. Andreas Klima
Lehrstuhl für Humangeographie
Universität Augsburg

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1 Introduction

As the earth's population is growing continuously, so does the amount of people living in urban areas all over the world. The largest part of this growth is taking place in the world's developing countries. Due to this increase, especially in these developing countries, enormous urban structures, often with more than ten million inhabitants, are emerging – so called mega cities. Because of the omnipresent lack of enough suitable housing many people are forced to dwell in informal settlements. Since this is an illegal process, it is very difficult to observe and control these developments. Furthermore, it is nearly impossible to organize and govern mega cities due to their enormous extents. Even if data are available e.g., about housing quantity, quality or land tenure, in most cases data are not complete (Taubenböck et al. 2012: 162). This incompleteness requires accurate research to support the local governments of cities or states facing that mentioned problem, like in this study the metropolitan region of Rio de Janeiro.

Furthermore, general research about such future relevant issues helps to understand these concerns and leads to solutions that can support the process of solving these problems. Doing research with the method of using remote sensing data has many advantages. First, up-to-date and area-wide remote sensing data are available for free and in the quality of very high spatial resolution. Second, in contrast to conventional methods, it only requires little manpower with the benefit of making research cost efficient. All these advantages enable governments of developing countries to compensate for their lack of finances and qualified employees. The main difficulty is the derivation of the slum areas from remote sensing data. Since the official definition of slums introduced by the United Nations only uses qualitative characteristics, such as lack of sewage systems or drinking water (UN-Habitat 2003: 11f.) which are not visible from above, another definition of slums using visible morphologic characteristics has to be found. Based on these morphologic characteristics, such as e.g. slum size, building density or amount of storeys, it is interesting how various types of slums differ. According to Ford (1996: 437ff.) Latin American slums mostly are found in peripheral locations, which leads to the challenge whether this can be proven for Rio de Janeiro using remote sensing data and furthermore, whether diverse slum types show the same spatial pattern. Moreover, slums tend to be located in disadvantaged areas that are not suitable for settlement e.g. on steep slopes (UN-Habitat 2003: 11). Thus, this has to be tested for the derived slums.

Due to the lack of a generally accepted definition of slums, this study starts with the discussion of different definitions of the term slum. After that, a short summary about slums in Latin America in general and in Rio de Janeiro in particular is given. The second section ends with a survey of the current state of research of slum-mapping with remote sensing data.

The third section clarifies all of the used data. It starts with a short overview of the study area – the metropolitan region of Rio de Janeiro – followed by the introduction of the used external data sets revealing their benefits and limitations for this study. It ends with the presentation of the produced data including the mapping of the slum polygons and assignment of morphologic characteristics.

The fourth chapter places the emphasis on the analysis of the slums based on the produced data. The first step is a contemplation of the spatial distribution of different slum types. Afterwards, the differences between the slum categories in terms of the four morphologic characteristics slum size, building density, average building height and average slope are presented and discussed.

This study concludes with a summary and comparison of the results of the analyses, confirms the classification of the slum categories and ends with a short outlook.

2   Background

The aim of this chapter is to explicate the theoretical background. Thus, it starts with the discussion of different definitions of the term slum and the clarification of its meaning for this study. Afterwards, a general overview of slums in Latin America is given which is followed by the explication of the history and the handling of slums in Rio de Janeiro. The chapter ends with a summary of the current state of research in slum-mapping using remote sensing data.

2.1   Definitions of the term slum

At first it has to be mentioned that there are many different definitions of the term slum in literature. However, there are also several synonyms in use (Taubenböck/Kraff 2013: 17). Hence it is necessary to define how the term slum is used in this particular thesis.

The first verified definition of the term slum was given by James Hardy Vaux in his "Vocabulary of the Flash Language" in the year 1812, when it was used for racketeering (Davis 2007: 26). In comparison, according to Harris (2009: 158) the term slum dates back to the 1820s. First being used only for rooms it was then also used for poorer districts of London and other industrial cities of the United Kingdom, northwestern Europe and later North America as well.

Today the term slum is defined as "a residential area with substandard housing that is poorly serviced and/or overcrowded, and therefore unhealthy, unsafe, and socially undesirable" (Harris 2009: 157). Furthermore, the United Nations (UN-Habitat 2003: 8f.) characterize slums by physical and spatial criteria of high densities and low standards of housing. Additionally, social and behavioural criteria like squalor (and suffering of the population) are important characteristic traits. This definition also includes the traditional meaning of the term slum, which implies old buildings that were once inhabited by wealthy people of the upper class, but are now run-down, subdivided and overcrowded by groups of lower income. In addition to that, slums are divided in the two categories "slums of hope" and "slums of despair" which differ in their development and environmental conditions (UN-Habitat 2003: 8).

As mentioned above, there are other terms for slums whose definitions differ in particular characteristics. Like slums the term "squatter settlement" generally describes low-quality housing and particularly illegal land occupation, but in contrast to slums it does not include rental housing. Furthermore, squatter settlements are usually located at the periphery of cities. However, even though "informal settlements" are quite similar to squatter settlements, they are not necessarily illegal. It is also possible that the settlers bought their land legally from the previous landowner who subdivided his land illegally before selling it. Compared to the status of land tenure the term "shanty town" only refers

to the condition and quality of the dwellings which often are constructed out of cheap and easily accessible materials like cardboard, plastic and corrugated iron (Willis 2009: 403).

Since there is no general definition and since the few listed above also vary in decisive details UN-Habitat (2003: 10f.) summarizes the different definitions in the following attributes of slums: Lack of basic services, substandard housing or illegal and inadequate building structures, overcrowding and high density, unhealthy living conditions and hazardous locations, insecure tenure (irregular or informal settlements), poverty and social exclusion and finally minimum settlement size. An operational definition is combined out of these attributes and specifies "a slum as an area that combines to various extents, the following characteristics […]: inadequate access to safe water, inadequate access to sanitation and other infrastructure, poor structural quality of housing, overcrowding, insecure residential status." (UN-Habitat 2003: 12).

All these mentioned definitions primarily are very qualitative and thus not helpful for mapping slums during visual image interpretation. Hence, to derive slums from remote sensing data, a quantitative definition is necessary that includes morphologic characteristics that are visible from above. So in this study the term slum is used for the type of settlement that shows distinct morphological parameters such as very high building densities, cheap roof materials, heterogeneous visual appearance, and presence of open space (Kuffer et al. 2013: 3). Furthermore, the term favela is used as a synonym, because it is the Brazilian term for slums (UN-Habitat 2003: 10).

2.2   Slums in Latin America

Despite the fact that the growth of mega cities in Latin America, in comparison to the rest of the developing countries, already slowed down (Borsdorf 2004: 9f.) and levels of urbanization have reached values of about 80 percent in the beginning of the 2000s, housing qualities are often very low and slum areas are ubiquitous in most of the major cities (UN-Habitat 2003: xxv).

To achieve a better understanding of slums in cities like Rio de Janeiro it is necessary to analyse Latin American cities in general. The origin of today's cities in Latin America almost exclusively dates back to the colonisation of the continent by the Spanish and Portuguese. They founded most of their cities on or near the coast (Violich/Daughters 1987: 2) in the short period from 1520/30 to 1570/80. Even today these cities are the key elements of the urban system in Latin America (Heineberg 2014: 295). Especially the cities founded by Spanish settlers were precisely planned in a similar manner and, in addition, all of the Latin American cities were affected by related conditions until today. So it was possible to describe the major cities with the model of the Latin American city (e.g. Bähr 1976, Griffin/Ford 1980, Bähr/Mertins 1981). Only for convenience the "new and improved model of Latin American city structure" (cf. figure 1) by Ford (1996: 438) will be discussed below. Since it is simple and yet includes all important components it is

used representatively for all existing models. The differences from the other models will be added and discussed afterwards.

