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Strengthening urban resilience through nature: The potential of ecosystem-based measures for reduction of landslide risk in Rio de Janeiro

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Abstract

Ecosystem-based measures have a high potential to replace or build on engineered solutions for Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA), not only in rural but also in urban areas. Based on the case study of Rio de Janeiro, Brazil, this working paper reveals the potential for implementing such ecosystem-based measures to protect informal settlements. These so-called favelas are often located on steep slopes and therefore prone to landslides that are triggered by heavy rainfall events. Deforestation and land degradation, inadequate infrastructure and ongoing informal building activities are additionally exacerbating risks.

Different – formal and informal – actors are already involved in urban disaster risk reduction; however, structural measures are mostly limited to engineered approaches and not yet aligned with the urban reforestation program. The two major constraints hindering a more efficient landslide risk management and the inclusion of ecosystem-based approaches that were detected in the study are a lack of coordination among the involved authorities as well as a lack of awareness of the potentials that ecosystem-based approaches offer. Investigations in the favelas Morro da Formiga and Morro dos Prazeres that are in the central and northern zone of Rio de Janeiro and severely affected by land and mudslides in the past, revealed a high potential for ecosystem-based measures for DRR and CCA that has hardly been tapped yet.

Based on literature surveys, expert interviews and site visits, a portfolio of suitable ecosystem-based measures for urban DRR and CCA for selected marginal settlements in urban risk areas of Rio de Janeiro is compiled, with lessons for the city and beyond. The potentials detected range from household to urban level, and propose pure ecosystem-based measures, but also hybrid ones and social as well as administrative tools.

Keywords: ecosystem-based disaster risk reduction (Eco-DRR), ecosystem-based adaptation (EbA), landslide risk, urban resilience, favelas, Rio de Janeiro, Assessment, Conservation, Environmental Management, Environmental Planning, Forest Land, Sustainable Development, Urban Development, Land Use, Natural Resources, Poverty

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Abbreviations and Acronyms

APA	Áreas de Proteção Ambiental (Environmental Protection Areas)
APP	Áreas de Preservação Permanente (Permanent Preservation Areas)
CCA	Climate Change Adaptation
CFA	Coordenacao de Fiscalizacao Ambiental (Coordination of Environmental Control)
CNRD	Center for Natural Resources and Development
COR	Centro de Operações (Operations Centre, Municipality of Rio de Janeiro)
COMLURB	Companhia Municipal de Limpeza Urbana (Municipal Company for Urban Cleansing)
CPA	Coordenadoría de Conservação e Proteção Ambiental (Coordination for Conservation and Environmental Protection)
DEM	Digital Elevation Model
DRM-RJ	Serviço Geológico do Estado do Rio de Janeiro (Geological Survey of Rio de Janeiro State)
DRR	Disaster Risk Reduction
EbA	Ecosystem-based Adaptation
Eco-DRR	Ecosystem-based Disaster Risk Reduction
FIFA	Fédération Internationale de Football Association
Geo-Rio	Fundação Instituto de Geotécnica (Geotecnical Institue of the Muncipal Secretary of Construction Works)
IBGE	Instituto Brasileiro de Geografía e Estatística (Brazilian Institute of Geography and Statistics)
IPCC	Intergovernmental Panel on Climate Change
IPP	Instituto Pereira Passos
IUCN	International Union for Conservation of Nature
IURD	Institute of Urban and Regional Development, University of California, Berkeley
MA	Millennium Ecosystem Assessment
NGO	Non-Governmental Organization
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
OECD	Organization for Economic Cooperation and Development
PBMC	Painel Brasileiro de Mudanças Climáticas (Brazilian Panel for Climate Change)
PES	Paymento for Ecosystem Services
PUC-Rio	Pontifícia Universidade Católico do Rio de Janeiro (Pontificial Catholic University of rio de Janeiro)
Rio-Águas	Fundação Instituto das Águas do Municipio do Rio de Janeiro (Water Institute of Rio de Janeiro Municipality)
SIG	Sistema de Informacao Geográfica (Geográphic Information System)
SLE	German Center for Rural Development
SMAC	Secretaria Municipal de Meio Ambiente (Municipal Secretariat of Environment)
SMU	Secretaria Municipal de Urbanismo (Municipal Secretariat of Urbanism)
SNAG	Subnormal Agglomerates
SNUC	Sistema Nacional de Unidades de Conservação (National System of

	Conservation Units)
TNC	The Nature Conservancy
UFRJ	Universidade Federaldo Rio de Janeiro (Federal University of Rio de Janeiro)
UN	United Nations
UNEP	United Nations Environmental Program
UNDEP	Center for Water and Environment of the United National Environmental Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNISDR	United Nations Office for Disaster Risk Reduction
UNU-EHS	United Nations University – Institute for Environment and Human Security
WRI	World Resource Institute

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Introduction

To reduce both the destructive force of a hazard event and the vulnerability of exposed people and infrastructure, environmental management solutions are increasingly being applied. Natural hazards, traditionally associated with rural contexts, are impacting increasingly on urban areas, especially in rapidly urbanizing developing and emerging countries (Guadagno et al. 2013). Population, and subsequently urban growths, as well as overexploitation of natural resources increase the pressure on ecosystems and lead to their loss or degradation, which often aggravates disaster risk, because the protective functions of ecosystems against natural hazards are negatively affected or in the worst case destroyed. This is particularly true for many emerging and developing countries, where high urbanization rates, poor urban development and planning procedures, and severe environmental degradation come together. As a result, both exposure and vulnerability of humans and elements at risk of natural hazards increase (Briceño 2015). Moreover, the impacts of climate change are particularly tangible in developing countries of the tropics and subtropics and will in some regions increase the frequency and intensity of extreme events that can trigger disasters (IPCC 2012, 2014). Particularly affected are many metropolitan regions and cities, where marginal settlements with inadequate and unenforced building codes in risk-prone areas, such as floodplains and unstable slopes, are among the most vulnerable (Bigio 2003; Quarantelli 2003; Joint UNEP/OCHA Environment Unit 2012; UNISDR 2015).

In many Latin American cities, including Rio de Janeiro, urbanization and suburbanization processes are still ongoing, even though overall population growth is already declining (Smyth and Royle 2000). This slightly reduced speed of urbanization might provide a realistic opportunity to improve urban planning policies and implement ecosystem-based measures to strengthen urban resilience and reduce susceptibility to natural hazards, such as landslides, mudslides and floods. At the same time these ecosystem-based measures could support the long-term strategies of climate change adaptation. Climate projections for the city of Rio de Janeiro (Dereczynski et al. 2013) suggest an increase of frequency and intensity of heavy precipitation until the end of the 21st century, and at the same time shorter wet and longer dry seasons. Therefore, sound urban ecosystem management could not only reduce risks related to natural hazards but also mitigate the long-term effects of droughts by stabilizing the urban climate.

After the severe land and mud slides in April 2010 that caused more than 40 fatalities in the municipality of Rio de Janeiro, a paradigm shift started, and several government institutions began to improve their services regarding disaster risk management. The progress that has been achieved since then is an improvement in early-warning, including the operation of a new meteorological radar system, activities related to the preparedness of communities (evacuation routes, sirens for alerts), the development of “grey” infrastructure such as containment walls, as well as risk mapping for the potential removal of houses that are at high risk. However, ecosystem-based solutions that integrate disaster risk reduction, climate change adaptation and the provision of other relevant ecosystem services are so far not the focus of attention for urban planners and risk managers in Rio de Janeiro.

Climate change impacts and other urban issues interact in the city, bringing to light different visions of future urban development and associated risk management preferences of the involved actors. In the best case this opens the possibility of renegotiating goals and priorities (Pelling 2011). We hope that this work can contribute to a better integration of ecosystem management, disaster risk reduction, and climate change adaptation in urban planning and stimulate researchers and practitioners to reflect more about the potential of ecosystem-based measures in urban environments.

Ecosystem-based approaches for disaster risk reduction and climate change adaptation

Ecosystem-based approaches for disaster risk reduction (Eco-DRR) and climate change adaptation (EbA) integrate the use of biodiversity and ecosystem services into an overall strategy to reduce people’s vulnerability and increase their resilience to natural hazards and climate change (Lange et al. 2014; Nehren et al. 2014). Eco-DRR can be defined as the sustainable management, conservation and restoration of ecosystems to reduce disaster risk, with the aim to achieve sustainable and resilient development (Estrella and Saalismaa 2013). EbA uses a similar ecosystem-based approach but focuses on the long-term adaptation to the adverse effects of climate change (Secretariat of the Convention on Biological Diversity 2009). The IPCC, Intergovernmental Panel on Climate Change, (2012, 2014) considers ecosystem-based approaches for DRR and CCA as "no-regret" strategies, providing multiple socio-economic benefits regardless of disasters, including carbon storage and sequestration, biodiversity conservation, and poverty alleviation. Eco-DRR and EbA are approaches by which ecosystems (such as mountain forests, wetlands and mangroves) are systematically harnessed to prevent, mitigate or buffer against natural hazards and impacts of climate change. Recent IPCC studies (2012, 2014) have highlighted the importance of such measures as part of necessary adaptation: "Healthy, natural or modified ecosystems have a critical role to play in reducing risks of climate extremes and disasters" (IPCC 2012, 370).

Both concepts assume that well-managed ecosystems can act as a natural infrastructure and buffer, reducing physical exposure to many hazards and increasing socio-economic resilience of people and communities by sustaining local livelihoods and providing essential natural resources such as food, water and building materials. But apart from offering an opportunity to strengthen natural infrastructure and human resilience against hazard impacts, sound ecosystem management also generates a range of other social, economic and environmental benefits for multiple stakeholders (no-regret strategy), which in turn feed back into reduced risk. In this context the Millennium Ecosystem Assessment (MA 2005) points out that healthy ecosystems have the potential to reduce social-economic vulnerability by sustaining human livelihoods and providing essential goods. Eco-DRR and EbA are anthropocentric approaches and as such also have high potential for integrating local communities; but for good participation people must be sensitized to increase the perception and knowledge regarding ecosystem-based measures (Lange et al. 2016; Sandholz 2016).

Traditional measures for disasters prevention, mitigation and recovery focus on 'grey' infrastructure like containment walls, channelization of rivers and other technical solutions, while 'green' solutions are often underestimated (Sudmeier-Rieux et al. 2006). This is especially true in densely inhabited urban areas, where ecosystem-based solutions are so far, the exception. The potential for green and hybrid solutions that combine grey and green approaches has thus not been tapped fully yet, but it could be a cost-efficient and feasible approach for risk reduction in urban areas. Notably marginal settlements could benefit from this, as green solutions, such as protection forests, are low-cost measures that can be implemented even by the communities themselves (White and Rorick 2010).

In the literature, a variety of ecosystem-based measures for landslide risk reduction are discussed under multiple concepts. While Eco-DRR is widely used in the disaster risk community and focuses explicitly on disaster risk reduction, EbA and green adaptation are commonly used in the climate change community and aim for long term strategies to adapt to the impacts of climate change, which includes the risk component as an integral part. Both concepts have in common that sustainable management, conservation and restoration of ecosystems are key elements, so that the measures are widely identical. Apart from these concepts, there are others that aim at integrating engineering and ecology, such as ecological engineering and building with nature, and those that put a stronger focus on environmental and urban planning, such as natural infrastructure and green infrastructure (van Wesenbeeck et al. 2016). All these concepts contain risk reduction as a key component and range from small-scale (e.g. house level) to landscape approaches, for rural as well as urban areas.

Urban Eco-DRR and EbA

Adapting cities to climate change impacts is among the biggest urban challenges (Bigio 2003; Mucke 2014; Pelling 2011). Governing climate change at the urban scale is influenced and shaped by processes of urbanization, discourses of responsibility, and the willingness and capacity of officials and those at risk to act and reduce exposure and susceptibility to climate change-related hazards in a specific place (Bulkeley 2010; Pelling 2011). Abbate (2010) calls this interplay of urbanization, modifications of the geographic and topographic features and changes of micro- and macroclimate a vicious cycle, longing for a modification of urban planning methods. This is particularly the case in the rapidly urbanizing cities of the developing world (Angel et al. 2011; Bulkeley 2010) that are facing socio-spatial fragmentation (Bolay et al. 2005), high levels of informality (Simone 2010), lack of budgets (Mucke 2014), as well as long-term planning (Abbate 2010).

Accelerated urbanization and unsustainable use or depletion of ecosystem services are triggers of vulnerability and proneness to disasters, resulting in recurrent and increasingly costly events (Fra Paleo 2013). Needs for urban transition to adapt to climate change impacts and cope with natural hazards are especially high in developing countries. Unfortunately, the significance of ecosystem services in an urban context is often poorly understood and overlooked. Population density in urban areas is much higher and consequently the built environment has been modified tremendously, easily resulting in the misperception that neither nature nor environmental risks are of major concern (Grove 2009; Krasny et al. 2014). This perception and a lack of integrating policies of urban climate change, disaster risk reduction and urban environmental protection, which are often seen as a policy sector, are potential obstacles for long-term development strategies (Bulkeley 2010) such as ecosystem-based approaches.

Eco-DRR and EbA require longer time horizons to demonstrate effective protection against hazard impacts, e.g. a protection forest needs time to grow before it can stabilize a slope to protect people settling further down the valley (Nehren et al. 2014). In addition, hard engineering or 'grey' infrastructure solutions are still often preferred over 'green' or ecosystem-based ones for disaster management. Cities are usually dominated by built infrastructure; consequently, planning often overlooks ecosystem potentials and benefits in favor of pure engineered solutions to cope with disasters (Guadagno et al. 2013; Mercer et al. 2012). Attempts to control nature through dams, levees, and reclamation of swamps and wetlands were and still are popular and favored over ecosystem-based solutions, although non-properly planned engineered solutions may even increase the impacts of an event, e.g. the severity of flooding (Quarantelli 2003).

Measures that support environmental protection and livelihoods, both root causes of vulnerability, serve to reduce disaster risk in the long run (Ingram et al. 2006; Wisner et al. 2004). To implement such measures, an understanding of the interactions between urban activities and ecosystems is essential (Dizdaroglu et al. 2012). In this context, reducing urban sprawl and returning to plan more compact cities, the need to consider more open and green spaces (Beck 2012), and the implications of urbanization on risk and vulnerability of different societal groups (Garschagen 2014) have gained momentum. There is growing awareness on the benefits of ecosystem services for sustaining livelihoods in urban contexts, e.g. on the modification of climate, hydrology or soil dynamics (Grove 2009). Urban green spaces and urban protected areas can contribute to mitigate risk impacts and support climate change adaptation and mitigation (Beck 2012; Nehren et al. 2016; Secretariat of the Convention on Biological Diversity 2012; Trzyna 2014). Ecosystem-based approaches have already proven to be effective based on various case studies (cf. Dudley et al. 2010; Trzyna 2014; UNEP et al. 2014). Example of urban initiatives include the city of New York's green infrastructure plan launched in 2010, which includes green roof tops, green sidewalks, upstream and urban wetlands, as well as ponds for cooling the city and for storm water retention. The city of Bogotá, Columbia is pursuing upstream landscape conservation and restoration as an alternative to more conventional water treatment technologies. Ho Chi Minh City, Vietnam, launched a program favoring mangroves instead of building dikes to protect shorelines from storm damages (World Resources Institute 2012).

Linking sustainable urban development with sound ecosystem management requires a holistic approach, involving various actors (Secretariat of the Convention on Biological Diversity 2012). Such an approach would have to consider ecosystem services in urban contexts, along with the risk and livelihood profiles of urban dwellers, who are often not a homogenous group. Rather, urban dwellers are generally heterogeneous, experiencing different levels of risk. Urban poor, often settling informally in the most vulnerable locations, are facing comparable high environmental risk from natural hazards and global environmental change (Pelling 2003, 2012). Adapting urban infrastructure to the impacts of climate change and natural hazards by using ecosystem-based approaches, as many cities in developing and emerging countries are currently doing (Schauber 2014), could be a viable tool particularly for such informal settlers who often continue to rely on local natural resources (Guadagno et al. 2013).