**Figure 1: A new and improved model of Latin American city structure
(Ford 1996: 438)**

Ford (1996: 439f.) first of all points out that all of the depicted zones are supposed to contain mixed uses to a certain extent. Moreover, the model of the Latin American city basically exists of three concentric zones (maturity, in situ accretion, and peripheral squatter settlements), in which the quality of housing decreases with growing distance from the urban centre (Griffin/Ford 1980: 405). Its core is characterized by a market and the commercial zone, which is mostly concentrated in the core itself, but additionally extends through the elite residential sector up to a mall or a competing and newly developed edge city. The three concentric zones are interspersed with the elite residential sector mentioned above, a sector of disamenity where, besides the zone of peripheral squatter settlements, the poorest people live. Finally, the industrial sector mostly follows railways and highways (Ford 1996: 439) leading from the city centre to an industrial park. Moreover it is situated at the fringe of the city. It is assumed that in most Latin American cities a "periferico" or ring highway connects this industrial park to the mentioned mall and the "edge cities" and furthermore acts as a border between the old and the new spreading parts of the city. After all, two areas neither match the concentric nor the sectoral pattern of the other zones. Hence, firstly the middle-class residential track is attached to the elite residential sector but it only occurs in the periphery of the city

or sometimes in the zone of in situ accretion next to the industrial park (Ford 1996: 440). Secondly, there is an area in the zone of maturity close to the central business district (CBD) and the elite residential sector where processes of gentrification are visible.

The biggest difference between the models of Ford (1996: 437ff.) and Bähr (1976: 127ff.) and Bähr/Mertins (1981: 15ff.) is that the two latter include the dynamic component of migration. This increases the precision of the models as well as their complexity. In addition, in contrast to Ford's zone of peripheral squatter settlements, many individual slum settlements are proposed which can be distinguished by their legal status and their spatial appearance (inner-city vs. peripheral). Furthermore, a complete zone of inner-city slums is added which is located around a zone of mixed uses.

Summarizing, it can be stated that on the one hand mainly small slums can be found in the centre of the city. On the other hand the largest slums can be expected at the periphery of the city. The latter is proved by Violich and Daughters (1987: 8) for the cities of Mexico City, Lima, Santiago and Buenos Aires. However, it leaves the question whether the same holds true for Rio de Janeiro. Hence it has to be analysed whether Ford's theory (1996: 437ff.) also applies to the chosen study area using quantitative data derived from remote sensing data.

2.3 Slums in Rio de Janeiro

45 years ago Parisse (1970: 197ff.) already declared that slums in Rio de Janeiro, generally named favelas, are a very heterogeneous phenomenon. Especially today they can be distinguished by the socio-economic diversity of their dwellers. The reason for that is an economical regression in the 1980s, which caused mainly people of the lower middle class to move to favelas due to reduced living costs in slums (O'Hare/Barke 2002: 237). However, UN-Habitat (2003: 225) identified four different types of slums in Rio de Janeiro: Favelas, Loteamentons, Invasoes, and Cortiços.

Favelas and Invasoes (cf. squatter settlements in chapter 2.1) are both self-built and established illegally on occupied public or private land without following any rules of urban planning. They only differ in their state of consolidation, whereas Favelas are located all over the city and Invasoes can mainly be found on disadvantaged spots like riverbanks, swamps, steep hills or alongside roads. Loteamentons (cf. informal settlements in chapter 2.1) are characterised by an illegal subdivision of the land and are especially located in the eastern part of the city. All three mentioned types of slums lack of basic infrastructure and services. Furthermore, all slums of these three types, but especially Invasoes, tend to be located in mainly naturally disadvantaged areas. As a result, they run the risk of being flooded or buried by landslides.

Cortiços, however, are the counterpart to the traditional meaning of the term slum mentioned in chapter 2.1. They could be considered as a part of social housing but always only single or few buildings are comprised in that definition. Mostly due to

overcrowding living conditions are very bad in all of the Cortiços. This type of slum is mostly associated with older buildings and hence it is mainly located in the old city centre.

2.3.1 History and facts

In 2010, an estimated population of nearly 1.5 million lived in the slums of Rio de Janeiro (Cavallieri/Vial 2012: 5), which is the result of a process of about 135 years. The history of favelas in Rio de Janeiro began in 1881 when three small slums emerged, because the poorest families could not afford the lowest rents in existing houses. The first bigger slum, "Morro de Providencia", was founded in 1898 by returning military veterans who did not find any accommodation in the city (O'Hare/Barke 2002: 232). The following establishments of new favelas in the city of Rio de Janeiro can be seen in table 1, which shows the development in time periods of 20 years.

Table 1: Creation of new favelas in the city of Rio de Janeiro
(O'Hare/Barke 2002: 228)

Period of origin	No. of new favelas
pre 1900	6
1900-1920	20
1921-1940	90
1941-1960	182
1961-1980	163
1981-1999	124
Total	**585**

Hence, in the first 40 years of slum foundation the increase of new slums occurred very slowly. After that the growth doubled from 90 new slums in the period of 1921 to 1940 up to 182 new favelas between 1941 and 1960. Although the overall number of new slums dropped to 163 between 1961 and 1989 and 124 between 1981 and 1999, there was a huge gain of new favelas during this period of time.

The reason of the increased count of slums in Rio de Janeiro was the interaction of various phenomena such as high fertility rates, industrialisation and migration from rural areas to the city (UN-Habitat 2003: 225). Especially after 1940, the high number of new favelas can be explained by the fact that, mainly industrialisation resulted in a huge migration wave to the city (Barke et al. 2001: 262) even though adequate housing was not available in sufficient amount. This enormous increase of population after 1940 is illustrated in figure 2.
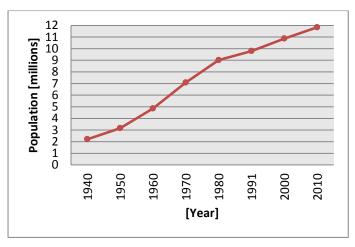
Figure 2: Development of inhabitants of the metropolitan region of Rio de Janeiro (Data source: 1940-1991: Gilbert 1995: 94; 2000-2010: Brinkhoff 2015)

Thus, during the 40 years with the highest numbers of new slums (1941 - 1980) also the population grew very fast. Within these 40 years the area of today's metropolitan region of Rio de Janeiro gained a massive amount of nearly seven million inhabitants.

In addition to the gain of new slums, especially in the southern zone of the city in the 1980s, the already existing slums underwent the process of densification and verticalization (Pamuk/Cavallieri 1998: 453). That means that on the one hand new buildings were added and on the other hand already existing buildings were extended with additional storeys (O'Hare/Barke 2002: 236). This leaves the question whether these processes took place all over the study area, and furthermore whether they are still in progress. Therefore, this will be analysed later on.

2.3.2 Handling of slums

Just as diverse as the slums are themselves, also the handling by the authorities of these settlements varied in approaches, which changed significantly over the last 135 years. The first strategy in handling slums was given by the Agache Plan in 1930 which emphasised the importance of their eradication by pointing out the need to save public health and security (Gilbert 1995: 144). To realise the execution of this strategy a programme called "Parque Proletario" was launched in the early 1940s (Oliveira 1996: 75) and even a specific Squatter Settlement Extinction Commission was installed (O'Hare/Barke 2002: 234). This approach of eradication and resettlement was vitalised and promoted by the military government partly cooperating financially with the United States Agency for International Development (USAID) and mainly targeting slums near residential areas of the upper-income class or spreading industrial areas (Barke et al. 2001: 263). Besides the hygienic and security reasons, the eradication strategy often was used to clear space for new urban projects such as roads, high-rise apartment buildings for the upper-income class or even parks (Gilbert 1995: 115).

After this period of eradication and resettlement, which occurred until 1975, a political disinterest appeared and lasted until 1983. After that the new approach not to eradicate

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but upgrade and integrate the favelas into the existing structure of the city emerged with the election of the state governor Leonel Brizola in 1982. Since then, several favela upgrading programmes were installed which were enabled by the implementation of democratic institutions (Pamuk/Cavallieri 1998: 454f.). A further reason for the avoidance of the eradication approach was the sheer amount of favelas that would have needed to be destroyed (Barke et al. 2001: 264).

The slum upgrading approach of Favela Bairro had the highest influence due to its large resources and political attention (Riley et al. 2001: 521). This programme was launched in 1993 and its goal was to enhance the living conditions of the slum inhabitants by installing adequate sanitation services, to link the favelas with the existing city structure, to supply social services appropriate to the dwellers, and to legalise land tenure (Pamuk/Cavallieri 1998: 456). However, also this programme had limits. There was a financial support by the Inter-American Development Bank which was limited to 2,500 US$ per family (Acioly Jr. 2001: 515). To reach the maximum amount of 4,000 US$ being spent per household the difference of 1,500 US$ was compensated by the municipality (Riley et al. 2001: 526). Due to this financial limitation slums were selected for the programme only where upgrading was reasonable. Hence, more than 100 slums were excluded because an upgrade would not have been feasible (Acioly Jr. 2001: 516). Until 2006 178 slum settlements have been upgraded by the Favela Bairro programme in two phases spending a total amount of 600 million US$ (Dias Simpson 2013: 14). However, even though more than 145,000 supposedly successful households were reached (phase 1: 69,226 (Riley et al. 2001: 528); phase 2: 75,796 (Magalhães/Villarosa 2012: 140)) Dias Simpson (2013: 14) points out that only the physical component was accomplished while the promised social and economic improvements were neglected.

Due to these unsuccessful social upgrading attempts violence emanating from the slums and the settlements themselves grew further. This lead amongst others to the controversial approaches of invisibilisation and transformation of Rio de Janeiro's slums in combination with sporting mega events such as the FIFA World Cup 2014 and the Olympic Games in 2016. The invisibilisation process is simply enforcing the disappearance of slums either by destroying them or hiding them behind high walls or by deleting them in visual media like Google[TM] Maps (Steinbrink 2013: 132ff.). In comparison to this approach the process of transformation firstly appears more sustainable and not as cruel as the invisibilisation of slums. In fact, at first the favelas are pacificated by armed special police and military forces to disperse the local drug traffickers. After the occupation of the slum a station of the Unidade de Policia Pacificadora (UPP) is established to guarantee the control of public security. Like during the Favela Bairro programme, the official goal of this approach is to implement social and economic services. But the recent past showed that the pacification is only used to realise the beautification of the favela itself and the valorisation of its surroundings (Saborio 2013: 131ff.).

The aim of the government is to pacify the majority of the city's slums until the Olympic Games in 2016 with the help of 60,000 new recruited UPP-officers (Pellacini 2011: 622). Both of the described processes have to be considered very critically. On the one hand in particular slums are transformed or made invisible which are located near to the places where the sporting mega events take place and not in the areas with higher violence rates (Saborio 2013: 133). On the other hand the pacification of slums leads to gentrification processes and touristic valorisation and hence to the rise of housing prices what affects the eviction of the original slum dwellers (Steinbrink 2013: 143).

2.4 Slum-mapping with remote sensing data

For the purpose of mapping slums a variety of approaches can be applied. The most accurate is to map them in situ which easily results in a very labour-intensive and expensive undertaking. Because of that and due to the improved availability and quality of remote sensing data especially in very high resolution (VHR), various studies used remote sensing data to map slums in cities all over the world.

The main challenge of slum mapping is first of all to locate the existing buildings and afterwards to distinguish between formal and informal areas. Therefore all approaches use the morphological characteristics of formal and informal settlements which are designated by different values of building density, size of buildings and their spatial arrangement, street pattern and presence of open and green space (Kuffer et al. 2013: 3, Graesser et al. 2012: 1166).

To finally get to the delineation of slum areas there are different methods. Kit and Lüdeke (2013: 131ff.) extracted slums in Hyderabad, India, from QuickBird and World View 2 images using edge and line detection tools as well as lacunarity thresholds. In comparison to that, Kuffer et al (2013: 3ff.) generated homogenous urban patches using object based analysis and then they characterized them by means of building density, greenness, occurrence of formal buildings (delineated with a grey-level co-occurrence matrix (GLCM)), and shape complexity. Based on these values informal settlements in Mumbai, India, could be identified. In the same city also Weigand (2014: 4) delineated informal settlements based on analysis of second order texture features of multi-polarized synthetic aperture radar (SAR) data using Kennaugh-elements and linear discriminant analysis. Furthermore, Hofmann et al. (2008: 531) mapped slums from VHR data using an object based approach in Rio de Janeiro. However, one of the most lavish approaches was executed by Graesser et al. (2012: 1164). They used e.g. GLCM, Histogram of Oriented Gradients, line detection, lacunarity and vegetation indices to differ between either two formal and informal settlement areas in four different cities achieving very high accuracies between 85% and 92%. By using three dimensional data, like building heights or density, in addition to VHR satellite images, Taubenböck and Kraff (2013: 15ff.) developed a different approach to distinguish slums from formal settlements.

In comparison to these automated detection methods a few studies classified slums by visual interpretation of high or very high resolution satellite images. Angeles et al. (2009: 8ff.) and Gruebner et al. (2014: 1ff.) mapped slums in Bangladeshi cities using IKONOS, IRS and QuickBird data. While Angeles et al. (2009: 10f.) did large fieldwork in order to prove the quality of the data, Gruebner et al. (2014: 2) especially used Google[TM] Earth timescale images and geolocated amateur photographs to verify their results. The work of Gunter (2009: 388ff.) suggests using Google[TM] Earth as the basemap for mapping slums due to the fact that these information is not charged for, which is a meaningful advantage especially for governments of the global south.

3 Data

This section first describes the study area and then introduces the external used data before presenting the generated data.

3.1 Profile of the study area

The study area is the metropolitan region of Rio de Janeiro, which was founded in 1974 (Gilbert 1995: 101f.) and is located around the Guanabara Bay in the southeast of Brazil (cf. figure 3).

Figure 3: Study area - Municipalities of the metropolitan region of Rio de Janeiro (background imagery: Esri World-Imagery)

The city of Rio de Janeiro was founded by Portuguese explorers in the year 1565 as the city of "São Sebastião do Rio de Janeiro" subsequent to the first permanent settlement which was installed out of military reasons 29 years before. It gained more importance after the province of Rio de Janeiro was established in 1619. Due to its success in gold trading, the growing economic strength and the already existing improved urban form it became the capital of colonial Brazil in 1763. At this time the city already counted 50,000 inhabitants but the most important effect to urban growth and the political influence was the arrival of the royal family of Portugal. They escaped the Napoleonic Wars in Europe in 1808 and declared Rio de Janeiro the capital of the Portuguese empire. With Brazil achieving its independence from Portugal in 1822, Rio de Janeiro also became the capital of the Brazilian empire and furthermore the leading industrial, commercial and cultural centre of Brazil. It was at the turn of the 20th century when the city had its highest growing rates and the low-income suburbs emerged and grew in the "Fluminense Lowlands" north to Rio de Janeiro. The city remained the most important Brazilian

agglomeration until the second half of the 20th century, when the capital was moved to Brasilia in 1960 and São Paulo overtook Rio de Janeiro in both population and economic importance (Gilbert 1995: 93ff.). After this loss of supremacy, the city of Rio de Janeiro became the city state of Guanabara for compensation of the abolition of its federal district. Such a city state was unique in Brazil and only lasted until 1974 when it was merged with the surrounding state of Rio de Janeiro. Only after this fusion the metropolitan region could be invented because metropolitan regions were impossible to be cross-border (Gilbert 1995: 100ff.). Although Rio de Janeiro suffered from the mentioned loss of political and economic importance the city nevertheless still remains the cultural and touristic centre of Brazil (Acioly Jr. 2001: 510).

Today the metropolitan region of Rio de Janeiro can be characterized as a very heterogeneous agglomeration which is interspersed with various types of neighbourhoods. The region can be divided into the richer southern, the old central, and the poorer northern zone. While the southern zone basically consists of high-rise apartment buildings for groups of higher income, the northern zone is characterised by low-income suburbs, favelas, and industrial parks, whereas the old central zone remains the central business district with its office towers (Ribbek 2003: 154).

The metropolitan region of Rio de Janeiro was selected as the study area because on the one hand the city structure outreaches the administrative border of the city of Rio de Janeiro and on the other hand existing literature mostly considered only the city itself when studying favelas in that region (e.g. Pamuk/Cavallieri 1998: 449:ff., Barke et al. 2001: 259ff., O'Hare/Barke 2002: 225ff., Hofmann et al. 2008: 531ff.). Today it includes the 19 municipalities listed in table 2 covering an area of 5,292 km², with an overall population of 11,838,752. Hence the metropolitan area of Rio de Janeiro is a so called mega city with more than ten million inhabitants.