Research design

The methodology of the study uses quantitative and qualitative procedures and is divided into three parts. In the first part of the study, current prevention and mitigation plans and activities from the state and local government as well as initiatives by other relevant stakeholders are analyzed with respect to their consideration of ecosystem-based measures for DRR and CCA. To gain a deeper insight on processes, goals, policies and governance of urban planning in general and especially of ecosystem-based approaches, overall twelve expert interviews were conducted. A list with information on the interview partners and their organizations is provided in Appendix B. When being quoted, the interviewees appear with numbers from 01 to 12. All interview partners are linked to the research topic in their working life; they are dealing with aspects of urban disaster risk reduction and/or ecosystem management either in state or municipal authorities or as researchers. Most experts work for municipal authorities, namely the Geotechnical Institute (Geo-Rio), the municipal Water Institute (Rio-Águas), the Civil Defense (Defesa Civil) as well as different departments of the Municipal Secretary of Environment. The interviews were done in a semi-structured way, following a guideline applied throughout all interviews. The interview length ranged from 25 minutes to 2.5 hours; on average an interview took around 1 hour 15 minutes. The subsequent evaluation was done based on the following dimensions of analysis:

- Environmental risk and underlying factors for landslides;
- Analysis of prevention and mitigation plans and activities from state and local government as well as initiatives by other relevant stakeholders with respect to the consideration of ecosystem-based measures;
- Risk perception of the interviewees;
- Related legal framework, including potential shortcomings and conflicts;
- Own work and organizational responsibilities related to landslide risk and ecosystem potentials, including institutional and cooperation and their perceived functionality;
- Implemented measures for landslide risk prevention and mitigation, their focal areas, perceived effectiveness and potential improvements;
- Personal awareness of ecosystem-based approaches and its potentials, including the consideration of such measures in the interviewee's work;
- Interviewee's opinion related to the potential/suitability of ecosystem-based measures; and
- Interviewee's opinion regarding gaps and needs to foster ecosystem-based approaches.

The interviews were supported by a survey of corresponding legislations, local governance system and previous scientific publications on related topics.

In the second part, the official risk mapping and legally declared risk areas are analyzed at the municipality level for Rio de Janeiro and in a higher resolution for selected informal settlements regarding their relation to ecosystem status and ecosystem degradation. In this step geospatial data, secondary literature and documents from authorities and previous research projects were collected. The data comprises existing landslide susceptibility maps and other geographic data (land use/land cover, settlements, topography, etc.), as well as the relevant literature on landslide risk and marginal settlements. Besides the GIS-based analysis using existing risk mappings, land use and land cover data and other geo-data on the urban level, the data evaluation is also comprised of literature and document analysis. The main objectives of this part are the analysis of the relationships between ecosystem status/ecosystem degradation (land cover), environmental protected areas and risk susceptibility, as well as the identification of gaps and needs regarding the implementation of Eco-DRR/EbA measures.

Besides the expert interviews with authorities, two local case studies were analyzed: Morro da Formiga and Morro dos Prazeres. Both informal settlements have suffered from past landslide events and were also affected in the 2010 events mentioned previously. The case study area selection was done based on preliminary data collection and analysis (as a part of research step one), as well as input gained during expert interviews. In both favelas different formal measures to reduce the landslide risk were and are carried out. The case study area assessments are comprised of field surveys and interviews with local actors as well as on-site inspections of affected areas and measures that have already been implemented. In addition, available project data was collected and analyzed.

In the last research step, based on part one and two, potential improvements for existing ecosystem-based measures as well as recommendations for additional measures in Rio de Janeiro are given. Ecosystem-based measures for DRR and CCA are identified and systemized in the form of a portfolio, for Rio de Janeiro in general and the two case study areas, comparing protective functions of ecosystems during and after landslide events.

Rio de Janeiro

Rio de Janeiro is internationally well known for its unique scenery between mountains covered with lush tropical rainforest and famous beaches. Being located on Brazil’s Atlantic coast, it fringes in its southern parts the open sea and towards the east and northeast the Guanabara Bay. The city was founded in 1556 by the Portuguese because of the strategic location: easy for the defense from attacks from land and sea. Today, this setting does not only make the city Brazil’s main tourist attraction, but it exposes the urban inhabitants to different natural hazards and poses urban planning challenges.

For centuries, large-scale sugarcane production had a decisive influence on the urban landscape development; later coffee plantations particularly in the hilly areas shaped the landscape (Nehren et al. 2013). Rio de Janeiro became capital city of Brazil in 1763; in 1808 it gained even more importance with the escape of Portugal’s royal family to Rio. Political importance and economic prosperity resulted in large-scale urban development projects, while the abolition of slavery in 1888 led to a massive inflow of poor migrants and the emergence of low-income settlements.

Today, with an estimated population of 6.48 million inhabitants in the municipality and 12.28 in the metropolitan region (IBGE 2015), the municipality of Rio de Janeiro is the second biggest city of Brazil. Of the 1,224 km^2 of the municipality, about 644 km^2 are urbanized and the rest is covered with forest, agricultural areas, grass or other natural areas (cf. Figure 1). Rio de Janeiro is one of the main economic hubs of Brazil, a large share of the country's gross domestic product is produced here, and it houses some of the major national companies' headquarters. At the same time, a large share of the population is poor and 22 percent of the population (IBGE 2010) lives in one of the more than 1,000 informal settlements called favelas (Cavallieri and Vial 2012). High social inequality is one of the triggers for urban violence, like the constant armed conflicts between drug trafficking fractions and the police. Moreover, the city faces severe environmental problems such as the pollution of the Guanabara Bay- the lagoons and freshwater bodies which can be traced back at least partly to informal construction activities, poor sanitation infrastructure, and untreated inflow of waste water.

Formal and informal urban development

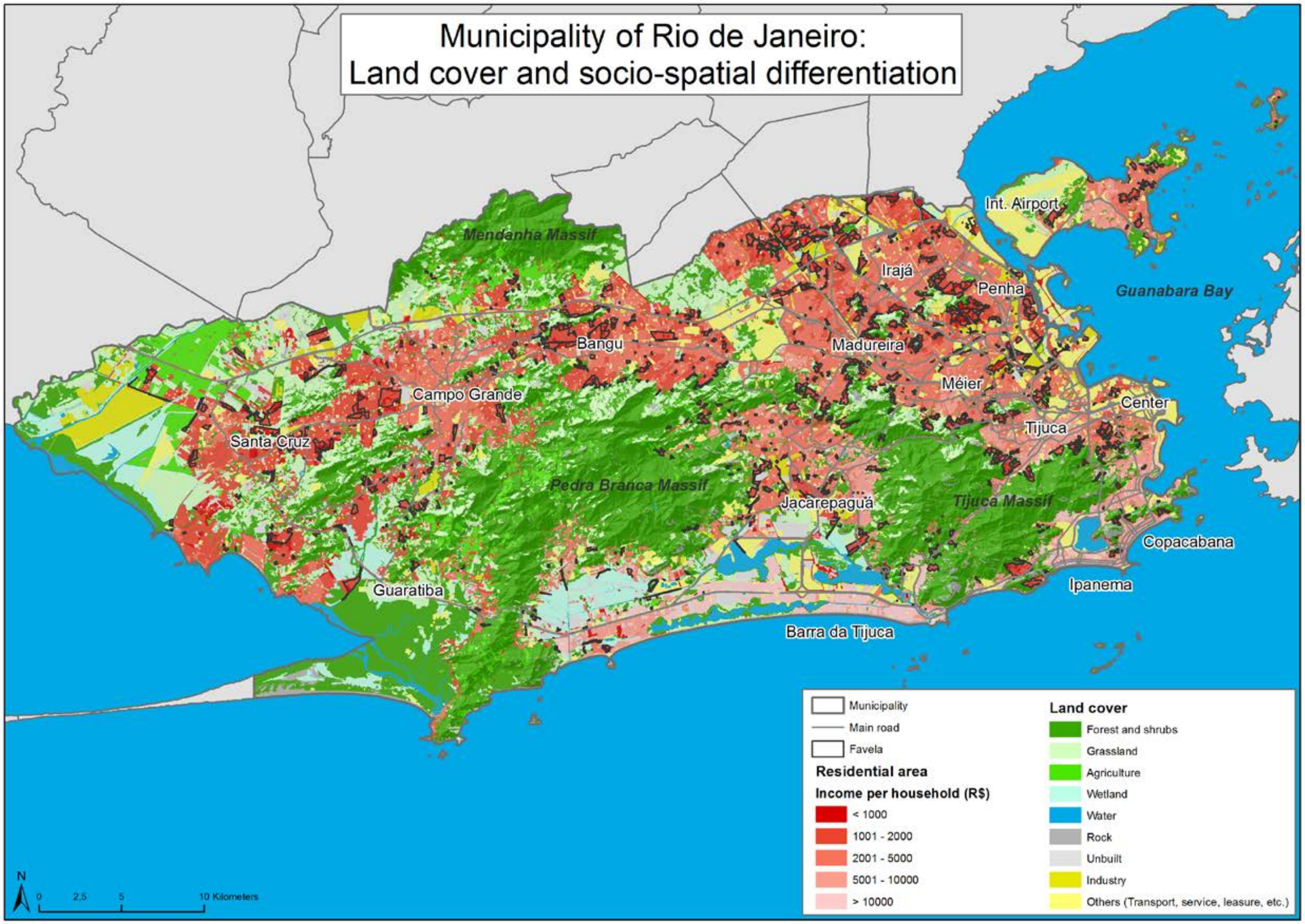
Rio de Janeiro's urban landscape is characterized by a fundamental polarization of rich and poor (Ribeiro 1996; UN-Habitat 2008). Socio-spatial disparities become visible in middle and upper classes residing on the plane lands near the sea and the marginal population occupying the yet vacant areas. Thus, the spatial gradient of income distribution decreases from the South Zone with its core area in Ipanema and Copacabana and Barra da Tijuca district to the North and West Zone (see Figure 1). This highly significant scheme of socio-spatial segregation is only disturbed by fragmented pockets of the informal settlements in the South Zone and middle-class areas in the sub-centers of the suburbs in the North Zone and peri-urban regions of the West Zone.

This segregation pattern is rooted in the historic urban development. With the end of slavery in 1888 many former slaves moved to urban areas like Rio de Janeiro. The first informal settlement in Rio dates to 1897 when veterans of the War of Canudos started to occupy the slopes of the Morro da Providência close to a hill known as "Morro da Favela," named after a poisonous plant of the Euphorbiaceae family (Mattos 2007).

Formal and informal urbanization processes peaked in the early 20th century, the cities attracted a continuously growing number of people and many of them moved to Rio de Janeiro, which was the country's capital from 1763 to 1960. During that time major urban renewal projects were carried out due to the growing housing demands. The city center was restructured following models from Haussmann's plans for Paris, and new posh quarters emerged along the easy accessible coastline southwest of the center (Kamarid and Leupert 2009), namely Copacabana and Ipanema.

Brazil's urban growth rate increased during the 1930s and 1940s and reached its highest value between the 1950s and the 1970s. The growing number of inhabitants resulted in urban sprawl and the densification of inner-urban areas (Bähr and Mertins 1995; Lara 2011). Since then, high-density neighborhoods and apartment houses became popular (Aragão and Maennig 2013), which was the starting point of Brazilian Gated Communities, the so-called *condominios fechados*, e.g. Barra da Tijuca in Rio de Janeiro (Herzog 2013). The rapid increase of metropolitan population also led to a growth of informal settlements, many of them in vacant areas of the center (Athayde 2011; Coy 2006; Coy and Pöhler 2002). In Rio de Janeiro much of this took place on the environmentally fragile and risk-prone slopes of the Atlantic Forest (Mata Atlântica).

Figure 1: Land cover and socio-spatial differentiation in Rio de Janeiro (source: Instituto Pereira Passos 2012, cartography: W. Lange)



During the 1980s and 1990s, the ongoing construction of gated communities and the continuous expansion of informal settlements further fragmented the urban layout (Dowall 2006; Fernández-Maldonado et al. 2014). As a result, the gap between the spaces of wealth and those of marginality grew (Herzog 2013), triggered by speculative land markets, clientelist political systems, elitist urban planning practices and exclusionary legal regimes (Fernandes 2006; Furtado et al. 2014; Roy 2009). By 1989, the income distribution of Rio de Janeiro was the most unequal of the whole country. Poor migrants from other regions constituted the largest share of population growth and the main reason for the still growing favelas, despite the often-precarious living conditions with very poor infrastructure (Herzog 2013). Informal settlements are often constructed without legal supply of basic infrastructure (Lara 2011) like electricity, water or sanitation. Particularly, the lack of properly planned water runoff and sanitation is potentially adding to the risk level, as it may exacerbate slope destabilization. Buildings themselves are constructed in a non-engineered way, casting doubts on their foundation and capacity to withstand hazards like intense rainfalls and landslides.

Informal settlements were already considered a societal problem for Rio de Janeiro in the 1920s and 1930s when they continuously grew (Freire-Medeiros 2009). The often-unaffordable prices and a lack of adequate social housing policies forced many of the poor migrants to settle in marginal areas (Perlman 2010). Such less-favored and risky areas comprised the steep slopes of the massifs (Freire-Medeiros 2013; Romero Jacob et al. 2015). The growing problem of slum expansion was increasingly perceived and institutionalized when the term favela became a category for informal settlements. However, it was not until 1937 under the presidency of Getúlio Vargas that the Building Code *(Código de Obras)* officially recognized the existence of favelas and at the same time demanded their elimination (Valladares 2000). Even though the government created housing areas for the working-class (the so called *parques proletários*) to turn informal dwellers into “adjusted citizens” (Madeiros 2002, cited in Freire-Medeiros 2013), the informal settlements continued to grow. According to Pino (1997, 111), the “explosive era of favela growth” even started in the 1940s with President Getúlio Vargas’ industrialization drive that attracted many migrants from the Northeast, so that in 1950 already 7.2 percent of the population of the Federal District (around 170,000 inhabitants) lived in informal settlements (IBGE 1953).

In the 1960s and 1970s informal settlements increased rapidly in both number and size (Boyer 2005), even though Rio de Janeiro was no longer the capital city of Brazil. Migrants from the interior states, neighboring states and the Northeast came to the city to find better job opportunities (Madeiros 2009). Even though most of the new residents settled in suburbs, the informal population of the North and South Zones of the city increased by 98 percent from 1950 to 1960 (Abreu 1987). According to the census data, the informal settlements had a total population of 337,412 in 1960 (10.20 percent of the total population) and 563,970 in 1970 (13.26 percent of the total population) (Perlman 2003). By the 1970s, 13 percent of the urban population lived in slums (UN-Habitat 2003). The rapid population growth led to severe traffic and population problems in the city (Xavier and Magalhães 2003; Herzog 2013), along with the expansion of informal settlements due to high forest losses. This process reached its apex in the main urban centers in the early 1980s with a combination of a decrease in birth rates and the reduction of rural-urban migration (Xavier and Magalhães 2003). **Error! Not a valid bookmark self-reference.** shows the horizontal expansion of the favela Rocinha in Rios South Zone from

1975 to 1996. It can be clearly stated that the spatial growth in this period happened mainly until 1996.