Table 2: Population, area and population density of the municipalities of the metropolitan region of Rio de Janeiro (Palladini 2011: 4)

Municipality	Population (Year 2010)	Area in km²	Population density
Rio de Janeiro	6,323,037	1,182	5,348
São Gonçalo	999,901	249	4,013
Duque de Caxias	855,046	465	1,840
Nova Iguaçu	795,212	524	1,518
Niterói	487,327	129	3,767
Belford Roxo	469,261	80	5,881
São João de Meriti	459,356	35	13,185
Magé	228,150	386	592
Itaborai	218,090	424	514
Mesquita	168,403	35	4,844
Nilópolis	157,483	19	8,221
Queimados	137,938	77	1,793
Maricá	127,519	362	352
Itaguaí	109,163	272	402
Japeri	95,391	83	1,152
Seropédica	78,183	284	275
Guapimirim	51,487	361	143
Paracambi	47,074	179	262
Tanguá	30,731	147	210
Total	**11,838,752**	**5,292**	**2,237**

In contrast to the total population density of 2,237 people per km² there are some municipalities which have much higher or lower values. The highest density values of the two municipalities São João de Meriti and Nilopolis (13,185 and 8,220 inhabitants per km²) can be explained by little shares of non-built-up areas. Compared to that there are communities like Guapimirim, Paracambi, Seropédica, and Tanguá (all less than 300 inhabitants per km²) which all include a large area which is covered by forest or agricultural land. An additional aspect influencing the population density is the natural landscape which makes it very difficult to settle in certain areas. Hence, for the settled areas e.g. in the city of Rio de Janeiro even higher population density values can be expected than the overall value of 5,348 because larger areas are impossible to urbanize due to very high slopes.

3.2 ASTER digital elevation model

Considering Rio de Janeiro's partly rough topography it is reasonable to get adequate information about the average slope. This information will be considered in the analyses proving whether the slums are located in disadvantaged areas. This data is derived from the ASTER digital elevation model (DEM), which is a product of METI (Japanese Ministry of Economy, Trade and Industry) and NASA (US-American National Aeronautics and Space Administration), by using the Esri slope tool. This tool calculates the gradient of each raster cell. Both the input DEM and the output slope data sets have a spatial

resolution of 30 metres. Figure 4 shows the output dataset with the five defined classes of slope displayed by green (minor slopes of zero to five degrees), yellow/orange (slopes between five and ten degrees) and red (slopes greater than ten degrees) colours. The classification steps of 2.5 degrees were chosen to identify for construction disadvantaged areas and to get a precise overview of the given topography of the study area. Furthermore this classification has equal class widths and anyway allows accurate analyses.
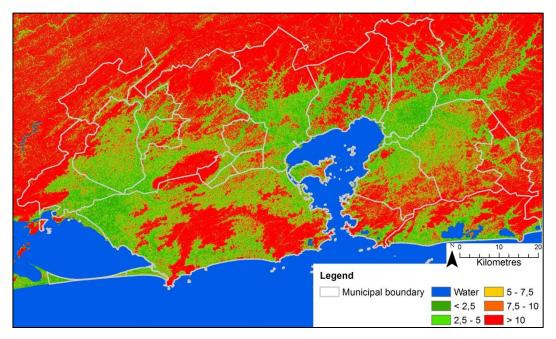

Figure 4: Calculated classes of slope

Moreover, figure 4 underlines the above mentioned rough topography of the study area showing large areas with very high slope values over ten degrees mainly in the city of Rio de Janeiro itself and at the edge of the study area. The eventually used average slope of the slum blocks is calculated as follows. At first, every cell of the raster data set is converted into a point holding the slope information. After that, the average slope of a slum block is deviated by calculating the mean value of all points that are included in the respective slum block.

3.3 Urban footprint

Since slums are growing and emerging over the years it is necessary to get a temporal component to the slum dataset. In addition, a reference area is needed to derive the percentage of slum area in comparison to the settled area. Using remote sensing data it is comparatively cheap and easy to get accurate spatial and temporal data about growing mega cities and the informal and mostly illegal process of the appearance and growth of slums. Taubenböck et al. (2012: 162ff. and 2014: 177ff.) introduced an approach to monitor the urbanization of the then existing 27 mega cities of the world at four different time steps producing a so called urban footprint. This urban footprint can be interpreted

as a settlement mask including all man-made structures. To derive this urban footprint three different Landsat datasets (MSS for 1975, TM for 1990, and ETM+ for 2000) and TerraSAR-X data for the year 2010 were used. For delineating the urbanized areas from the Landsat data a hierarchical, object-based classification algorithm was used eliminating water, vegetation and soil in this order. In contrast to that the TerraSAR-X data were classified by a pixel-based algorithm introduced by Esch et al. (2012: 5ff.). This data enables spatial as well as temporal analyses of settlement patterns and based on that the derivation of further information of the temporal development of slums.

Before using the urban footprint for further analyses it is necessary to prove the quality of the data. An adequate approach for such a revision is the calculation of the overall accuracy based on an error matrix introduced by Congalton (1991: 36f.). To get to the overall accuracy 100 random check points were set both inside the urban footprint and outside of it (but inside of the study area). Then they were compared to the Esri World-Imagery-basemap proving whether the check points were truly classified. This was exemplarily processed for the complete urban footprint, considering all time steps at once, comparing it to current reference data from 2014. The resulting error matrix is shown in table 3.

Table 3: Error matrix of urban footprint

Prediction	Reference	
	Settled area	Not settled area
Settled area	78	22
Not settled area	9	91
Total	**87**	**113**

This error matrix shows that the settled area is overestimated in comparison to the unsettled area. Contemplating the given data it becomes obvious that especially in the outer forest regions of the study area geometric structures were identified as urban particularly at the 2010 time step. Furthermore, from the error matrix above another indicator of data quality, namely the kappa coefficient introduced by Cohen (1960: 39f.), can be calculated. The resulting values of both indicators are 84.5 percent for the overall accuracy and 0.69 for the kappa coefficient. Comparable studies of Taubenböck et al. (2012: 173) show similar values of these two indicators. This legitimates the use of the urban footprint for analysing e.g. the percentage of slum area in comparison to the total urban area.

The urban footprint for the study area is shown in figure 5 at the four time steps 1975 (yellow), 1990 (orange), 2000 (red), and 2010 (brown).
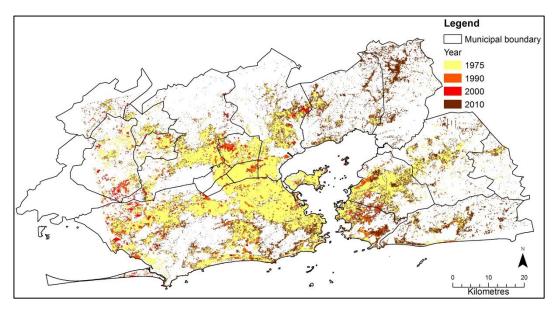
Figure 5: Urbanized area of the study area
(Layout and data: Taubenböck et al. 2012)

More than half of today's built-up area had already been urbanized in 1975, whereas in the following 30 years only some small regions at the edge of the already existing areas were built up. In the period of 2000 to 2010 a major increase of the urbanized area can be identified in the north eastern and south eastern part of the study area, mainly in the municipalities of Guapimirim, Niterói, and Maricá.

Despite the high overall accuracy and kappa coefficient of the urban footprint, there is the disadvantage of missing urban footprint data in the western and northwestern part of the study area limiting the area for further analyses. Yet, the few slums located outside of the limited area can be neglected because of their small quantity, and therefore this has no effect on further analyses.

3.4   Data acquisition

This chapter describes the process of acquisition of the generated data.

3.4.1   Mapping of slum polygons

To delineate the slums of Rio de Janeiro polygons were drawn during visual interpretation of the Esri World-Imagery-basemap. The slums were identified according to the definition of Kuffer et al. (2013: 3) mentioned in chapter 2.1, thus based on the differing morphological characteristics compared to their surrounding areas. The digitizing process was simplified by the generation of a grid covering the whole study area and containing 274 cells of an average size of 25-30 ha. After that, these cells were visually scanned for slums which were digitized by drawing polygons. All in all 2,022 polygons were drawn and accordingly over 2,000 slum blocks were identified. Usually these polygons were mapped on block-level, except when the blocks were too small and could be clustered without losing the original layout. The slum blocks were treated as individual slums if they

were divided by a road or free space if the road width or distance exceeded ten metres. Otherwise the blocks were drawn adjacent to each other and interpreted as parts of a bigger slum consisting of more than one block. The isolation distance of ten metres was defined according to Gruebner et al. (2014: 3) since it can be assumed as the average width of a major road.

The mapped slums were basically divided into two categories based on the differentiation of slums in Rio de Janeiro introduced by UN-Habitat (2003: 225). The first category combines the two UN-categories Favela and Invasoe which both show very heterogeneous morphology and often are located at steep slopes (cf. figure 6 (a)). This combination was necessary because the differences of the two slum types cannot be distinguished by visual interpretation of VHR data. In contrast to the heterogeneous morphology, the slums of the second category Loteamenton have a more regular appearance and visible streets (cf. figure 6 (b)) due to the subdivision of land. Furthermore they tend to be located on flat land. Figure 6 shows one example of each category and illustrates the difference of their appearance.

Figure 6: Examples of the two different mapped categories of slums
(a: Favela/Invasoe (part of Rocinha), b: Loteamenton (Vigário Geral))

The fourth introduced slum category Cortiço could not be mapped since it consists only out of one or few buildings (cf. chapter 2.3) that cannot be differed from the surrounding buildings during visual interpretation of remote sensing data. Thus, the two mapped slum categories could be drawn based on their different spatial, structural, and contextual characteristics in comparison to non-slum areas (Graesser et al. 2012: 1164).

Through the whole process of digitizing the slums several problems occurred. While the differentiation of Favelas and Invasoes from their surrounding areas is very simple, this procedure is difficult with Loteamentons. This is easy in the first category due to the enormous difference in their morphologic appearance. However in the second category this difference is less distinctive. Especially where Loteamenton blocks border on formal settlements of low quality or industrial areas, it is very difficult to decide whether the blocks belong to slums or formal settlements because often the mentioned types of built-up area look similar due to the mostly regular road network and similar building materials. However, the regular road network simplifies the separation of the unique slum blocks.

Due to missing streets this is difficult in the first slum category because identifying block separating paths in Favelas and Invasoes requires a detailed but time-consuming examination of the slum blocks.

3.4.2   Assignment of density values

This study tries to discriminate the two mapped slum categories with analyses based on quantitative data. These analyses require several quantitative criteria about the digitized slums. One of these used criteria is the building density which is defined by the ratio of built-up area to the associated block area. Thus, for determining the exact building density of each slum block, every single building has to be digitized due to the lack of such data. As this would be too time-consuming, the building density is estimated during visual interpretation with the aid of using five density classes with a range of 20 percent. For simplifying this process five slum polygons, which all probably belong to a different density class, were selected. To verify whether the polygons really belong to the right density class or not a two-step approach was used. First the respectively included buildings were digitized and then the actual building density was calculated. The chosen slum polygons and the digitized buildings of each density class are shown in figure 7, whereas the calculation of the density values can be seen in table 4.
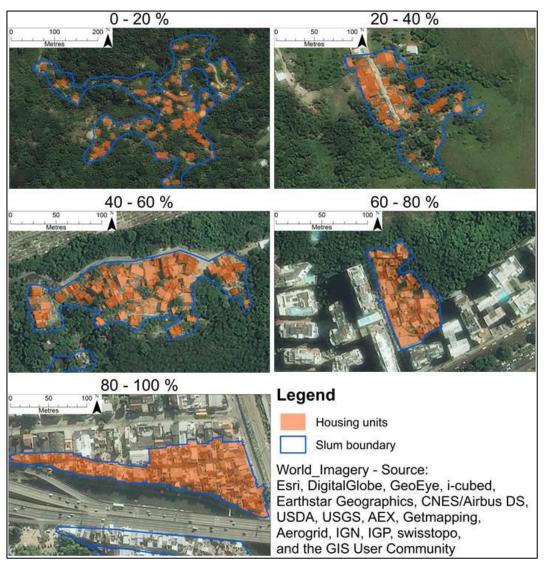
Figure 7: Examples for density classes used in this study

Table 4: Calculation of density classes used in this study

Slum Object ID	Total area in m²	Total area of buildings in m²	Density	Class
2696	46,457	9,156	0.1971	0-20%
2755	11,071	3,115	0.2814	20-40%
2796	11,008	5,278	0.4795	40-60%
2897	4,461	2,933	0.6575	60-80%
2081	11,425	9,492	0.8308	80-100%

The assignment of the density classes to each slum polygon was finally done by visual interpretation and by comparing with example polygons identifying the respective density class.

3.4.3   Assignment of building height

Another quantitative criterion for further analyses is the average building height. As well as the building density the building height has to be estimated due to the lack of official data. The average amount of storeys of the individual slum blocks was estimated by visual interpretation of the used basemap. If the image quality was not good enough to identify the building height and to enhance the result in general, Google™ Street View and Google™ Earth views were used.

All in all, one out of five categories of building heights were assigned to every polygon with each category representing one (2, 4, 5) or two (1, 3) building floors (cf. table 5). This classification, partly summarizing two storeys in one class, was chosen because it is very difficult to distinguish the amount of storeys using the given data, especially if the slum blocks consist out of low-rise buildings.

Table 5: Categories of building heights used in this study

Category	Storey
1	1 and 2
2	3
3	4 and 5
4	6
5	7

4 Spatial and morphologic analyses of slums

The data set resulting from the digitizing process includes all mapped slum blocks which are divided into the already mentioned two categories Favela/Invasoe and Loteamenton (cf. chapter 3.4.1). They furthermore contain information about building density and the average building height (cf. chapters 3.4.2 and 3.4.3), the average slope (cf. chapter 3.2) and a temporal information of whether the slums were existent at four different time steps (1975, 1990, 2000, 2010) (cf. chapter 3.3). All in all, 2090 polygons were digitized which can be summarized to 577 individual slums of the Favela/Invasoe category and 148 separate slums of the Loteamenton category. Moreover, altogether the slums cover an area of nearly 30 km² (Favela/Invasoe-category 21.6 km² and Loteamenton-category 8.3 km²).

4.1 Spatial distribution of slums in Rio de Janeiro

The spatial distribution of both slum categories is shown in figure 8 with blue colours representing Favelas and Invasoes, purple colours Loteamentons and grey colours the settlement area (urban footprint, cf. chapter 3.3).
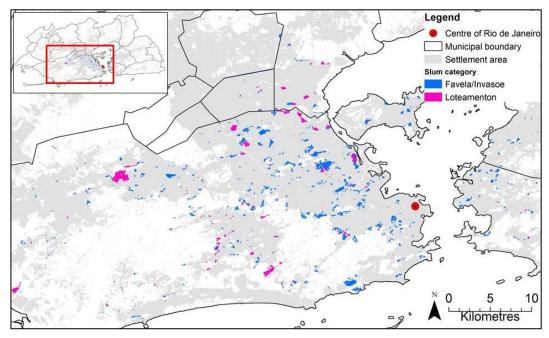

Figure 8: Spatial distribution of slums in the metropolitan region of Rio de Janeiro

Against the assumption that especially the larger slums of Latin American cities are in the periphery of the settled area (cf. chapter 2.2), figure 8 indicates that slums of all sizes are distributed randomly over the visible section of the study area (outside of this section there is only a negligible little amount of slums). This is underlined with figure 9, which shows that both small and large slums occur up to a distance of 50 km to the city centre. If this distance is exceeded, only slums smaller than one ha are existent, which is the opposite of the assumed theory by Ford (1996: 437ff.) in chapter 2.2.
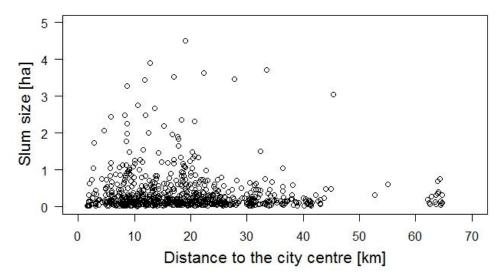
Figure 9: Spatial distribution of slum sizes

For the city of Rio de Janeiro itself this circumstance was already stated by O'Hare and Barke (2002: 227), highlighting that slums can mainly be found in internal peripheral locations which can be characterized as remote (e.g. alongside traffic infrastructure) or naturally disadvantaged (e.g. steep hills (cf. chapter 4.2.4), river flood plains, etc.). Furthermore Harris (2009: 160) points out that in Rio de Janeiro slums are located both in the city and in the suburbs which is also mentioned by UN-Habitat (2003: 225) especially for the slum type Favela.