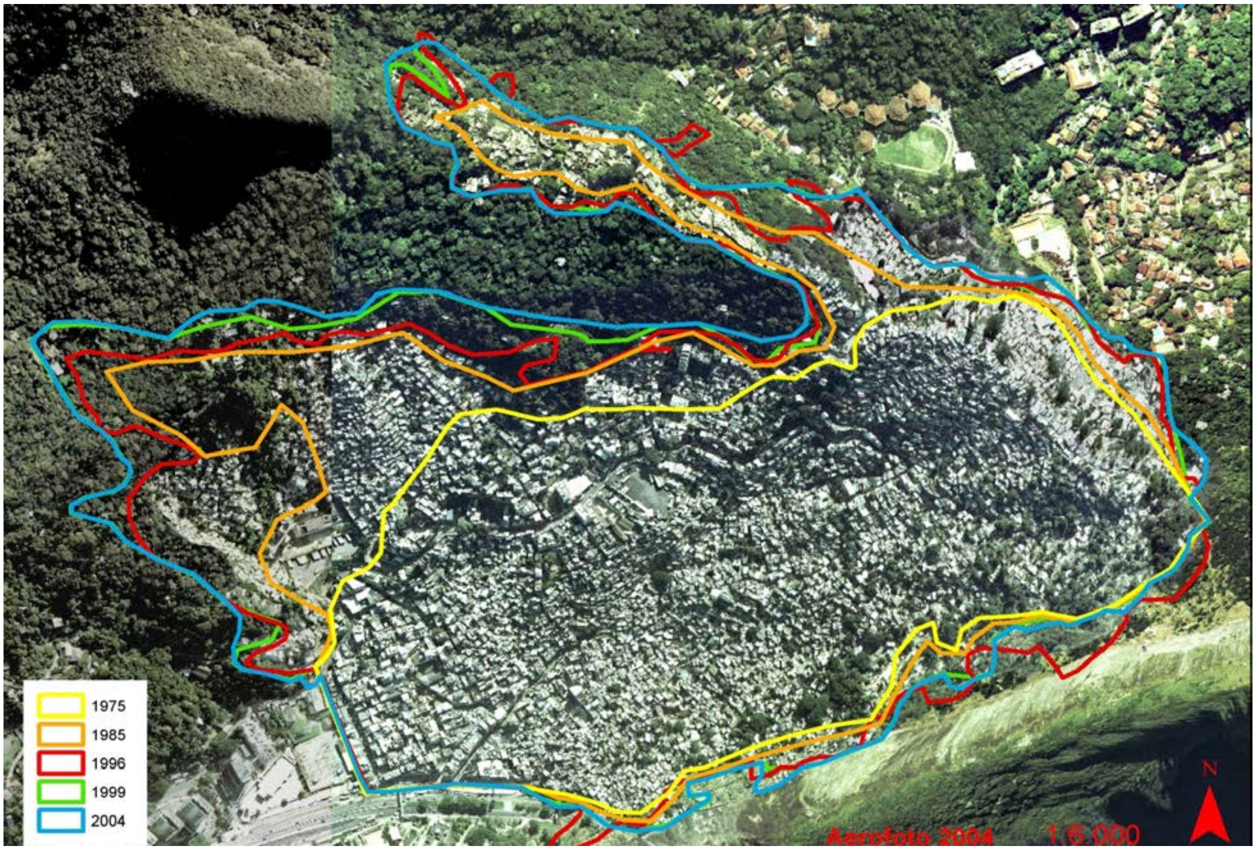


Figure 2: Spatial growth of favela Rocinha between 1975 and 2004. (Source: Instituto Pereira Passos)

The Brazilian Institute of Geography and Statistics (IBGE) uses the term ‘Subnormal Agglomerates’ (SNAG) to classify residential units that illegally occupy public or private land. The SNAGs include settlements with a minimum of 51 household units and are characterized by:

a) “Illegal occupation of land, i.e., construction in a third-party property – public or private – now or recently (ownership title of the property obtained in ten years or less); and
b) Urbanized out of the legal standards – reflected by narrow and irregular ways, plots with different sizes and formats and constructions not legalized by public offices – or low provision of essential public services (water supply, sewage collection, garbage collection and electric energy)” (IBGE 2010).

In 2010, the municipality of Rio de Janeiro counted as many as 1,034 informal settlements (Cavallieri and Vial 2012) with a population of 1.443 million (ca. 23 percent of total population) (IBGE 2010). In the 1990s Rio’s urbanized region growth rate was around 7 percent, while in the same period the informal settlements grew at the impressive rate of 25 percent (Perlman 2010).

Data of IBGE shows that between 2000 and 2010 the population growth of the informal settlements (19 percent) was almost four times higher than that of the formal city (5 percent) (Cavallieri and Vial 2012). This demographic growth of the favela residents was not mainly due to spatial growth or increase of the number of informal settlements, but more likely due to an increase of population density by verticalization of the constructions. The monitoring of the favelas with aerial images shows that the area occupied increased between 2004 and 2010 by only 1 percent (Lopes et al. 2010).

The political handling of favelas has changed a lot over time. Until the 1930s favelas were usually 'cleared,' e.g. by burning them. In the 1940s, first state-driven social programs addressed the favela problem, however with only very limited scale. The first projects actively fostering self-help stem from the 1960s, under the presidency of Kubitschek, when also first laws were passed to protect illegal dwellers from eviction. Favela clearing however continued, now done with bulldozers and coming along with a relocation of the affected population towards peripheral areas, mostly to the North and West Zone. These attempts turned out to be not too successful, as the relocation sites hardly comprised of the necessary infrastructure, furthermore relocated people were often employed in the central quarters, e.g. as staff in upper class households (Herzog 2013; Kamarid and Leupert 2009).

During the 1960s and 1970s more than 26,000 dwellings in 80 favelas were cleared; more than 140,000 inhabitants lost their homes. Until the 1980s relocation to public housing projects continued, though with very limited success. Consequently, the strategy changed towards a legalization of favelas and the support of community-based organizations (Kamarid and Leupert 2009). Nevertheless, tensions between favelas and the rest of the city are still high. They are rooted in the high crime rates, some of which became connected to the evolution of favela-based gangs, drug smuggling, and violence (Herzog 2013). The latest development is characterized by the attempt of the so-called pacifications of favelas, often with a massive police presence to reduce the crime rates. The "pacification processes" often resulted in a change but not the reduction of crime rates, with new actors not infrequently involving the police itself. During the 2014 FIFA World Cup and the 2016 Olympic Games relocation processes gained a momentum again, particularly in those areas close to the event places, strategic locations or besides new transport routes, likely to intensify segregation and marginalization (Steinbrink et al. 2011). Nevertheless, over the past decades a trend towards legalization instead of dis-appropriation can be perceived, backed by approaches to improve the local infrastructure like water supply, sanitation and road access.

Still the high level of informality is among the main challenges Brazilian cities must deal with (Altvater and Mahnkopf 2003). Social movements for urban reforms that emerged around two decades ago resulted in the 2001 *Estatuto da Cidade* (Statute of the City), providing legal support for municipalities to promote land tenure and legitimate different new legal instruments for urban areas. Furthermore, it obligates that Brazilian municipalities over 20,000 people must issue a master plan *(Plano Diretor)* every five years (Dowall 2006; Serra et al. 2004). This tool is meant to guide long-term holistic and strategic urban planning, integrating different sectors. Nevertheless, the inclusion of informal settlements is still challenging, also because their consideration depends a lot on the current urban government and their political views.

One result of the past and ongoing expansion into environmentally vulnerable areas is environmental degradation. Despite the urban authorities' awareness of the need to address environmental aspects, the environment is still often sacrificed for the sake of development processes or rather ignored in the context of marginal settlements.

Risk and climate change profile

The landscape of Rio de Janeiro is characterized by mountains and rock formations that are offshoots of the Serra do Mar as part of the Brazilian Highlands. These coastal mountain ranges are formed of Pre-Cambrian gneiss and granite rocks striking Northeast-Southwest (Heilbron 1995, quoted in Coelho Netto 1997). Due to its natural conditions with a rugged topography, unstable geological features such as fractures and joints, as well as vulnerable weathering mantles and colluvial covers, the state of Rio de Janeiro is prone to landslides and debris-flows (Fernandes et al. 2004; Jones 1973; Lacerda 1997; Schuster et al. 2002). Heavy rainfall events with 200-300 mm in 1-2 days occur preferably in summer and are the main trigger for mass movements (Brandão 1997). Over the last decades, several heavy landslides, mudslides and flood events caused many casualties and severe material damage in the state, undermining development gains. Particularly serious events occurred in 1966 and 1967 (Barata 1969; Da Costa Nunes 1969), 1988 (Brandão 1997; Schuster et al. 2002), 1996 (Coelho Netto 1999, Coelho Netto et al. 2007; Fernandes et al. 1999) and 2010 (Avelar et al. 2011; Machado de Mello et al. 2014). The latter caused more than 1,500 fatalities (Avelar et al. 2011) and a material damage of about 4.78 billion Brazilian Reais (Machado de Mello 2014) - 2.66 billion US$ at that time - in the Serrana region as part of the Serra do Mar mountain range. Within the city of Rio de Janeiro the worst events of the last decades in terms of victims were those in 1967 with 110 fatalities (Da Costa Nunes et al. 1979; Jones, 1973), in 1988 with about 120 fatalities and 22,000 people who lost their houses (Schuster et al. 2002), and in 2010 with 67 fatalities, hundreds of houses being destroyed, and severe damage to the urban road and traffic system (Government of Mexico and the World Bank 2012). Apart from these catastrophic events, numerous smaller landslides in different years caused significant material damage particularly in the favelas that are located on the steep slopes of the Tijuca, Pedra Branca and Gericinó massifs (Coelho Netto et al. 2007; Government of Mexico and the World Bank 2012), with the poorest affected the most.

Extreme meteorological events are the main triggering factors for landslides and floods and are not new to the region. Due to climate change, their frequency and intensity have increased since the middle of the 20th century (Marengo 2008). Projections for the study region indicate that rainfall will increase by 20 percent until 2070 and by up to 30 percent until 2100 (PBMC 2013a). Consequently, climate change will likely increase disaster risk and vulnerability (PBMC 2013b) in an already fragile region.

Even though landslides are natural phenomena that control landscape evolution in the Serra do Mar in the long term (Bigarella et al. 1965), the intensity and impacts of landslide events are strongly affected by human intervention (Coelho Netto 2005; Mello et al. 2014). Several studies in different places of the world have shown that road and house construction as well as landfills can trigger landslides (Brunsden and Prior 1984; Crozier 1986). However, for a long time only little attention was paid to the vegetation cover and its degradation status as another important anthropogenic risk factor. Among the few studies in Rio de Janeiro focusing on this aspect are those of Oliveira et al. (1996) and Coelho-Netto et al. (2007) in the Tijuca National Park. Both investigations clearly demonstrate that landslide susceptibility is considerably lower under preserved forest compared to degraded forests and grass or shrub cover. Oliveira et al. (1996), who mapped landslide scars larger than 500 m² originating from the 1996 event, found that only 12 percent of the landslides occurred under preserved forest compared to 42 percent under degraded forest and 43 percent under grassland and shrub cover (the remaining 3 percent are assigned to other land use/land cover classes).

Loss and degradation of forests is closely related to the expansion of illegal settlements, as demonstrated by Fernandes et al. (1999) who showed that within a period of 30 years 47 percent of all landslides in the Tijuca Massif occurred in favela areas that are spreading into the forested slopes. Therefore, the forest-urban interface and construction activities, particularly the sprawl of informal settlements and subsequent environmental degradation processes are focus when thinking about ecosystem-based measures for landslide risk reduction, even though some of the past landslides also occurred in legal residential areas.

Institutional arrangements

The following chapters will highlight findings from the Rio de Janeiro case study, beginning an analysis of the actors involved in disaster risk reduction in favela areas, an assessment of landslide susceptibility as well as an analysis of existing ecosystem-based measures. This is done on two scales, for the municipality of Rio de Janeiro and for two selected favelas: Morro dos Prazeres and Morro da Formiga. The analyses of actors, landslide susceptibility and existing ecosystem-based measures is the basis for the development of a portfolio of suitable ecosystem-based.

Different institutions (see list below) have been involved in DRR for a long time, having either an engineering (namely Geo-Rio and Rio-Águas) or a technical and social focus *(Defesa Civil).* In 2010, the operations center (*Centro de Operações* - COR) was established to allow for a comprehensive monitoring, open data availability and thus an improved risk and crisis management for the whole city. Regarding risk reduction in informal settlements on steep slopes, several formal actors, namely such responsible for urban planning, environment, risk, infrastructure and social concerns, are involved. In addition, due to the often still informal character of the favelas, informal and formal local actors such as community-based initiatives are participating as well.

The institutions responsible for landslide risk prevention and mitigation as well as disaster preparedness, response and recovery in informal settlements are the municipal environmental, water, urban planning and construction works departments, as well as the municipal civil defense. Some are engaged actively and others passively, as a co-benefit of other measures. The following list provides an overview of the key stakeholders and their duties and responsibilities.

- Since 2010, the *Centro de Operações Rio* (Operations Centre, COR) serves as a citywide command center for various emergency situations, such as extreme weather events and floods, but also for day-to day management of urban functions like traffic. Thirty institutions are integrated into all stages of a crisis management from the anticipation, reduction and preparedness, to the immediate response to events such as heavy rains, landslides and traffic accidents. Its core element is visual displays, displaying data from various sources, including weather radar and surveillance cameras, allowing for real-time monitoring and simulations (UN-Habitat 2013).

- The Defesa Civil, Rio de Janeiro's Civil Defense, has the duty to set up, coordinate and implement action to reduce urban disasters. Most of the action is related to early response measures and risk prevention, e.g. by installing early warning and escape route systems in communities at risk. Formally, the civil defense is part of the city's fire fighters.
- Geo-Rio was founded in 1966 after severe rainfall-induced landslide events, with the aim to monitor and stabilize slopes. Its staff has mostly an engineering or geology background. The work comprises all kinds of activities from site surveys, cadasters, monitoring, planning, licensing and implementation of protective measures.
- Rio-Águas is the responsible authority for managing municipal rain water and sanitation, their work comprises planning, execution and maintenance of practical flood protection measures. In addition, Rio-Águas is responsible for managing surface water and sanitation.
- The Municipal Secretary for Environment (Secretaria Municipal de Meio Ambiente – SMAC) is the key actor in environmental issues like permitting, taxation or conservation activities. Besides the conservation of protected areas, SMAC is also engaged in reforestation programs. Furthermore, SMAC is carrying out public awareness activities to promote environmental conservation.
- Urban land use planning is under the authority of SMU – the Secretaria Municipal de Urbanismo, which is responsible for Rio's *Plano Diretor* (master plan), urban parceling, zoning and issuing building permits.

In addition, local civil society and research institutions as well as state departments are supporting action and data acquisition. Figure 3 gives an overview on the activities of the key actors according to the disaster risk cycle. While many institutions are involved in the prevention and mitigation phase, the focal areas of key actors are mostly in preparedness and response.