For the further analyses the centre of the city of Rio de Janeiro (cf. figure 8) was set in the Avenida Rio Branco located in the central business district, where also monumental churches and theatres are located representing the cultural centre. Around that concentric buffer zones with a distance of five kilometres were generated enabling small-scale spatial analyses. The few slums which are located more than 55 km from the centre of the city could not be considered due to the partial lack of settlement reference data outside of this distance (cf. chapter 3.3).

To get a detailed overview about how each slum category is distributed over the study area, the share of slum to settlement area in each buffer zone is plotted in figure 10 with blue colours representing Favelas and Invasoes and red colours depicting Loteamentons. Furthermore, the total share of the mapped slums to the settlement area can be derived from this figure.
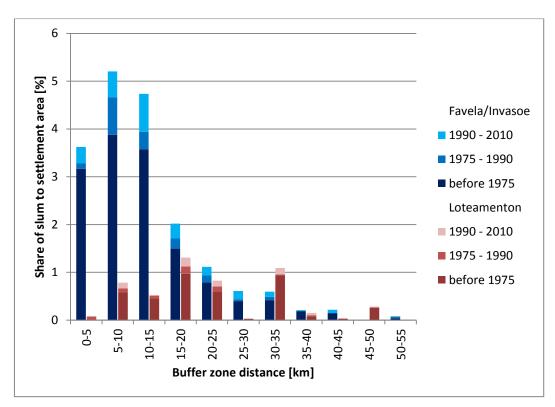
Figure 10: Share of slum area to settlement area in respective buffer zone

First of all it is obvious that Favelas and Invasoes have a much higher share of the settled area than Loteamentons which is caused by the higher amount of slums in the first category (cf. chapter 4). Contemplating the distribution of Favelas and Invasoes a concentration of the first slum type near the centre of the study area is conspicuous. Within the four innermost buffer zones the share of Favelas and Loteamentons exceeds two percent having its peak in the 5-10 km buffer zone where this type of slum covers more than five percent of the settlement area. In addition, another noticeable trend is apparent. The shares of Favelas and Invasoes are decreasing continuously from the mentioned peak to a minimum of zero or only a little over zero in the two outermost buffer zones.

In comparison to Favelas and Invasoes the greatest shares of Loteamentons to the settlement area can be found at medium distances to the centre of the study area. Thus in the 15-20 and 30-35 km buffer zones more than one percent of the settled area is covered with Loteamentons. In addition, all buffer zones between 5 and 25 km have shares of at least 0.5 percent. On the contrary, the ratios of the remaining buffer zones are less. Since four of the five buffer zones having shares of more than 0.5 percent are neighboured, this can be interpreted as a spatial concentration similar to the first slum category, but to a much more less extent.

In summary, both slum categories have greater shares of slum to settlement area in medium or short distances to the centre of the study area. Furthermore, Favelas and Invasoes show a considerable concentration in the four innermost buffer zones. Related to that, Loteamentons have a small spatial concentration from the second to the fifth

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buffer zone excepting the seventh buffer zone which has the second greatest share of slum to settlement area. Thus, Ford's theory (1996: 437ff.) that the greatest share of slums can be found in peripheral locations is not valid for the metropolitan region of Rio de Janeiro.

Considering the temporal aspect of the slums spatial distribution, two relationships are visible. In almost every buffer zone and irrespective of the slum type, slums that emerged before 1975 have the greatest share. This circumstance is consistent to table 1 which shows that the majority of slums were created between 1940 and 1980. Moreover, especially in the second and third buffer zone, the share of newer Favelas and Invasoes that emerged between 1975 and 2010 is noticeable. Thus, the majority of the newer slums belonging to the first slum type are located near the centre of Rio de Janeiro.

4.2 Morphologic characteristics of slums in Rio de Janeiro

After analysing the spatial distribution of both slum categories it is necessary to test whether they differ in morphologic characteristics. The aim is to prove the qualitative discrimination of the two slum categories (UN-Habitat 2003: 225) based on quantitative analyses. Therefore both types of slums are tested in terms of their size, building density and building height. Furthermore the average slope is analysed to verify the theory that especially Favelas and Invasoes are located in disadvantaged areas. All analyses are based on the mapped blocks of slums excepting the comparison of the slum sizes. Here, the size of the combined blocks, which are adjacent to each other, is analysed. For the temporal components the time step of the year 2000 was combined with the 2010 time step because now there are two nearly equal periods of 15 and 20 years between the time steps.

4.2.1 Comparison of slum sizes

The first analysed characteristic is the size of the individual slums. The distribution of this attribute can be seen in figure 11 for both slum types.
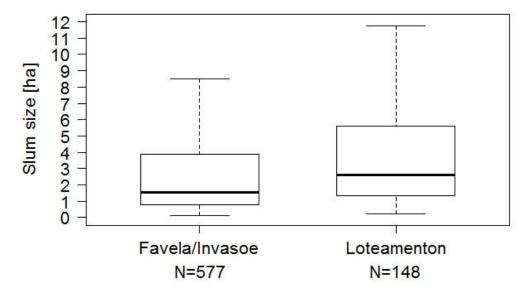

Figure 11: Distribution of slum sizes

The size of Favelas and Invasoes ranges from about 0.1 to 8.5 ha. The 2nd and 3rd quartiles are located between 1 and 4 ha, whereas the median lies at 1.5 ha and the mean value is 3.7 ha. Hence, half of the Favelas and Invasoes are smaller than 1.5 ha. Thus the mean value, which is more than twice as high as the median, is caused by the greater range of the remaining half of the slums of the first category.

The Loteamentons show a different distribution. Slums of this category have a size between 0.2 and 12 ha. The 2nd and 3rd quartile range from 2 to 6 ha while the median and mean values are 2.5 and 5.6 ha. The much higher mean value can be explained by the same reason as in the first category while in the second slum type this circumstance is much more distinct.

Summarized, all analysed statistical criteria have higher values in the second slum category. The difference between the medians and the ranges of the 2nd and 3rd quartile is one ha whereas the mean values have a deviation of nearly two ha. According to that Loteamentons are larger than Favelas and Invasoes. The different origin of both slum types could be a reason for that. Dwellers of Favelas and Invasoes just look for a piece of land to build a house not considering the size of the surrounding area whereas Loteamentons have a certain given size due to the size of the coherent but then subdivided land (cf. chapter 2.3).

4.2.2   Comparison of building densities

In chapter 2.3.1 a densification process was mentioned for slums in the city of Rio de Janeiro. Whether this is applicable to the whole study area for the analysed time period will be verified in this section. In addition, both slum types are compared to each other based on their building density. Figure 12 shows the distribution of this characteristic being quite similar in both slum categories.
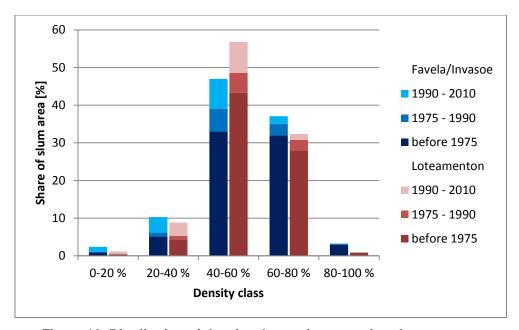

Figure 12: Distribution of density classes in respective slum category

Obviously, the majority of all slum blocks have density values between 40 and 80 percent. These two density classes have combined shares of more than 80 percent in both slum types. The remaining three classes have minor ratios of ten or less percent. In addition the difference between the slum categories referring to these three density classes only ranges between one and three percent. Yet, the difference between the two slum types lies within the two classes mentioned at first. The share of blocks belonging to the third density class (40-60 %) is ten percent higher in the Loteamenton category. This circumstance is the other way round in the fourth density class (60-80 %) where the ratio of Favelas and Invasoes is five percent higher than the ratio of Loteamentons. Hence, blocks of the first slum category are denser than blocks of the second category. This leads back to the fact of mostly missing streets in Favelas and Invasoes which can be seen in figure 6.

Contemplating the temporal component in both slum categories signs of a densification process appear that are indicated as follows. There is a huge difference between the first two and the last density class considering the temporal origin of the slum blocks. While the share of blocks emerged before 1975 is very small in the lowest density class and about 50 percent in the second class, this share is very decisive in the highest class. Compared to that, the ratios of slum blocks emerged in the period between 1990 and 2010 show an opposed distribution. Whereas this ratio is comparatively high in the first

two density classes, it is missing in the last class. Thus, the following trend can be derived: The older a slum block, the denser it is. Hence, the process of densification mentioned in chapter 2.3.1 took place in the whole study area.

4.2.3 Comparison of building heights

Analogous to chapter 4.2.2 this section verifies the mentioned process of verticalization and compares both slum categories based on the attribute of the average building heights. The distribution of this characteristic in the respective slum categories can be seen in figure 13.
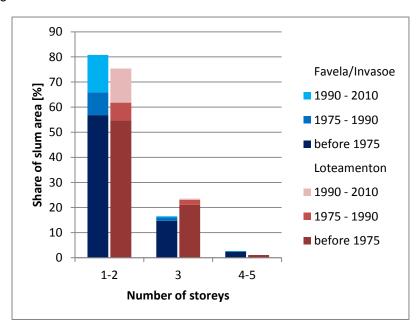

Figure 13: Distribution of building heights in respective slum category

Basically, both slum types show a similar distribution of building heights, the majority of both having one or two storeys and most of the rest consisting out of buildings with three floors. Yet, they differ in these two height classes. In relative terms, there are more Favelas and Invasoes than Loteamentons having buildings with one or two storeys but regarding the three floor buildings it is the other way round. Thus, the second slum category tends to have higher buildings than the first slum category.

Regarding the temporal development of the building heights a small trend gets apparent. The share of newer slum areas, emerged between 1975 and 2010, is shrinking from the first height category to the last. While more than 20 percent of both slum categories are dedicated to this time period and consist out of one or two buildings, only less than two percent of both slum types are allocated to the same period and consist out of buildings having three or more floors. Thus, the process of verticalization mentioned in chapter 2.3.1 is proven for the whole study area for the time period of 1975 to 2010.

4.2.4 Comparison of the average slope

Referring to chapter 4.1, in the study area slums are not found at the spatial periphery. Thus, it is necessary to analyse whether they are located at other disadvantaged locations. One indicator of such disadvantaged locations is the average slope of the slum blocks because it is much more difficult to build dwellings at a steep slope than in flat area. Furthermore, due to the lack of accurate consolidation of the ground and missing sewage systems, especially in slums the risk of natural hazards like landslides is very high if the slums are located at steep slopes (Smythe/Royle 2000: 105f.). The results of the slope analysis are visualized in figure 14 showing that the two slum categories differ enormously in terms of this morphologic feature.
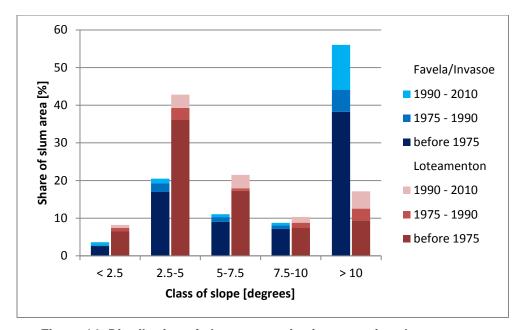

Figure 14: Distribution of slope categories in respective slum category

To the first class of slope only less than five percent of Favelas and Invasoes and less than ten percent of Loteamentons are allocated. In the two classes of slope including values between 2.5 and 7.5 degrees, the share of Favelas and Invasoes is only the half of the ratio of Loteamentons. Yet, with 20 and over 40 percent, which is the greatest ratio of Loteamentons, the shares of both slum types are twice as much in the 2.5 to 5 degree class than in the class including slopes of 5 to 7.5 degrees. The only class where both slum categories have similar ratios of about 10 percent is the fourth class with slopes of 7.5 to 10 degrees. Apparently the biggest difference between the Favela/Invasoe and the Loteamenton type lies within the slum blocks having average slope values greater than ten degrees. While the majority of the first slum category belongs to the last class of slope, only 17 percent of the Loteamenton category have slope values greater than ten degrees.

The reason for the huge difference between the two slum categories lies within their differing definitions. Favelas and Invasoes are illegally built-up areas, thus they claim available land. Especially near the city centre, only steep hillsides are left over because

they are not suitable for commercial development. Such disadvantaged areas are called an internal periphery (O'Hare/Barke 2002: 229). Compared to that, Loteamentons are located on developable land with minor slopes that was bought by landlords in the first place and then subdivided and sold to slum dwellers (cf. chapter 2.3). According to this definition the 17 percent of Loteamentons having slope values greater than ten degrees are untypical. This can be explained by the fact that perhaps original Favelas or Invasoes were classified as Loteamentons. Due to upgrading programmes like e.g. Favela Bairro (cf. chapter 2.3.2), in Favelas and Invasoes streets, squares and walkways were opened and paved (Riley et al. 2001: 526). Furthermore, where resettlement was necessary, new houses were built (Barke et al. 2001: 265). Hence, slums in which this process took place, today probably look more like Loteamentons, where e.g. streets are visible (cf. chapter 3.4.1).

In summary, the majority of Favelas and Invasoes are located in very disadvantaged areas. Nevertheless, also even more than a fourth of Loteamentons is located in areas having slope values greater than 7.5 degrees.

Contemplating the temporal information, it is apparent that the share of newer slum blocks increases with the average slope values in both slum categories. In the last class of slope, especially in Favelas and Invasoes, the ratio of slums that emerged between 1990 and 2010 is very high compared to all other classes of slope. This can be interpreted as an indicator for the lack of land suitable for housing.

5 Conclusion and Outlook

In developing countries the share of people living in slums is rising, therefore also the number of slum dwellings is rising. As this is an illegal process it is nearly impossible to monitor this process and also very difficult to generate accurate data about quantity and quality of housing. Moreover, the lack of a general definition of slums complicates the whole thematic.

Due to the given reasons this study derived polygons of two different slum categories in the metropolitan region of Rio de Janeiro based on visual interpretation of the Esri World-Imagery-basemap. During this process a total of 725 individual slums covering an area of nearly 30 km² were digitized. 577 slums were classified as Favelas and Invasoes based on clear morphologic characteristics such as heterogeneity, cheap roof materials and very high building densities. The remaining 148 slums were allocated to the Loteamenton category, showing a more regular pattern and visible streets. Afterwards, the estimated time step of slum establishment and the average slope were derived from urban footprint data and the ASTER DEM. Data about the building density and average building height were generated during the visual interpretation of remote sensing data with the help of classifying the values into five and three categories. Afterwards, the collected data were analysed with the aim of confirming the classification of the two mapped slum categories based on quantitative data.

For both slum categories applies that, in contrast to other Latin American mega cities, the majority of slums is not located at the peripheral regions of the metropolitan region of Rio de Janeiro. Both categories show a spatial concentration near the centre of the study area while the concentration of Favelas and Invasoes has a much higher extent. Furthermore, also the newer slums of the Favela/Invasoe category are located near the centre of Rio de Janeiro.

In terms of their morphologic characteristics the two slum categories show very huge differences. On average, individual slums of the Loteamenton type are larger than Favelas and Invasoes while the Loteamenton blocks tend to consist out of higher buildings. Considering the remaining two characteristics, blocks of the first slum category are denser and definitely tend to be located at more disadvantaged locations regarding the average slope. Thus, it is the first category which is more vulnerable to natural hazards such as landslides.

In summary, this study successfully confirmed the classification of the two mapped slum types based on quantitative data. It turned out that in terms of every analysed morphologic characteristic both slum categories show distinct features. Furthermore, the processes of densification and verticalization could be proved for all slums of the study area considering the temporal development of the building density and average building height.

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By reason of the above presented results, this study shows that slum areas can be derived from visual interpretation of remote sensing data. The resulting data set is very consistent probably only missing some very small slum blocks that were not capable of being differentiated from the surrounding formal settlements due to their very small size. But the data set can also be improved by analysing VHR data from new satellites such as Terra-SarX or Spot 7 which both have a spatial resolution of up to one metre. Furthermore, the given research can be extended by deriving morphologic patterns from textures. This was in part already been done for different cities using different approaches that are image based (Graesser et al. 2012: 1164ff., Kuffer et al. 2013: 1ff.), object based (Hofmann et al. 2008: 531ff.), lacunarity based (Kit/Lüdeke 2013: 130ff.) or based on texture analyses using Kennaugh-elements (Weigand 2014: 4ff.). If the same approach is used in different cities around the world, they will be comparable in terms of e.g. the spatial distribution of their slums or their morphologic characteristics. In addition this study has to be continued so that the temporal analyses are consistent. This provides the possibility to analyse whether the described trends are continuous or not.