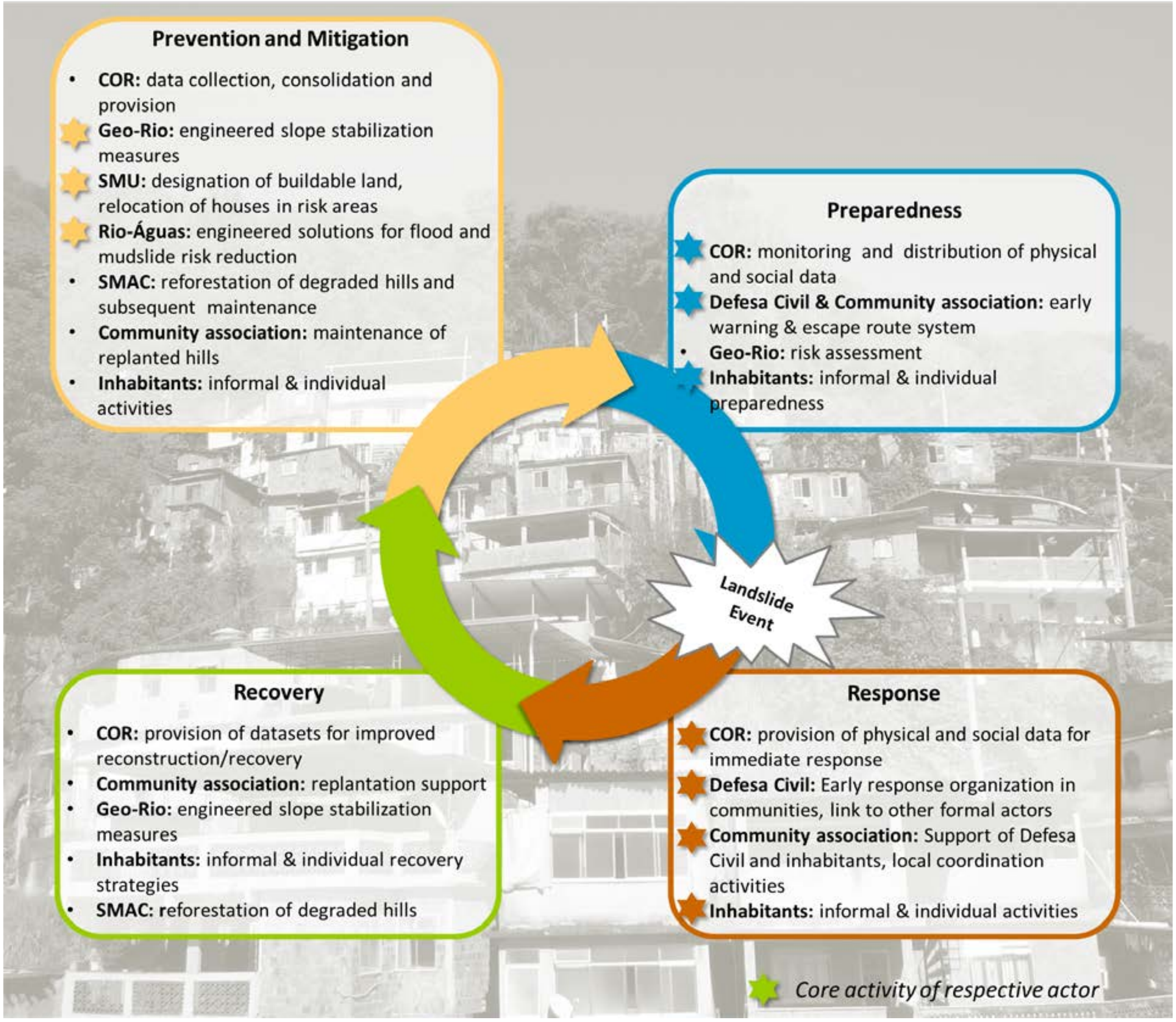


Figure 3: Present activities related to landslide hazards in informal settlements, classified according to risk cycle and actor groups (Source: own figure)

Overall, there is a variety of different measures, which mostly can be classified into social and structural ones. By far, most structural measures implemented to reduce risks from land- and mudslides are focusing on engineered approaches. Table 1 gives an overview on the organizations and their main responsibilities with a focus on activities related to informal settlements.

Table 1: Main actors and responsibilities related to landslides in informal settlements

Actor	Function/ responsibility	Usual action/ measures in case of informal settlements at risk from landslides	Focal area classification according to disaster risk cycle	Potential impediments related to Eco-DRR potentials
Defesa Civil Municipal (Civil Defense of the municipality)	Plan and coordinate action to reduce disasters in the municipality	Civil defense, focus on civil society activities, e.g. support of early warning and escape route systems, community-based preparedness	Risk preparedness and early response	Mostly focusing on societal processes and infrastructure in terms of early warning system
Geo-Rio - Fundação Instituto de Geotécnica	Municipal authority to monitor and stabilize slopes and take necessary measures	Lowering of risk level by means of engineered constructions like concrete walls, drainage, etc.	Reconstruction and prevention	Focus on pure engineered approaches
Rio-Águas- Fundação Instituto das Águas do Município do Rio de Janeiro	Municipal water authority, responsible for management of rain water, sanitation and flood prevention	Flood and mudslide risk reduction	Prevention	Focus on pure engineered approaches, not all favelas included in measures
SMAC - Secretaria Municipal de Meio Ambiente	Municipal environmental agency, responsible for conservation, municipal protected areas and park/garden management, environmental education reforestation and taxation	Reforestation of degraded hills to reduce landslide risk, maintenance of reforested parts, plantation activities in different succession steps, usually involving local communities in plantation and maintenance activities	Mainly reconstruction & prevention	-
SMU- Secretaria Municipal de Urbanismo	Municipal planning authority, responsible for urban planning, policies, land use planning and monitoring	Potential relocation of buildings or communities at risk	Reconstruction, prevention and preparedness	Due to their informal character favelas are often not included in formal SMU planning processes
Academia	No formal responsibilities, potential advisors to authorities	-	Accompanying research	-
Heads of Favelas communities	Lead of local communities, contact persons for municipal authorities	Involved actors in activities like early warning and reforestation	Preparedness, recovery and prevention	Awareness of suitable measures and techniques, potential lack of budget

Most actors can be classified as formal ones, mostly on the municipal level. Within the favelas, informal actors as well as formal ones like the favela associations and the heads of favela communities are key actors as well. Interaction between formal and informal actors is still very much upgradable. Even the interaction among the formal actors, which belong to different sections of the municipal administration, is partly weak (cf. Figure 4). Each of the formal actors is obliged to follow the specific set of rules of that organization, which often is very complex and with limited adjustment to the regulations of other actors.

Most of the interviewees mentioned they already collaborate with colleagues from other departments or institutions. However, most of that cooperation is not following formal schemes but is rather based on personal contacts. Although such personal contacts are mostly regarded as useful and well-established, they are on the line to get lost in case of a staff turnover. In addition, the non-institutionalization of cooperation schemes is hindering joint and cross-institutional risk reduction efforts by sharing information and combining various interdisciplinary approaches and methods from the different authorities.

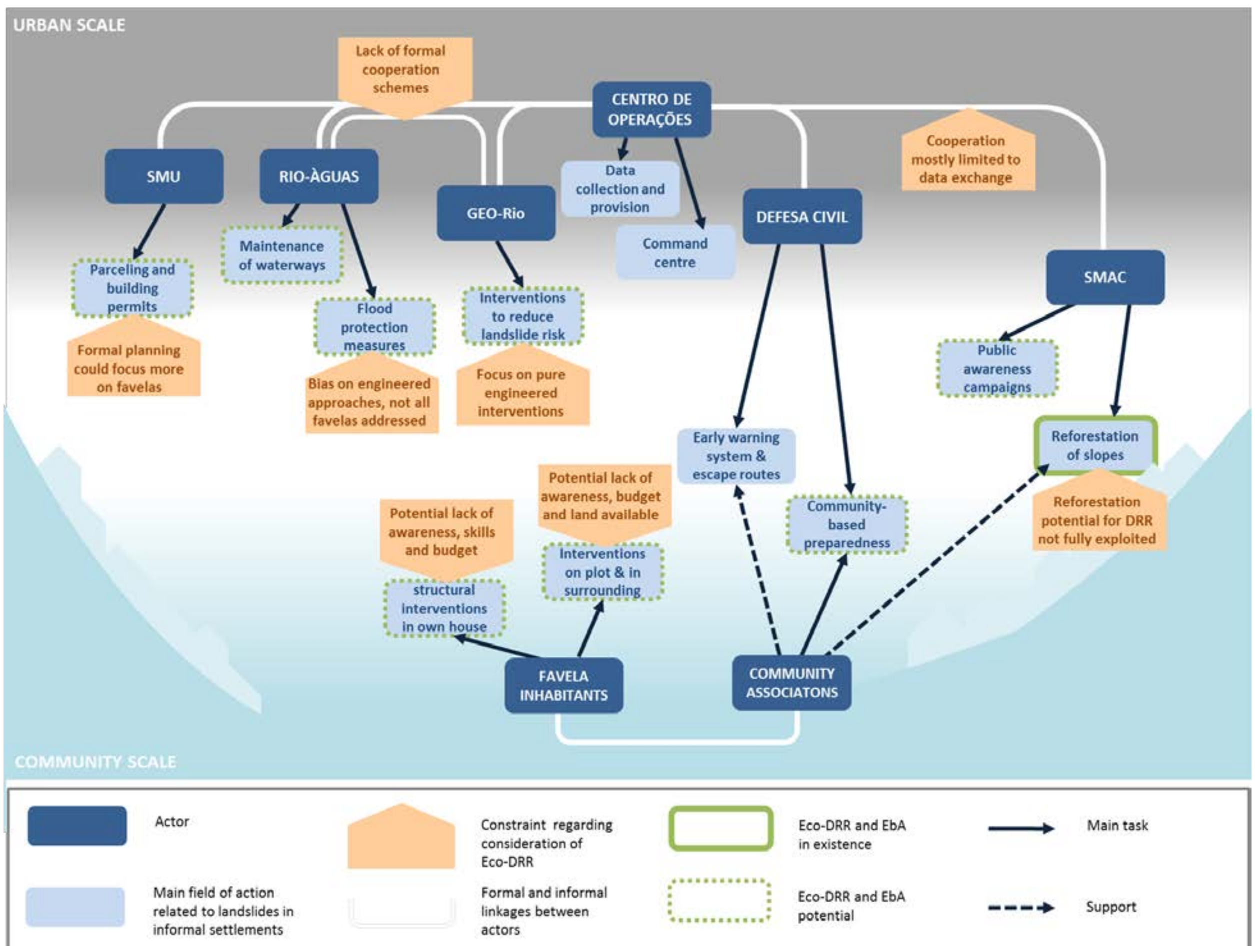


Figure 4: Actors, activities and related constraints regarding landslides risk reduction and Eco-DRR and EbA potentials (Source: S. Sandholz)

According to the interviewees, hardly any of their institutions are actively following ecosystem-based approaches, apart from the municipal reforestation program. Most of the work of both

Geo-Rio and Rio-Àguas is focused on engineered measures, such as concrete walls with included drainage for slope stabilization. Defesa Civil is working with civil society organizations and not involved in the construction part itself, but rather in risk preparedness. Therefore, Defesa Civil does not carry out any ecosystem-based measures. Nevertheless, Defesa Civil agents are at least aware of any action from other authorities in informal settlements, as they probably are the municipal authority with the closest and most permanent relation to the informal dwellers. SMU is foremost involved in 'formal' planning schemes and much less in favela-centered activities. Consequently, the ecosystem-related measures are still very much upgradable.

Two main biases identified that are hindering a better implementation of Eco-DRR and EbA measures are a lack of awareness as well as the governance system itself. The current system is not yet emphasizing integrated schemes which would bring together the expertise and skills of the different authorities. Such concerted action can still be considered as exceptional, though promising attempts are in place. It is therefore recommendable to build upon both, those cooperation schemes that already exist as well as on the existing personal understanding of experts in the different involved authorities and to consolidate them. At the same time the lack of awareness regarding the potential of Eco-DRR and EbA measures was identified as a major obstacle throughout the research. Most of the interviewees was not aware of potential ecosystem-based measures or regarded them as complementary to engineered solutions instead of as an alternative. In this context, the background of Geo-Rio in predominantly engineered approaches may be another obstacle that has to be overcome.

Landslide susceptibility in Rio de Janeiro

Geo-Rio as the responsible institution carried out two official mappings to assess the risk of landslides in the city: (a) A landslide susceptibility map at the city level in the scale 1:10,000 and (b) detailed maps for selected areas in the scale 1: 2,000. Figure 5 shows the susceptibility of landslides in the entire area of the municipality of Rio de Janeiro in three levels: low, medium and high. The map has been produced using multi-criteria spatial analysis incorporating several susceptibility factors that derive from (a) digital elevation model (DEM); (b) geomorphological, geological-geotechnical, geological, and land-use maps; (c) maps of Permanent Protection Areas (*Áreas de Preservação Permanente* - APPs), and (d) maps indicating the past occurrences of landslides (d'Orsi 2012). As the slope gradient is one of the main factors that determine landslide susceptibility, the main areas of high susceptibility are in the steep mountainous regions of the Tijuca and Pedra Branca massifs. About 58 percent of the mapped area is of low, 30 percent of medium, and 12 percent of high landslide susceptibility.

Clipping the susceptibility map with the most recent data on land use/land cover from the Instituto Pereira Passos shows that the vast majority of areas that are highly susceptible to landslides are covered by forests and shrubs, followed by grassland (Table 2).[1] Regarding urbanized areas (the first five land cover categories in Table 3), the analysis indicates that areas

[1] There is a more detailed vegetation map by SMAC, but it should not be used for this purpose as reforestation areas are not classified by vegetation type.

of high susceptibility are more than five times larger in informal settlements than in formal residential areas.

Figure 5: Landslide susceptibility map of Rio de Janeiro (Source: Geo-Rio; cartography: W. Lange)

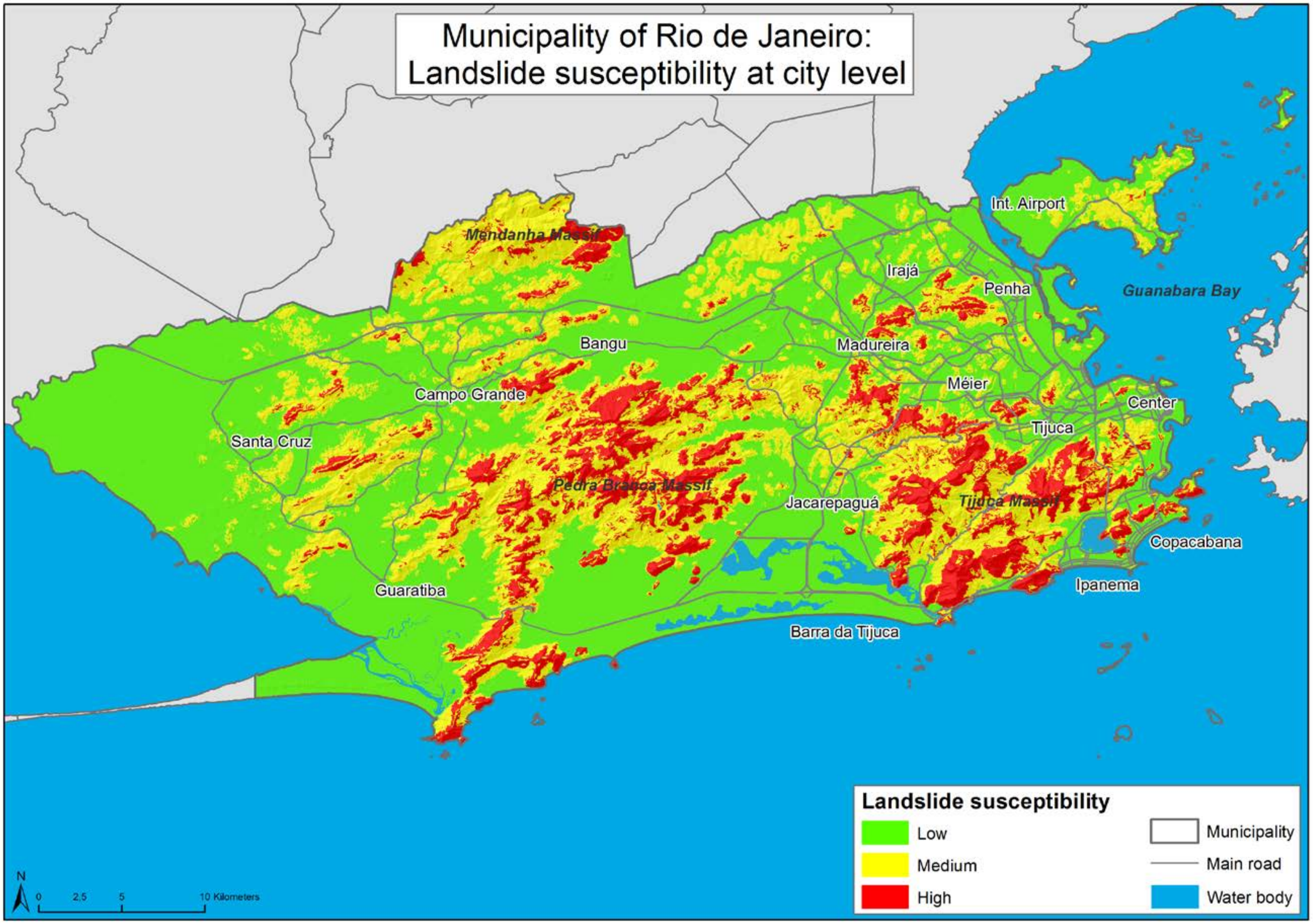


Table 2: Susceptibility by land cover

Land cover \ Susceptible area (ha/%)	Low	Medium	High
Residential	28,419.6 (41.5)	7,633.3 (29.6)	177.2 (0.7)
Favela	2,016.3 (2.9)	1,576.4 (6.1)	981.3 (4.0)
Industry	2,821.8 (4.1)	167.9 (0.7)	0.3 (0.0)
Others (Transport, service, Leisure, etc.)	8,483.6 (12.4)	1,246.6 (4.8)	114.9 (0.5)
Unbuilt	3,425.1 (5.0)	709.3 (2.8)	25.5 (0.1)
Agriculture	2,627.1 (3.8)	1,160.5 (4.5)	277.3 (1.1)
Forest and shrubs	9,738.1 (14.2)	9,885.5 (38.4)	18,707.5 (75.8)
Grassland	7,118.6 (10.4)	2,355.2 (9.1)	4,300.9 (17.4)
Wetland	3,228.1 (4.7)	2.3 (0.0)	0.0 (0.0)
Rock	653.2 (1.0)	1,039.4 (4.0)	93.5 (0.4)
All	68,531.5 (100.0)	25,776.4 (100.0)	24,678.4 (100.0)

Source: Own calculation, based on data from Geo-Rio and IPP)

An additional analysis at the city level compares APPs with the land cover data. APPs are defined in the Brazilian National Forest Code *(Código Florestal Brasileiro, Lei nº 12.651, de 25 de maio de 2012)* and include among other hilltops, headwater areas, slopes >45°, and riverine forests that should be covered by native vegetation. As they have the function to preserve water resources, landscape, geologic stability, biodiversity, protect soil and ensure the well-being of human populations, the integrity of APPs is very important for reducing risks including those from landslides. The SMAC has mapped these APPs at the city scale. Overlaying the two important types of APPs for landslide risk reduction - steep slopes and hilltops - with the land use/land cover map shows that most of these two APP categories are covered by forests and shrubs, but that formal residential areas occupy two times more area in APPs than favelas. In the case of steep slopes, formal residential areas even account for three times more area occupied.