References

Acioly Jr. C. (2001): Reviewing urban revitalization strategies in Rio de Janeiro: from urban project to urban management approaches. In: Geoforum 32, pp. 509-520.

Angeles G., Lance P., Barden-O'Fallon J., Islam N., Mahbub A. Q. M., Nazem N. I. (2009): The 2005 census and mapping of slums in Bangladesh: design, select results and application. In: International Journal of Health Geographics, pp. 8-32.

Bähr J. (1976): Neuere Entwicklungstendenzen lateinamerikanischer Großstädte. In: Geographische Rundschau 28 (4), pp.125-133.

Bähr J., Mertins G. (1981): Idealschema der sozialräumlichen Differenzierung lateinamerikanischer Großstädte. In: Geographische Zeitschrift 69 (1), pp. 1-33.

Barke M., Escasany T., O'Hare G. (2001): Samba. A Metaphor for Rio's Favelas? In: Cities 18 (4), pp. 259-270.

Borsdorf A. (2004): Landflucht als Teil der Mobilitätstransformation. Das Beispiel Lateinamerika. In: Praxis Geographie 34 (7-8), pp. 9-14.

Brinkhoff T. (2015): City Population. Rio de Janeiro Metropolitan Area. URL: http://www.citypopulation.de/php/brazil-metro.php?cid=RM0006 (08.06.2015)

Cavallieri F., Vial A. (2012): Favelas na cidade do Rio de Janeiro: o quadro populacional com base no Censo 2010. In: Colleção Estudos Cariocas 12, pp. 1-18.

Cohen J. (1960): A coefficient of agreement for nominal scales. In: Educational and Psychological Measurement 20 (1), pp. 37-46.

Congalton R. G. (1991): A Review of Assessing the Accuracy of Classifications of Remotely Sensed Data. In: Remote Sensing of Environment 37 (1), pp. 35-46.

Davis M. (2007): Planet der Slums. Berlin.

Dias Simpson M. (2013): Urbanising favelas, overlooking people: Regressive housing policies in Rio de Janeiro's progressive slum upgrading initiatives. London.

Esch T., Taubenböck H., Roth A., Heldens W., Felbier A., Thiel M., Schmidt M., Müller A., Dech S. (2012): TanDEM-X mission – new perspectives for the inventory and monitoring of global settlement patterns. In: Journal of Applied Remote Sensing 6 (1), pp. 061702-1-061702-21.

Ford L. R. (1996): A new and improved model of Latin American city structure. In: Geographical Review 86 (3), pp. 437-440.

Gilbert R. (1995): Rio de Janeiro: the Make-up of a Modern Megacity. In: Habitat International 19 (1), pp. 91-122.

Graesser J., Cheriyadat A., Vatsavai R. R., Chandola V., Long J., Bright E. (2012): Image Based Characterization of Formal and Informal Neighborhoods in an Urban Landscape. In: IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 5 (4), pp. 1164-1176.

Griffin E., Ford L. R. (1980): A Model of Latin American City Structure. In: Geographical Review 70 (4), pp. 397-422.

Gruebner O., Sachs J., Nockert A., Frings M., Khan M. H., Lakes T., Hostert P. (2014): Mapping the Slums of Dhaka from 2006 to 2010. In: Dataset Papers in Science 2014, pp.1-7.

Gunter A. W. (2009): Getting it for free: Using Google Earth^{TM} and ILWIS to map squatter settlements in Johannesburg. In: Geoscience and Remote Sensing Symposium, 2009 IEEE International, IGARSS 2009 3, pp. 388-391.

Harris R. (2009): Slums. In: International Encyclopedia of Human Geography, pp. 157-162.

Heineberg H. (2014): Stadtgeographie. 4th edition, Paderborn.

Hofmann P., Strobl J., Blaschke T., Kux H. (2008): Detecting informal settlements from QuickBird data in Rio de Janeiro using an object based approach. In: Blaschke T., Lang S., Hay G.J. [Eds.]: Object-Based Image Analysis. Spatial Concepts for Knowledge-Driven Remote Sensing Applications, Heidelberg, pp. 531–554.

Kit O., Lüdeke M. (2013): Automated detection of slum area change in Hyderabad, India using multitemporal satellite imagery. In: ISPRS Journal of Photogrammetry and Remote Sensing 83, pp. 130-137.

Kuffer M., Pfeffer K., Baud I., Sliuzas R. (2013): Analysing sub-standard Areas using High Resolution Remote (VHR) Sensing Imagery. Case Study of Mumbai, India. In: N-AERUS XIV.

Magalhães F., di Villarosa F. (2012): Slum upgrading: Lessons learned from Brazil. Washington, D.C.

O'Hare G., Barke M. (2002): The favelas of Rio de Janeiro: A temporal and spatial analysis. In: GeoJournal 56, pp. 225-240.

Oliveira N. S. (1996): Favelas and Ghettos: Race and Class in Rio de Janeiro and New York City. In: Latin American Perpectives 23 (4), pp. 71-89.

Palladini E. (2011): Creating More Livable Cities: The Case of the Rio de Janeiro Metropolitan Area. World Bank [Editor], Washington, DC.
URL: https://openknowledge.worldbank.org/handle/10986/10070 (26.01.2015)

Pamuk A., Cavallieri P. F. A. (1998): Alleviating Urban Poverty in a Global City: New Trends in Upgrading Rio-de-Janeiro's Favelas. In: Habitat International 22 (4), pp. 449-462.

Parisse L. (1970): Favelas de l'agglomeration de Rio de Janeiro. Leur place dans le processus d'urbanisation. Strasbourg.

Pellacini A. (2011): Sicherheitskonzepte im Vorfeld sportlicher Mega-Events. Eine Chance für Rio de Janeiro? In: Zeitschrift für Außen- und Sicherheitspolitik 4, pp. 615-625.

Ribbeck E. (2003): Städtebau und Stadtplanung in Rio de Janeiro. In: Kohlhepp (Hrsg.): Brasilien. Entwicklungsland oder tropische Großmacht des 21. Jahrhunderts? Tübingen.

Riley E., Fiori J., Ramirez R. (2001): Favela Bairro and a new generation of housing programmes for the urban poor. In: Geoforum 32, pp. 521-531.

Saborio S. (2013): The pacification of the favelas: mega events, global competitiveness, and the neutralization of marginality. In: Socialist Studies 9 (2), pp. 130-145.

Smyth C. G., Royle S. A. (2000): Urban landslide hazards: incidence and causative factors in Niterói, Rio de Janeiro State, Brazil. In: Applied Geography 20, pp. 95-117.

Steinbrink M. (2013): Festifavelisation: mega-events, slums and strategic city-staging – the example of Rio de Janeiro. In: DIE ERDE 144 (2), pp. 129-145.

Taubenböck H., Esch T., Felbier A., Wiesner M., Roth A., Dech S. (2012): Monitoring urbanization in mega cities from space. In: Remote Sensing of Environment 117, pp. 162-176.

Taubenböck H., Kraff N. J. (2013): The physical face of slums: a structural comparison of slums in Mumbai, India, based on remotely sensed data. In: Journal of Housing and the Built Environment 29, pp. 15-38.

Taubenböck H., Esch T., Wiesner M., Felbier A., Marconcini M., Roth A., Dech S. (2014): Spatial Dynamics and Patterns of Urbanization. The Example of Chinese Megacities Using Multitemporal EO Data. In: Weng Q. [Editor]: Global Urban Monitoring and Assessment through Earth Observation Series in Remote Sensing Applications. Boca Raton, pp. 171-194.

UN-Habitat (2003): The Challenge of Slums. Global Report on Human Settlements 2003. London.

Violich F., Daughters R. (1987): Urban planning for Latin America. The challenge of metropolitan growth. Boston.

Weigand M. (2014): Discrimination of formal and informal settlements based on multipolarized TSX imagery in the Megacity Mumbai, India. Unpublished Bachelor Thesis, University of Würzburg, Germany.

Willis K. D. (2009): Squatter Settlements. In: International Encyclopedia of Human Geography, pp. 403-408.

Eidesstattliche Erklärung

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Fricke, Jonas

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