Table 3: Permanent protection areas of selected types by land cover

Land cover \ APP type (ha)	Steep slope (> 45°)	Hilltop
Residential	33.4	33.2
Favela	11.2	20.3
Industry	0.2	0.0
Others (Transport, service, Leisure, etc.)	43.8	8.6
Unbuilt	2.7	3.1
Agriculture	4.3	66.1
Forest and shrubs	791.2	2,560.6
Grassland	57.5	265.0
Wetland	0.0	0.0
Rock	442.5	38.4
All	1,386.8	2,995.3

Source: Own calculation based on data from SMAC and IPP

The northern part of the Tijuca massif, as the most densely occupied region of the city on steep slopes, and the area around the Complexo do Alemão have been chosen for the detailed mapping at the scale 1:2.000. Again, three risk levels were defined. Figure 6 shows the example of Morro da Formiga. Of the 196 mapped favelas, 116 contain sections of high landslide risk, which sum up to about 18,000 dwellings that are at high risk (d'Orsi 2012).

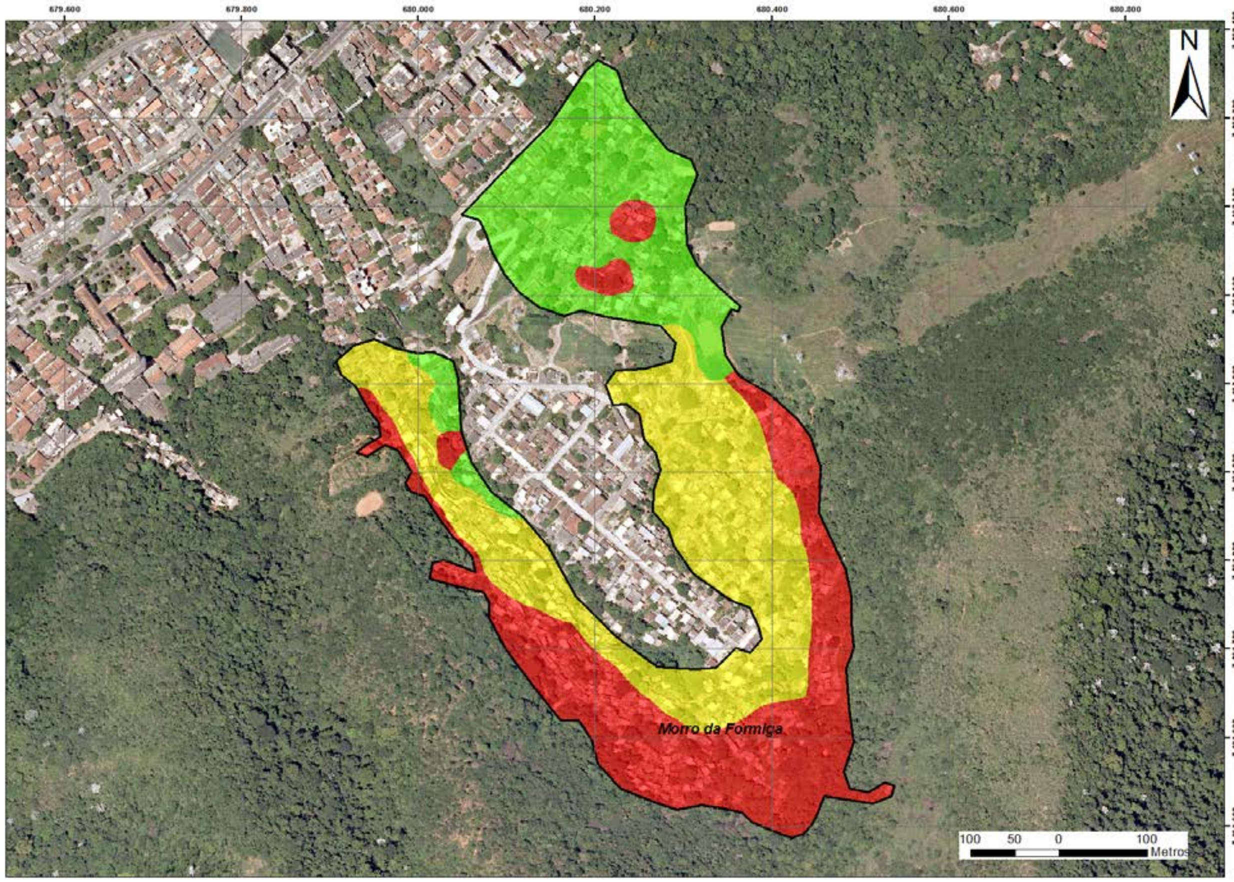


Figure 6: Mapping of risk sectors of Morro da Formiga in 1:2.000. Red = high, yellow = medium, green = low risk (Source: Geo-Rio)

Apart from the risk mapping, a field report that describes the history of events, geological and geomorphological situation, and a risk inventory using geological and geotechnical schematic analysis and illustrations has been elaborated by Geo-Rio. The analysis of the risk situations aims at confirming the usefulness of the stabilization projects designed to eliminate these risks (d'Orsi, 2012).

With respect to the question if land and ecosystem degradation in and around favelas increases landslide susceptibility, the available data and maps do not provide a basis for in-depth analysis. The primary reasons are on one hand the few underlying land use/land cover classes and its scale, and on the other hand missing data related to soil properties. To provide clear statements, there is a need to differentiate between different forest types, as for instance a stable old growth forest has a much higher potential to prevent shallow landslides than a degraded secondary forest. This is supported by several studies in different forest ecosystems that point out in particular the importance of (a) the roots system (Roering et al. 2003; Bischetti et al. 2005; De Baets et al. 2008; Danjon et al. 2008; Preti 2013), (b) the species composition (Wehrli and

Dorren 2013), (c) the successional stage of the forest (Cammerat et al. 2005; Pohl et al. 2009), and (d) the management practices (Dorren et al. 2004; Runyan and D'Odorico 2014, Basher et al. 2015) as determining factors for landslide risk. The same as for forests also applies for grasses and shrubs, as some grasses, such as vetiver (*Chrysopogon zizanioides*), stabilize slopes while others only provide little protection. Moreover, deforestation and forest degradation lead to different types of soil degradation which in turn increases landslide risk. Therefore, there is also the need to map the soil status and identify the relation between soil degradation patterns (among other loss of humus content, compaction, and erosion) and factors that have a direct impact on landslide risk, such as water capacity, infiltration, and bulk density.

Existing ecosystem-based measures

Current ecosystem-based measures in the municipality of Rio de Janeiro focus on the reforestation program *Mutirão Reflorestamento* (reforestation by voluntary community work) of SMAC. The general mission of this program is to restore the vegetation cover of the *Mata Atlântica* biome in the city of Rio de Janeiro by recovering degraded and permanent protection areas. The program started in the 1980s as part of measures by city hall to increase the quality of life in the informal settlements. The activities were from the beginning implemented with strong social inclusion as the workers for reforesting the areas came from the surrounding communities. Nowadays the program functions as well via contracting by private companies, environmental compensation or by mechanisms of tributary exemption (fiscal incentives). The expected benefits of the program are:

- Restoration of degraded natural environments through the restoration of the vegetation cover;
- Protection of forest remnants;
- Stabilizing soils reducing the risk of geotechnical accidents;
- Creation of ecological corridors aiming to restore gene flow between forest fragments;
- Expansion of the labor supply in low-income areas;
- Protection of areas of environmental relevance from the expansion of irregular human occupation;
- Regulation of the water regime of hydrological basins;
- Reduction of sediment flow preventing blocking of the drainage system and silting of rivers and channels;
- Stabilizing the river banks of waterways and protection of estuaries;
- Improving air quality;
- Carbon sequestration; and
- Providing protection, shelter and food for wildlife.

Thus, reforestation projects aim not only at reducing landslide risk, but at the same time contribute to biodiversity protection and enhancement of ecosystem services, such as carbon sequestration and food provision as well as increasing scenic beauty. Therefore, these measures also seek to provide benefits for the communities, for instance using fruits and medicinal plant organs, according to the reforestation expert from SMAC. The interviewee was fully aware about the close linkage between land degradation and landslide risk and explicitly mentioned that more landslides occur under degraded vegetation such as shrubs, grass, *capoeira* (fallow vegetation) and degraded forests. Moreover, he pointed out that it is important to better understand microclimatic variations within the urban area, because slopes facing the north get less rainfall in summer and dry out. This in turn leads to more frequent fires and the exposure of bare soil, which increases the risk of erosion and landslides.

Furthermore, protected areas according to the Sistema Nacional de *Unidades de Conservação* – SNUC (National System of Units of Conservation), such as National Parks and *Áreas de Proteção Ambiental* - APAs (Environmental protection areas), as well as various conservation categories under federal state and community legislation must be considered when implementing reforestation projects. However, there are frequently overlaps of protection areas of various categories at national, state, and municipality level and between the different sectors, e.g. environmental and urban planning legislation, which may lead to legal uncertainties and conflicts. Moreover, environmental laws and planning frameworks are often not respected, so that conflicts with illegal settlements are common (according to interviews with experts from SMAC). There is illegal agriculture in protected areas, induced by a lack of control and monitoring to act against both illegal settlements and agricultural activities in protected areas.

Regarding the implementation of a reforestation project, a multi-criteria prioritization methodology has been developed more recently considering the following criteria:

- Adjacency to existing forest fragments;
- Adjacency to existing reforestation projects;
- Proximity to informal settlements less than 1,000 meters;
- Within an environmental conservation area;
- Area size bigger than ten hectares;
- Access via public road;
- Landslide risk;
- Slope higher than 30 percent; and
- Slope orientation to north.

These criteria are ranked by their importance which shows that the factor of landslide risk is so far of less priority as it only gets the lowest value of four, whereas the adjacency to existing fragments and reforestation areas get the highest values of 19.

Data of the vegetation mapping of SMAC *(SIG Floresta)* shows that reforestation projects have been implemented in 2,158 ha, but unfortunately there is no information available on the success of the measures or what kind of vegetation is now predominately making monitoring difficult. Reforestation has been mainly implemented on the northern parts of the Tijuca massif and to some extent as well in the northern part of the Pedra Branca Massif, as well as on minor hills of the North Zone (Figure 7). Overlaying the areas of existing reforestation with the risk mapping of Geo-Rio shows that restoration has been implemented in 51 percent of areas with high, 47 percent in medium and 2 percent in low susceptibility areas.

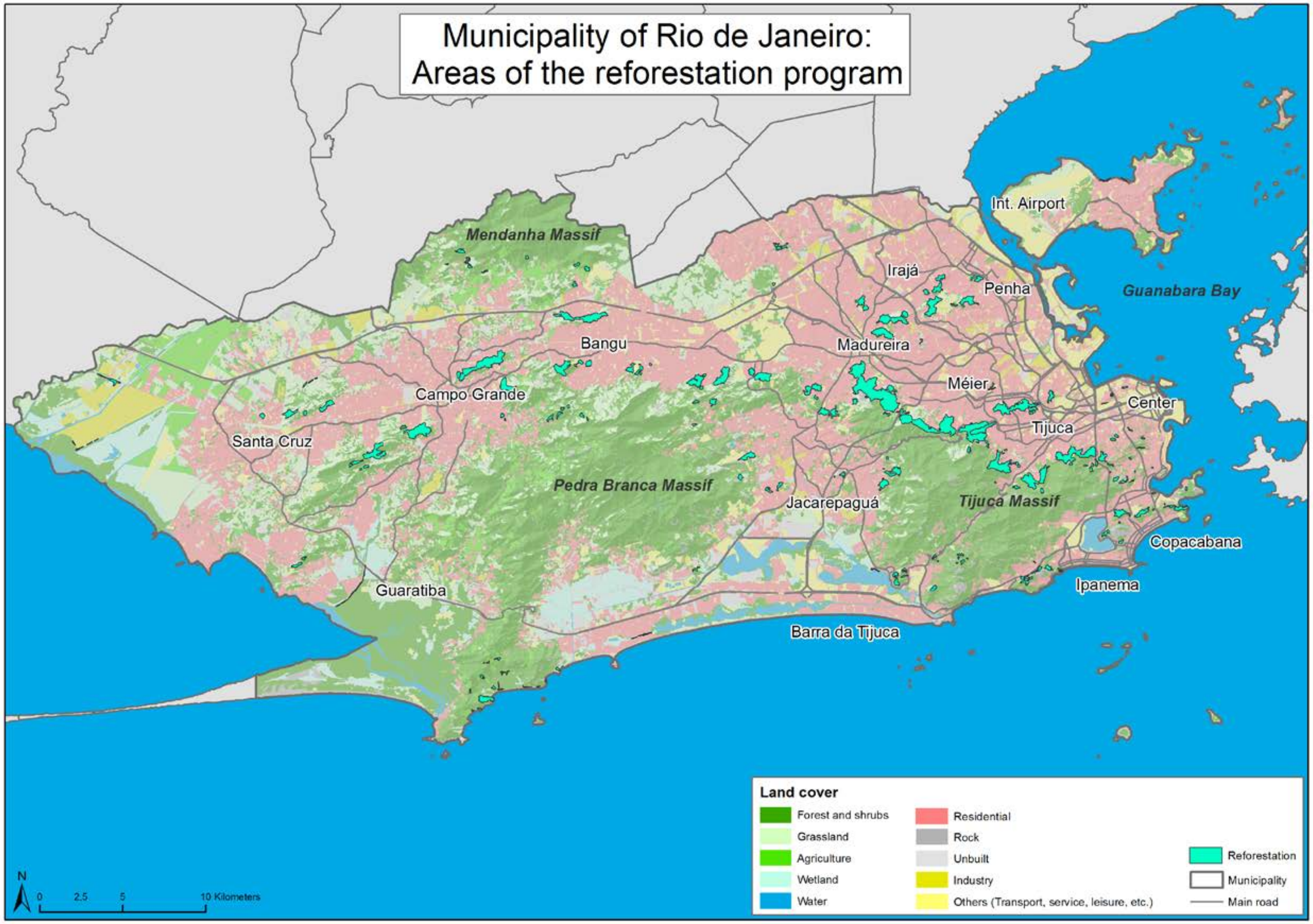
The *Mutirão Reflorestamento* program is responsible for the coordination and implementation of reforestation measures. Apart from this, NGOs and associations, such as the Associação dos

Amigos do Parque Nacional da Tijuca and the Amigos do Parque Estadual da Pedra Branca, carry out reforestation projects. However, these organizations are more focused on conservation and environmental education. There is close and fruitful cooperation of *Mutirão Reflorestamento* with Geo-Rio (risk mapping), Rio-Águas (water management), and other units of SMAC in the establishment of reforestation projects, but poor cooperation with the urban planning unit, as pointed out by the reforestation expert. The program started 27 years ago and so far, reforestation measures have been mainly implemented in unsettled, degraded large-scale areas and to a lesser extent in and around favelas (as reported in interview 07 with the responsible SMAC expert). However, according to the expert, further reforestation projects in favelas are planned.

The already implemented projects have been carried out in cooperation with the local communities. The interviewee explained that these projects have been improved over time using more suitable and native tree species. To provide planners and project staff with the necessary knowledge about the tree species used for reforestation, a manual for the identification of these species has been developed. In its second edition, this manual includes 54 local tree species that are classified in four successional categories: pioneer species, initial secondary forest species, advanced secondary forest species, and climax species, as well as two so-called functional groups, which include (a) fast growing trees with spreading treetops, and (b) slowly growing trees with less extensive canopies. In the beginning of each reforestation project, fast growing pioneer trees with spreading treetops are planted to create shadow and force back grasses and other invasive species. After some years, these species get gradually replaced by species of advanced successional stages. The manual includes a brief description of each tree species with respect to the scientific name, common name(s), family, successional stage, distribution, basic ecological information, utilization, flowering period, fruit type, dispersal, pollination, and leaf characteristics including phyllotaxis.

Even though green solutions are pretty much in the focus and several promising reforestation projects have already been established, there is a need to further explore the potential of ecosystem-based measures. So far, these measures primarily concentrate on classical reforestation projects combined with terracing, and in some cases, the additional use of geo-textile for slope stabilization. Other types of ecosystem-based measures including hybrid solutions have not been implemented so far. Moreover, interviewee 09 (vegetation expert at SMAC) pointed out that in the future more small, populated areas must be considered and that there is a need of a revised prioritization tool for areas to be reforested. Interviewee 07, in charge of the reforestation program, highlighted many positive experiences, but also emphasized some difficulties. Those are particularly related to the scarce financial resources for the implementation of reforestation projects, but also to the high level of crime in some of the settlements, which makes it too dangerous to work there. Moreover, the interviewee wishes for a closer cooperation with the urban planning authorities, an increased number of workers, and higher wages to improve and promote reforestation measures. The interviewee finally pointed out the continuous improvement of methodologies and species used for reforestation measures, but also sees a need for further research particularly with respect to the function of root systems for slope stabilization as well as the incorporation of reforestation measures in Payment for Ecosystem Services (PES) schemes to create financial incentives.

Figure 7: Map of the areas that received activities of the reforestation program (Source: SMAC, cartography: W. Lange)



Case studies' findings

Besides the research on a city-wide level, two favelas have been selected and analyzed in more depth, namely Morro dos Prazeres and Morro da Formiga in the North Zone of Rio de Janeiro (Zona Norte). Morro da Formiga has a population of around 4,300, living in overall 1,300 dwellings. Morro dos Prazeres has around half the population, around 2,100 in 622 houses (IPP 2010). Both favelas are located on steep slopes in the Tijuca massif. Consequently, both face landslide risk and have been affected in the 2010 land- and mudslide events. The next chapters provide an overview on the events and measures taken to prevent future landslides.

Morro da Formiga

On 6 April 2010 a shallow landslide occurred in Morro da Formiga, triggered by soil saturation during a heavy rainfall, and had an extension of about 80 m. It destroyed six houses and caused severe material damage to another two houses located on the lower slope. It also buried one person, who was still in one of the houses, but fortunately this person was rescued by community members, so that there was no loss of human life.

Figure 8 : Landslide in Morro da Formiga in 2010. (Photo: Geo-Rio 2010)

The geotechnical report (Geo-Rio 2010) states that the landslide occurred on a rectilinear natural slope with scattered arboreal, shrubby and grassy vegetation. The landslide was over soil ground and out of soil material and started on the top of the slope. Figure 8 shows clearly that the landslide originated in a degraded area with grass cover.

Landslide risk reduction measures in the settlement (Annex A-4) have been intensified after the disaster but have been focusing pretty much on the installed early warning system which includes two locations with sirens in the upper and lower part of the settlement as well as evacuation routes and a meeting point for the residents. Moreover, there is an evacuation plan for handicapped people. On the steep slopes towards both sides of the main road that dissects the settlement into two parts, some basic technical measures for risk reduction have been built. These include open sewage trenches to control the runoff, protective walls with drainage tubes, and sealing of bare soils with shotcrete and drainage tubes. The reforestation program of SMAC has been implemented from 1986 on, but not all the surrounding areas have been contemplated and the ecosystem is not totally recuperated yet (compare Annex A-5).

During our field studies we identified several risk factors for the houses built on the steep slopes. First, highly weathered rock outcrops and rounded blocks in the weathering mantle and soil, so called "woolsacks," constitute a potential or actual danger. After a heavy rainfall event these blocks may cause rock fall or trigger a landslide. This has also been stated by Geo-Rio for some locations. Another risk factor is related to the house construction. Even though most houses on steep slopes are limited to two stories (and only few to three stories), there is a risk due to the critical load of the buildings. Moreover, houses are frequently built on concrete pillars that are often seriously corroded (see Annex A-6). Waste deposits and landfills are another risk factor; in some cases, even heavy household equipment is deposited in steep slope positions.

Other risk factors are closely related to land use and ecosystem degradation. Due to its geographical setting, the steep slopes of the favela are characterized by clusters of dense built-up areas separated by rock outcrops and vegetation (compare Annex A-4). These open spaces are often used for small home gardens, where bananas are among the most planted crops. These banana plantations bear a high risk of landslides, as banana plants contribute to slope loading and at the same time offer only little slope protection by roots systems and canopies. Moreover, the soil is often unprotected due to intensive pesticide use in banana plantations, which suppresses protective understory vegetation. We therefore often find bare soils with biocrusts, which provide attack points where erosion starts, and landslides can be triggered. Finally, there are several grassland patches in the surrounding of the settlement. These grasslands bear not only high risk for landslides as the 2010 event has shown, but as well a high risk of fires after drought periods. In the surrounding of the favela, several wildfires already took place, which is still visible in the form of young successional stages with shrub vegetation and pioneer trees. After these wildfires the soil is widely unprotected and therefore prone to landslides. Therefore, grasslands in the surrounding of the settlement should be reforested, where possible. Overall, we think that there is a high potential for ecosystem-based measures in Morro da Formiga, which has not been explored so far and existing measures such as the reforestation program could be extended and improved.

Morro dos Prazeres

Morro dos Prazeres is facing high landslide risk due to its location on a steep slope (average inclination of 35°), humid climatic conditions (slope is facing the seaward side), high population density, and a compact settlement structure with multi-story buildings in steep slope positions. Moreover, the settlement is lacking a proper drainage system. Therefore, a geological expert report of 8 July 2010 designated parts of the favela as high-risk areas. Inside the built-up area there are only smaller green spaces with sparse grass cover and single trees. The settlement is surrounded by degraded forest and some open land that is covered by grasses and single trees. The degraded vegetation cover, where in some places the bare soil is already visible, increases the risk of erosion and landslides. However, according to interviews with experts from Geo-Rio, the highest risk is due to landfills in steep slope positions (see Annex A-1).

To reduce the landslide risk for the residents, an early warning system has been implemented. In case of a heavy rainfall event a siren sounds, and people are requested to use the evacuation routes and meet at a designated safe meeting point in the settlement. Technical risk reduction measures are rather basic and include concrete and brick walls with drainage tubes, slope sealing using shotcrete with drainage tubes to reduce infiltration and drain saturated soils, as well as some open sewage trenches that are mainly located along the steep stairways. However, in many cases the shotcrete already shows effects of ageing, so that the soil gets exposed, which increases the risk of erosion and landslides (see Annex A-2).

Ecosystem-based based measures are limited to a reforestation project on a steep slope covered by grassland, where in 6 April 2010 a landslide occurred. This landslide took place during the heavy rainfall events between 4 and 10 April 2010, where an average total precipitation of about 290 mm were measured in the city within only 6 days, which is 332.35% of the average rainfall in April. The landslide made 400 families homeless and claimed a total of 34 lives. According to the geological expert report (Geo-Rio 2012) the disaster was initiated at a pathway in the upper part of the favela at 175 m.a.s.l. and extended over 145 m stopping at 85 m.a.s.l. (Figure 8). It was triggered by waste and rubble deposition on the upper slope, which facilitated infiltration and additionally led to a mechanical overload. The pathway as water runoff to the waste disposal site aggravated the situation. As shown in figure 8, the landslide occurred in an area with mainly grassy vegetation. This fact, which was emphasized by interviewee 05, most probably contributed to the occurrence.

To stabilize the slope, a reforestation measure was initiated by the Environmental Secretary of the municipality of Rio de Janeiro in cooperation with the local community. Objectives of this measure are to create a dense forest cover on the hilltop to reduce infiltration and run-off and to stabilize the medial slope by terracing and planting local tree species according to the reforestation manual (see Annex A-3). Interviewees of the community said that the reforestation program is still underway, but that it faces serious challenges as the population continues to deposit waste and disrespect the reforested area, thus hindering the recuperation. Additionally, the program *"Reciclação"* was initiated. This program focuses on the selective collection of solid waste to create a cycle of recycling to avoid waste deposition on communal land and at the same time make use of the recycled materials. Apart from these measures, no other ecosystem-based projects have been implemented or are planned in Morro dos Prazeres.

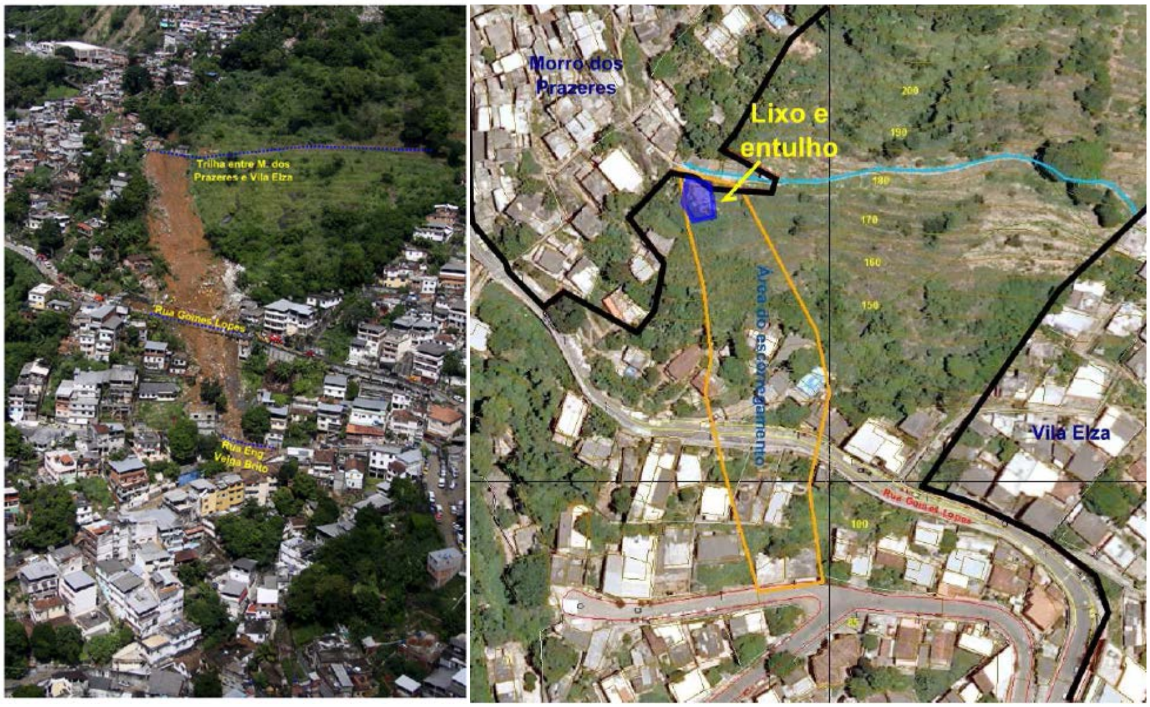


Figure 9a, b: (a) Landslide in Prazeres, 6 April 2010; (b) Waste and rubble deposition (lixo e entulho) triggered the landslide (Source: Geo-Rio 2012)

Portfolio of suitable ecosystem-based measures for urban DRR and CCA for selected areas of RJ

In the case of Rio de Janeiro, ecosystem-based approaches for landslide risk reduction are so far limited to reforestation measures in some risk areas. Several other activities that are already carried out have the potential to be adjusted to Eco-DRR and EbA. Overall, the potential measures can be classified according to their scale, ranging from urban to community or even household level, and regarding their focus, covering pure ecosystem-based approaches, hybrid ones but also social and administrative initiatives, as shown in Table 4.

The reforestation program by the Municipal Environmental Secretary (SMAC) includes various measures that are well planned and implemented and even a booklet with the suitable native tree species for reforestation has been published. However, the spatial extent of these kinds of measures could be expanded and the implementation in smaller areas where a forest cover can reduce the risks of landslides could be included as well. Furthermore, the selection criteria for the areas to be reforested include landslide risk as one factor, but this factor is underrated, and climate change adaptation as another important criterion is not considered at all so far. Therefore, the expansion of reforestation measures to more explicit risk-prone areas should be a main objective. The reforested areas are meant to be maintained for a long time, but there is often a lack of monitoring, especially regarding the protection functions of the forests. Apart from using native tree species for reforestation, it should be further explored in how far these species can generate an economic or social value for the communities, for instance by using them as medicinal plants or extracting fruits and other products. Moreover, on less exposed slopes agroforestry systems can be established in the form of commons that improve the livelihoods of the communities. Other services of the reforested areas should be used as well, such as water(shed) protection by establishing Payment for Ecosystem Services (PES) schemes that are beneficial to the local communities. It should also be considered that reforestation of hilltops and steep slopes not only reduce the risk of landslides, but also mitigate the risks of mudslides and flooding by decreasing the runoff during heavy rainfall events. These multiple values of ecosystem-based measures are often underestimated when compared to engineered structures. Here a closer cooperation between SMAC and the local communities is recommendable to foster even more local commitment for the reforested areas. The reforestation measure is closely linked to awareness campaigns but should be seen more integrated with the activities of Geo-Rio and their slope stabilization measures, e.g. in the form of hybrid approaches, linking ecosystem-based with engineered ones (cf. Table 4).

Other important, already existing ecosystem-based measures in and around informal settlements on the steep slopes of the Tijuca and Pedra Branca massifs are related to waste disposal, because in the past illegal landfills triggered several landslides. In some informal settlements, recycling programs and awareness campaigns have already been established. These programs and campaigns should be expanded to other settlements and moreover, composting of organic substances should be carried out, where possible. The compost could be used in home gardens as well as in reforested areas where it contributes to increased soil stability. Small gardens within the informal settlements contribute to the inhabitants' self-subsistence, but in some cases, they increase the risk of erosion and landslides. Bananas and plantains, for instance, contribute to slope loading, while at the same time only developing limited root systems and vegetation cover. Bananas and plantains should not be planted on steep slopes that are prone to landslides. Still many dwellers are not aware of this fact, so that both education and provision of alternative crops is needed. In addition, favelas should be better integrated into the formal urban waste disposal system to counteract the development of illegal landfills.

Ecosystem-based measures and hybrid solutions are so far not satisfactorily addressed in Rio de Janeiro's Risk Reduction Action Program. However, examples from other cities around the world show that it is at least worth thinking of these measures in built-up areas such as informal settlements and not only in the surroundings of the settlements where most of the current reforestation measures are located. Hybrid solutions that seem to be promising are those aiming to reduce the surface runoff by rain and grey water harvesting and re-use (see Table 4). However, in many informal settlements the sanitation system is mostly inadequate or even inexistent, so that these kinds of measures would have to be installed and maintained, which would generate high costs. Moreover, so far there is no clear evidence on the effectiveness of such measures for landslide risk reduction. Green roofs are another hybrid solution that has been successfully implemented in many cities around the world. There are already promising approaches in Rio de Janeiro and other Brazilian cities to green informal settlements, including the introduction of green roofs. However, as most buildings in informal settlements are constructed without building codes, the building stability for green roofs is questionable. Moreover, and depending on the construction method, green roofs could significantly increase the total load of the buildings which may even increase landslide risk. Therefore, the implementation of green roofs must be studied in detail and seems to be more suitable for settlements in less steep slope positions, where long-term maintenance can be ensured. Here they could contribute to a reduction of rainwater runoff and thereby reduce landslide and flood risk.

Table 4: Overview on potential ecosystem-based or hybrid measures (Sources: Jaffe 2010; Van Bohemen 2012; van Bueren et al. 2012; World Resources Institute 2012; European Commission 2013; New York City 2013; The Dow et al. 2013; HKV Consultants et al. 2014; The Nature Conservancy 2014; Trzyna 2014; UNEP et al. 2014)

Ecosystem-based measure	Potential & suitability	(Potentially) involved actors	Challenges and/or improvements needed
Approaches with a predominant focus on ecosystem			
Reforestation of degraded areas	Can serve to stabilize slopes, reduce erosion and decelerate rain water runoff	SMAC, Local communities	Already done by SMAC, but could potentially be implemented in more areas, not yet done due to prioritization and security matters Budget and personnel constraints to maintain and upgrade reforested areas Need to raise awareness of affected population to maintain the areas Improve monitoring especially for DRR and CCA functions of reforested areas Only implemented in bigger areas, need for reforestation as well in small scale for DRR & CCA Inclusion of tree species that add value to the local population for better preservation
Creation and management of combined agriculture and forestry	Would benefit local population and potentially increases participation processes in maintenance, can serve as commons that improve the livelihoods of the communities	Local communities, SMAC	Selection of species and maintenance
Measures on settlement & surrounding scale			
Waste management: composting of organic substances/avoidance of illegal dumping sites	Helps avoiding illegal dumping sites, and could contribute to regulated waste processing and reduced illegal dumping sites, potential to produce bio-fertilizer for reforested areas and urban agriculture	Local communities, NGOs, COMLURB, SMAC	Need to raise awareness among population to support waste system and to separate waste Need for space to store compost Environmental education
Hybrid measures on house/settlement scale			

Green roofs	Could serve to reduce and decelerate rainwater runoff, beneficial for building climate	Local communities, external experts on construction technique and suitable plants (municipality or NGO)	Most favela buildings are constructed in an informal way, therefore the building stability and suitability for green roofs is not ensured Long-term maintenance needs to be ensured Potential budget constraints
Grey water harvesting and re-use	Could serve to reduce water runoff and subsequent erosion, water might be used to water plants on green roofs and urban agriculture	Local communities, urban authorities (particularly SMU, Rio-Águas)	Sanitation system is mostly inadequate or even inexistent and would have to be installed and maintained Need to raise awareness (see below) Potential budget constraints
Rain water harvesting	Could serve to reduce and decelerate rainwater runoff and subsequent erosion, additional potential for reducing downhill flooding	Local communities, urban authorities (particularly SMU, Rio-Àguas)	Sanitation system is mostly inadequate or even inexistent and would have to be installed and maintained Need to raise awareness (see below) Potential budget constraints
Unsealing/facilitation of rain water infiltration	Unsealing of asphalted/built-up areas could benefit more even water infiltration and reduced erosion	Local communities, urban authorities (particularly SMU, Rio-Àguas)	Need for improved construction of housing and infrastructure Potential budget constraints
Social/administrative measures			
Awareness campaigns – for authorities and population	Authorities and population are not yet aware of ecosystem potentials to reduce risks, awareness raising campaigns could support the use of such measures	Local communities, all involved urban authorities, NGOs	Eco-DRR measures potentially require the involvement and cooperation of different institutions over time Eco-DRR measures potentially need more time until being efficient
Trainings for local communities	Trainings on local scale measures, e.g. use of appropriate seeds for gardening, rainwater harvesting	Local communities, experts	Need of commitment of local population, probably best to be linked to awareness campaigns
More systematic integration of ecosystem status in consideration of adequate measures in disaster inventories	Would consider ecosystem potentials already in early stage of decision-making	Geo-Rio	Need for staff educated in and aware of Eco-DRR measures to be able to include their integration in inventories Requires an institutionalization of inter-institutional cooperation
Research	Fill knowledge and data gaps with respect to efficiency and effectiveness of different ecosystem-based measures (such as selection of best tree species for risk reduction), economic aspects (such as financing of Eco-DRR/EbA, and	Universities, research institutes	Reasonable funding Improvement of transdisciplinary research approaches and methodologies Improvement of the data basis

	PES) as well as social aspects (such as social/societal potentials and hindrances for Eco-DRR/EbA)		

Looking at the populated areas of high landslide risk according to the landslide susceptibility map of Geo-Rio, we realize that most of them are informal settlements. Also, most casualties and losses of homes in the last landslide events were registered there. However, there were also fatalities and severe material damage in middle and upper-class settlements such as in Laranjeiras (1967) or in Jardim Botânico (1996). Considering on the one hand the natural risk factors (heavy rainfall events, steep relief, vulnerable geological and geomorphological setting) and on the other social inequality and lack of urban planning as major root causes for settling in high risk areas, it seems questionable if engineered structures alone can solve the problem. Nevertheless, by far most realized measures by the population are engineered ones, such as earth-retaining structures, concrete walls and drainage systems. Additionally, the city of Rio de Janeiro has established several preparedness measures such as weather surveillance radar and early warning systems (linked to and available through COR), which undoubtedly will save human lives during catastrophic events, but cannot prevent the damage to buildings and built infrastructure. Finally, the Risk Reduction Action Program presented to the mayor by Geo-Rio also includes the relocation of dwellers in high risk areas. This is for sure the most effective measure in terms of risk reduction, but at the same time the one with the most serious consequences for the residents who would have to leave their homes.

In her studies on marginality in Rio de Janeiro' favelas, Perlman (2003, 2006, 2010) talks about growing 'spheres of fear' (Perlman 2006, p. 173) over the past decades, resulting in a decrease of social capital, less socialization among friends, less memberships in community-based associations and less use of public space. If the forested hilltops and green areas are understood as public space, this decrease of social capital therefore comes along with a decrease of natural capital, harming the livelihoods of the favela inhabitants. Interviewee 05 described primary school visits of Defesa Civil where the school kids are asked to draw maps of their home, indicating areas of risk. Among these areas are 'dark' forests or trees where drugs are sold or where drug lords leave shot bodies. Consequently, green areas are perceived as dangerous or even as 'no-go-areas.'

Overall, it is recommendable to better integrate ecosystem-based approaches for disaster risk reduction and climate change adaptation into an urban planning concept that aims at enhancing resilience and reducing vulnerabilities, in particularly of informal dwellers that are the most affected. This can only be achieved by overcoming urban segregation and the provision of housing to the poor that has its roots in historical processes driven by socio-economic and political factors. However, understanding the complex socio-economic system and proposing adequate urban planning solutions is out of the scope of this work. Nevertheless, we think that the municipality should put increased efforts in developing holistic urban planning approaches, for instance by combining green urban spaces with biodiversity corridors, ecosystem-based disaster risk reduction measures and long-term adaptation strategies. Currently the interaction between the different units that deal with DRR, CCA, biodiversity conservation and urbanism are not fully tapped, so that possible synergies remain unused. Moreover, landslides, mudslides and floods should be considered as hazardous events triggered by the same principal causes, so that multi-risk assessments at the landscape scale and multi-risk governance are needed, where Geo-Rio and Rio-Àguas should work in close cooperation together with the other relevant municipal agencies. In this way, the widely positive effects of ecosystem-based solutions to reduce the risk from multiple natural hazards and the several co-benefits they offer would be clearly visible. This requires, however, awareness campaigns at different levels with key stakeholder such as policy-makers, urban and environmental planners, disaster managers and community representatives.

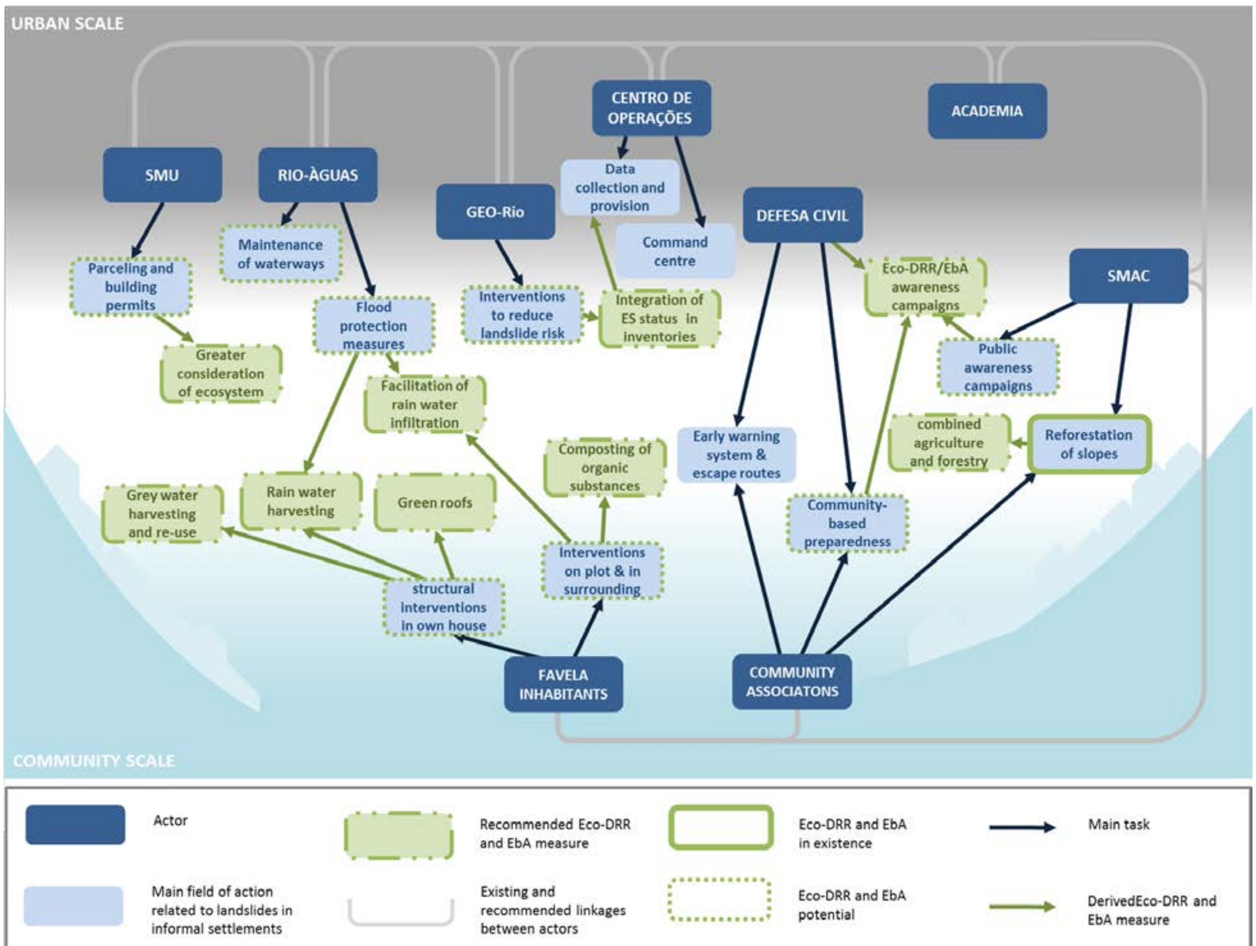


Figure 10: Recommended ecosystem-based measures for urban DRR and CCA and related actor network

To sum up, there is a wide portfolio of ecosystem-based measures that may help to reduce the risk of landslides and other natural hazards (cf. Figure 10), mudslides and floods. These solutions can partly complement the existing engineered structures and preparedness measures, and in other cases even make technical solutions redundant. However, we are also aware of the limitations, for instance due to the relatively high costs of hybrid measures such as water harvesting and re-use techniques or the weak building structures that speaks against green roofs in informal settlements. Reforestation measures can also bear certain risks, as they are prone to fires, on the drier north facing slopes. To both, engineered and ecosystem-based solutions applies that a residual risk always remains, so that an overall goal should be to counteract further occupation of landslide-prone slopes. For the existing settlements in susceptible areas, a combination of different engineered, ecosystem-based measure and preparedness measures seems to be the most promising, where the applicability and efficiency should be examined on a case-by-case basis.

Conclusions and thoughts on direction for future research and action

Because of this study, we identified several research gaps and challenges that should be addressed to implement ecosystem-based measures more effectively and efficiently:

Box 1: Targets for Action

1. Development of guidelines and procedures for the selection of the best tree species and planting methods for reforestation of landslide-prone areas based on the ecosystem status and on the size of the area;
2. Elaboration of a research agenda that addresses existing gaps with respect to landslide risk factors (e.g. properties of soils and weathering mantles, geohydrological conditions), the degree of land and ecosystem degradation, the implementation of suitable restoration methods, and the potential of structural interventions at the property level;
3. Development of an effective monitoring system for recuperated areas;
4. Extension of existing programs on awareness, preparedness and social responsibility of the local population for the environment in general and natural hazards in particular;
5. Creation of incentive systems for ecosystem-based measures for DRR and CCA in the form of Payment for Ecosystem Services (PES) schemes;
6. Creation of incentive systems for ecosystem-based measures on building and plot scale to include ecosystem-based and hybrid approaches in new constructions and building renovations;
7. Creation of direct and indirect use values of protection forests by integrating tree species with a direct economic value (e.g. fruits, medicine, wood) or an indirect value (e.g. shade, ornamental); and
8. Foster political commitment to improve the linkages and workflow between the involved actors in urban planning, ecosystem management and conservation, disaster risk reduction, and climate change adaptation.

It is the right time to consider ecosystem-based measures for both disaster risk reduction and climate change adaptation as the high-risk level is augmented from two directions: Climate change is likely to exacerbate extreme events in Southeast Brazil, thus augmenting the likelihood of poorly constructed informal houses to be damaged or even destroyed by landslides, mudslides or floods. Obviously, ecosystem-based measures do not impact directly on the building's quality itself, but by means of such measures at least risk from climate-induced hazards can be lowered.

The densely constructed informal settlements are further densified and increasingly verticalized, by adding stories to poorly constructed houses and by building up vacant plots. Decelerating or reducing the water runoff may contribute significantly to stabilize slopes and constructions. Here, ecosystem-based measures can be cost-efficient solutions which furthermore provide additional benefits to the population.

Ecosystem-based solutions have also been considered but are so far limited to reforestation measures that could be strongly enhanced and are not fully integrated in overall urban policies and planning. Here, a more holistic approach could serve to tap the full potential of reforestation measures, e.g. by including additional benefits for the local population or by combining approaches used by SMAC and Geo-Rio to hybrid solutions as well as paying more attention to small scale areas and monitoring. The interlinkages between urban planning, environmental management, climate change adaptation, and disaster risk reduction require a more systematic and comprehensive approach to disaster risk management, which in the past has mainly been reactive rather than preventive, engineering focused rather than based on planning and use of natural landscape features to prevent disaster risks. Thus, there is still a high potential that has not been explored yet.

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Appendix A: Photo documentation of case study areas

Morro dos Prazeres

Morro dos Prazeres is part of the quarter Santa Teresa in the North Zone (Zona Norte) of Rio de Janeiro, near the city center. It is characterized by a very dense settlement structure with multi-story buildings in steep slope positions (A-1a), most of them accessible by narrow lanes only. According to the head of the local community as well as the leader of a local NGO there is a trend of adding more stories to the existing buildings, what the interviewees perceived as a serious risk. The added stories may affect the stability of the buildings and their often-poor foundation.

In addition to the load of the buildings, water is collected in tanks on the rooftops, which increases the total load (A-1b). Despite the very densely build-up, there are small green spaces with grass cover and single trees even in the core of the settlement (A-1c). On the edges of the settlement concrete and brick walls with drainage tubes are located (A-1d). Around the settlement some of the land is kept open and covered by grasses and single trees; the partly degraded vegetation cover increases the risk of erosion and landslides (A-1e). The highest risk is due to landfills in steep slope positions, as shown in A-1f.

Appendix A-1: Settlement structure of the favela 'Morro dos Prazeres' (Photos: U. Nehren)

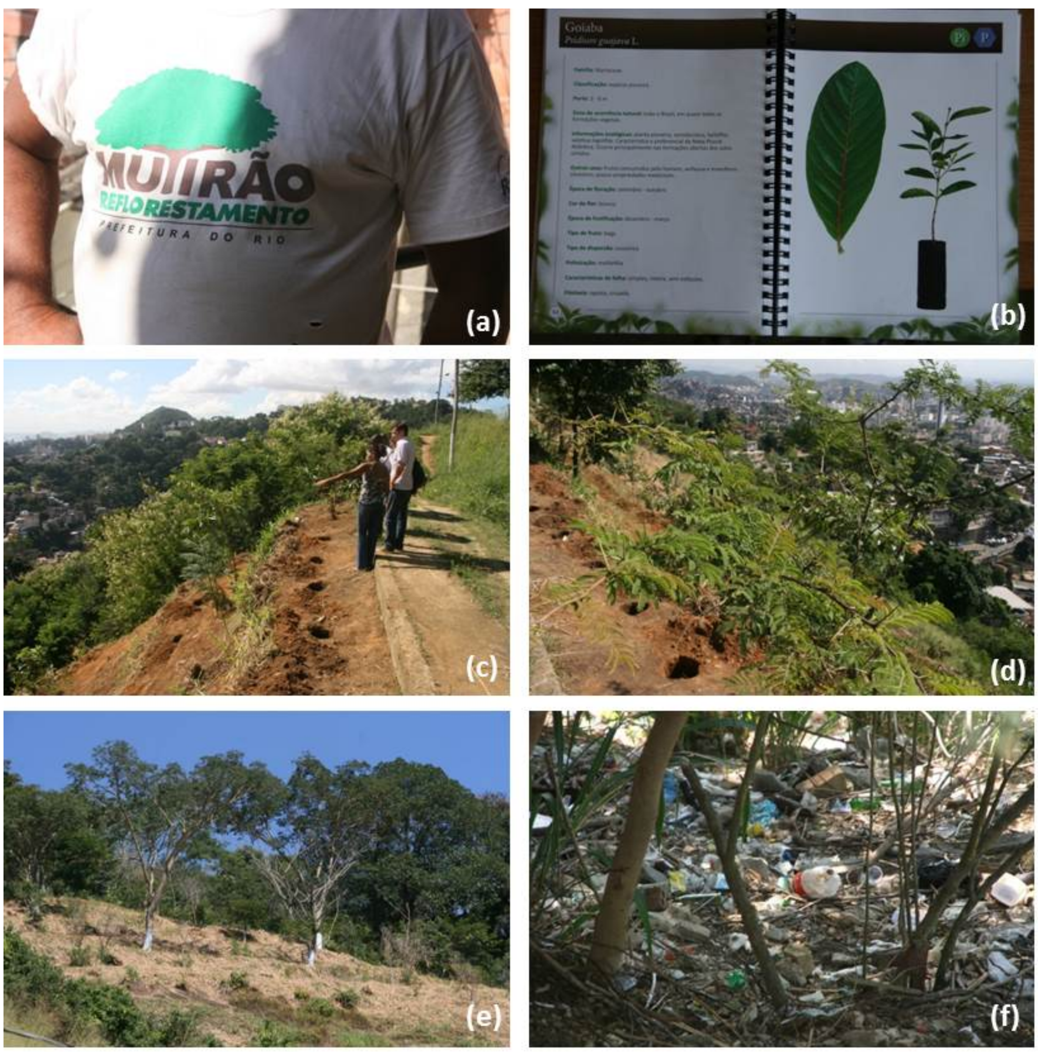
A main element for landslide risk reduction is the early warning system with alarm sirens that sound in the case of a heavy rainfall event (A-2a). In this case residents meet in a safe place, as shown in A-2b. The system has been installed and is maintained on regular intervals by Defesa Civil, which is cooperating with the local community.

Hard infrastructure includes open sewage trenches often along the steep stairways (A-2c) and shotcrete with drainage tubes to stabilize and drain steep slopes (A-2d). However, the shotcrete often shows effects of ageing due to weathering and subsurface flow (A-2e), so that the soil gets exposed and offers weak zones during heavy rainfall events. In addition, the shotcrete quality itself partly poses reasonable questions regarding its protective function. In other parts it may be under washed by strong rainfalls, resulting in sudden failure.

Appendix A-2: Conventional measures for landslide risk reduction in Morro dos Prazeres (Photos: U. Nehren)

Ecosystem-based measures are developed and implemented by SMAC in cooperation with the local communities in the program *Mutirão Reflorestamento* (A-3a). The secretary has published a manual for the identification of suitable tree species for reforestation; it includes so far 54 tree species, among them the Goiaba (*Psidium guajava* L.) that has an additional value for the community as a fruit tree and medicinal plant (A-3b). Reforestation measures take place on common land that is prone to landslides, as shown in A-3c, where already a severe landslide occurred. The slope is usually terraced, and local tree species are planted, among them several pioneer species of the *Fabacea* family (A-3d). In A-3e we see an advanced reforestation on a hilltop; it is important that hilltops are stabilized and covered with trees to reduce runoff and infiltration. Unfortunately, forest patches within the community are frequently used a waste deposits (A-3f). According to the head of the local community, pieces of broken glass in such waste deposits have resulted in fires in the past, affecting the replanted vegetation. Despite the inclusion of community members in the reforestation program, disrespect regarding the reforested areas and a consequent degradation of those areas has been related as a major issue.

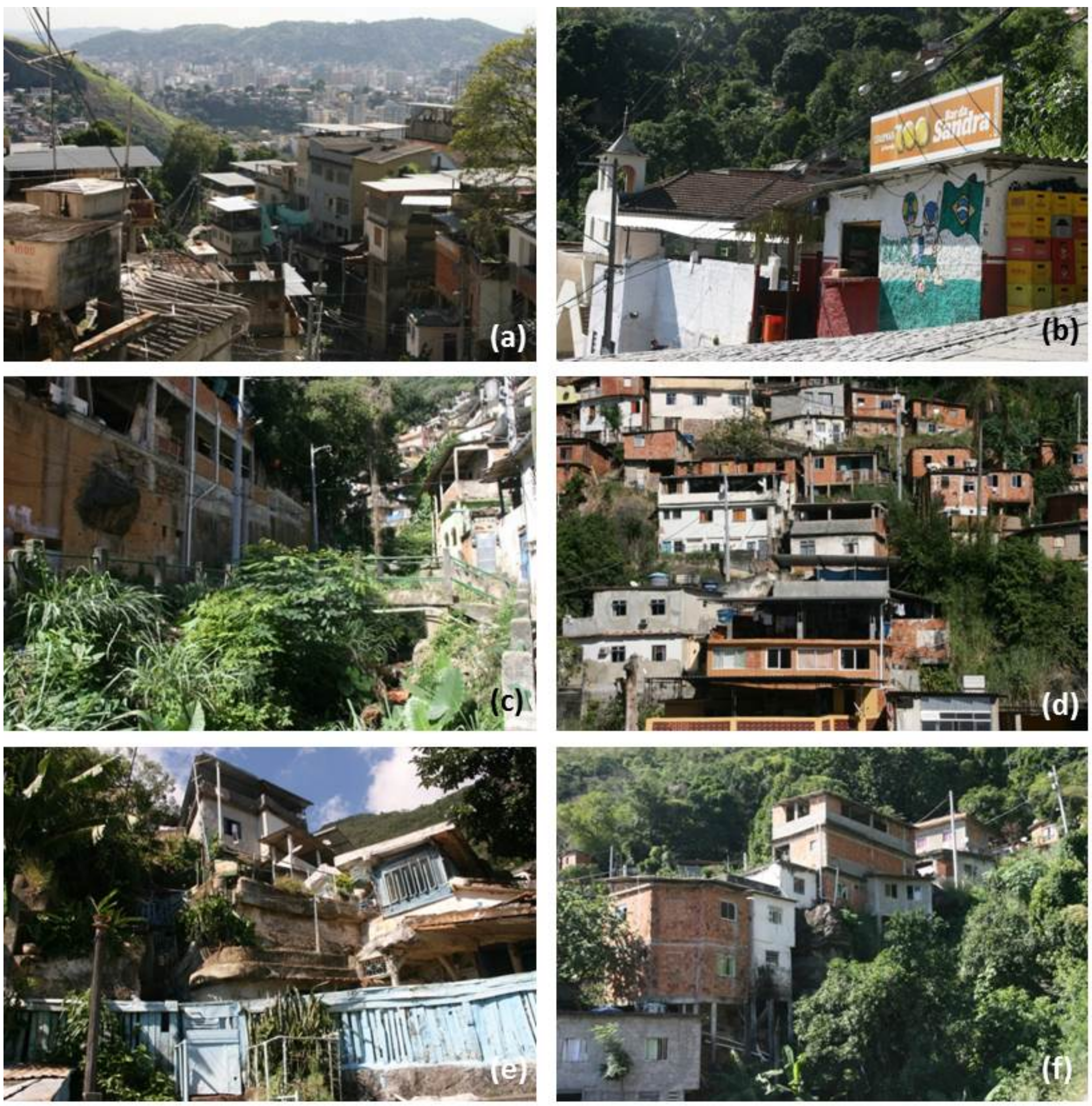
Appendix A-3: Ecosystem-based measures in Morro dos Prazeres (Photos: U. Nehren)



Morro da Formiga

Morro da Formiga is located in Tijuca in the North Zone (Zona Norte) of Rio de Janeiro (A-4a). It has developed from a colonial core area with an old cobblestone road and a historical church in its center (A-4b) and a small stream nearby (A-4c). Due to its history, the settlement is characterized by a heterogeneous structure with less dense built-up areas in the older parts, with comparably old buildings made of wood and bricks and green open spaces. In contrast, the houses on the steep slopes towards both sides of the valley are densely packed with two- to three- story buildings (A-4d) in ferro cement frame constructions with brick infills. However, due to the rugged topography and rock outcrops, the built-up area is rather dispersed with dense built-up areas separated by rock outcrops and vegetation (A-4d). The gradual expansion of the built-up area on the slopes can be clearly recognized by the different architectural styles and construction materials used over the decades (A-4e, f). Today the settlement expansion rate has reduced but continues in a more moderate form.

Appendix A-4: Settlement structure of the favela 'Morro da Formiga' (Photos: U. Nehren)



Like in Morro dos Prazeres, the Defesa Civil is actively engaged in setting up a disaster preparedness system. An awareness and preparedness campaign has been initiated (A-5a) and an early warning system has been established. In case of a heavy rainfall event the alarm system (A-5b) is triggered by the responsible persons of the community and in two places of the settlement sirens will sound (A-5c). In this case, residents are requested to meet at a designated evacuation place in the settlement (A-5d). Houses of handicapped persons are mapped, so that those people can be evacuated by Defesa Civil in case of an emergency (A-5d). Regular emergency exercises are carried out in the community. Technical measures for landslide risk reduction include open sewage trenches to control the runoff (A-5e), protective walls, and sealing of bare soils with shotcrete and drainage tubes (A-5f). Most of the area around Morro da Formiga has been reforested by SMAC, but there are still areas that can be recuperated, and the ecosystem of the reforested areas could be improved with better maintenance and monitoring.

Appendix A-5: Conventional measures for landslide risk reduction in Morro da Formiga (Photos: U. Nehren)

Due to the topographic and geologic setting, there is the risk of rock fall and weathering of large blocks (A-6a) that could be detached after heavy rainfall events. This risk has already been assessed by Geo-Rio. There is also a risk due to the buildings, as they are frequently built on concrete pillars that are often seriously corroded (A-6b, c). Open spaces are sparsely used for small home gardens; there is a risk of sliding during heavy rainfall events especially in banana plantations, as bananas contribute to slope loading, but offer only little protection by roots systems and canopies, while the soil is often unprotected (A-6d). Waste deposits and landfills are another risk factor; in this case (A-6e) even heavy household equipment is deposited on a steep slope. Finally, fire plays a role, as soils are widely unprotected after wildfires and therefore prone to shallow landslides; photo A-6f shows a young successional stage after a wildfire on a slope close to the settlement.

Appendix A-6: Remaining risk factors in Morro da Formiga (Photos: U. Nehren)

Appendix B: List of conducted interviews

No	Date	Institution
01	12.05.2015	*Governo do Estado do Rio de Janeiro, Secretaria de Desenvolvimento Econômico, Energia, Indústria e Serviço- Servi*ço Geológico do Estado – *DRM-RJ* State Government of Rio de Janeiro, Secretary of Economic Development, Energy, Industry and Services – Rio de Janeiro Geological Survey – DRM-RJ
02	13.05.2015	*Secretaria Municipal de Meio Ambiente – SMAC*, Coordenadoria de Fiscalização Ambiental – MA/CGCA/CFA Municipal Secretary of Environment, Environmental Monitoring Coordination
03	13.05.2015	*Secretaria Municipal de Obras Fundação Instituto de Geotécnica – Geo-Rio* Municipal Secretary of Construction Works, Geotechnical Institute – Geo-Rio
04	14.05.2015	*Centro de Operações,Prefeitura do Rio, Programa Rio Resiliente* Center of Operation, Rio de Janeiro Municipality, Program 'Resilient Rio'
05	15.05.2015	*Secretaria da Saúde e Defesa Civil, Subsecretaria de Defesa Civil* Secretary of Health and Civil Defense, Sub-Secretary of Civil Defense
06	18.05.2015	*Fundação Instituto das Águas do Município do Rio de Janeiro – Rio-Águas* Water Institute of Rio de Janeiro Municipality – *Rio-Águas*
07	19.05.2015	*SMAC – Coordenadoria de Recuperação Ambiental – MA/CRA*, Programa Mutirão *Reflorestamento* SMAC – Environmental Restoration, Reforestation program
08	19.05.2015	*SMAC - Coordenadoria de Conservação e Proteção Ambiental – MA/CPA* SMAC – Environmental Conservation and Protection Coordination
09	19.05.2015	*SMAC - Coordenadoria de Conservação e Proteção Ambiental – MA/CPA* SMAC – Environmental Conservation and Protection Coordination
10	19.05.2015	*Secretaria Municipal de Obras Fundação Instituto de Geotécnica – Geo-Rio* Municipal Secretary of Construction Works, Geotechnical Institute – Geo-Rio
11	19.05.2015	*Pontifícia Universidade Católica do Rio de Janeiro – PUC-Rio, Departamento de Arquitetura e Urbanismo, Instituto de Pesquisas em Infraestrutura Verde e Ecologia Urbana* Pontifical Catholic University of Rio de Janeiro, Department of Architecture and Urbanism
12	20.05.2015	*Universidade Federal do Rio de Janeiro – UFRJ, Departamento de Geografia, Laboratório de Geomorfologia* Federal University of Rio de Janeiro – UFRJ, Department of Geography, Geomorphology Laboratory