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RAPID URBAN GROWTH AND EARTHQUAKE RISK IN MUSIKOT, MID-WESTERN HILLS, NEPAL

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With 4 figures, 3 tables and 5 photos
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Summary: The rapid urban development of Musikot from a small bazaar settlement to a mid-size trade and service centre in rural Nepal increases the vulnerability of its inhabitants to natural hazards. Population growth and improved road accessibility has led to increased construction and an expansion and alteration of the built environment. The growing availability of modern construction materials like concrete and steel allows for new architectural designs and the erection of additional storeys on existing buildings, which contributes to the instability of the building stock. The aftermath of the April 2015 Gorkha Earthquake demonstrates the severe consequences of such haphazard construction practices in seismically active locations. A lack of implementation and enforcement of regulatory frameworks for building construction and spatial planning raises the risks for the local population. Taking Musikot as a characteristic case study of rapid urban change, this article analyses it's increasing local earthquake-risk in light of insufficient seismic building code implementation and risk-sensitive urban planning. Applying an approach that combines repeat photography and field mapping, the urban development of Musikot and the increasing fragility of the building stock are assessed using a modified seismic evaluation scheme for local building types. Almost one fourth of all construction was found to be at high risk of damage to earthquakes. It is argued, that without proper training in earthquake resistant construction techniques and awareness campaigns, the (mal-)adoption of modern construction materials will amplify earthquake risk in rural centres. This study stresses the need to broaden the research of disaster risk reduction and adequate adaptation strategies beyond the current focus on large agglomerations to include rapidly urbanising small settlements in rural areas, which are all too often neglected.

Zusammenfassung: Die rasche Entwicklung der ehemals kleinen Basarsiedlung Musikot zu einem mittleren Handelszentrum im ländlichen Nepal führt zu einer zunehmenden Verwundbarkeit der Bevölkerung gegenüber Naturgefahren. Bevölkerungswachstum und verbesserte Straßenanbindung führen zu verstärkter Bautätigkeit, zur Expansion der bebauten Fläche und zu einer Modifizierung der Gebäudestruktur. Die erweiterte Verfügbarkeit moderner Baumaterialien wie Beton und Stahl ermöglicht neue architektonische Designs und Aufstockungen bestehender Gebäude, woraus eine höhere Schadensanfälligkeit erwächst. Gleichzeitig zeigt das Gorkha-Erdbeben vom April 2015 die enorme Gefährdung, die sich aus einer planlosen Bautätigkeit in seismisch aktiven Regionen ergibt. Die mangelhafte Um- und Durchsetzung behördlicher Bauauflagen und raumplanerischer Vorgaben setzt die lokale Bevölkerung einem erhöhten Risiko aus. Am charakteristischen Fallbeispiel von Musikot erörtert der Beitrag die Zunahme der lokalen Gefährdung durch Erdbeben vor dem Hintergrund einer unzureichenden Umsetzung risikosensitiver Baustandards und Planungsvorgaben. Unter Verwendung von Wiederholungsaufnahmen und Kartierungen wird die urbane Entwicklung des Ortes Musikot erfasst und die zunehmende Fragilität des Gebäudebestands anhand einer an lokale Gebäudetypen angepassten Bewertungsmethode aufgezeigt. Nahezu einem Viertel aller Gebäude muss demnach im Falle eines Erdbebens ein hohes Schadenspotential attestiert werden. Es wird dargelegt, dass die Verwendung moderner Baumaterialien ohne angemessene Umsetzung einer erdbebensicheren Konstruktionsweise und eine entsprechende Aufklärungsarbeit zur Erhöhung des Erdbebenrisikos in ländlichen Zentren beiträgt. Die Studie zeigt, dass die bislang vorwiegend auf große städtische Agglomerationen fokussierte Forschung zur Katastrophenvorsorge und zu entsprechenden Anpassungsstrategien auf die allzu häufig vernachlässigten, rasch wachsenden kleinen Siedlungen erweitert werden muss.

Keywords: Earthquake, natural hazard, risk management, urban development, Nepal

1 Introduction

On a global scale, urbanization continues to take place at an unprecedented pace. According to United Nation's estimates, since the end of 2008 more than half of the world's population live in urban areas; and this share is expected to reach 60 % by 2030 (BLOOM et al. 2010; WANG et al. 2012). This trend is driven particularly by high urbanization rates in countries of the Global South. In many instances, large urban agglomerations are increasingly affected by and susceptible to environmental hazards (PELLING 2003; BEALL et al. 2010). Consequently, research on urban disaster risk has mainly focused

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on these large agglomerations (Cross 2001; Pelling 2003). Since the 1990s, entire issues in geographical journals have been devoted to disaster risk in megacities (cf. Parker and Mitchell 1995; Mitchell 1998; Pantuliano et al. 2012; Hayashi and Suzuki 2014). Because of the complexity and particular vulnerabilities of these largest urban agglomerations, the scientific community continues to focus primarily on them (e.g. Wenzel et al. 2007; Hochrainer and Mechler 2011). This concentration on large urban agglomerations has led to a worrying neglect of small cities and rural towns. Studies related to the analysis and management of earthquake risks are no exception in this regard. Most target big cities located in seismic active regions such as Santiago de Chile and Tokyo (Stein and Toda 2013), Tehran (Shakib et al. 2011), or Kathmandu (Dixit et al. 2013). While such assessments are certainly valuable and necessary, earthquake disasters in Gujarat (India, 2001) and Kashmir (Pakistan and India, 2005), Sichuan (China, 2008), as well as the most recent one in Gorkha (Nepal, 2015) have shown the devastating effects of earthquakes in regions outside such large urban agglomerations. In all cases, seismic shaking and secondary hazards like landslides destroyed hundreds of villages and small to mid-sized towns, killing thousands of people and leaving millions homeless (e.g. Owen et al. 2008; Sanderson and Sharma 2008; Halvorson and Hamilton 2010; Nüsser et al. 2010; Schütte and Kreutzmann 2011). There are several factors that make the residents of these settlements even more vulnerable to natural hazards as compared to inhabitants of large agglomerations. In many cases, this can be attributed to unequal distribution of knowledge, national funds, and international agencies involved in disaster risk reduction measures. In relative terms, small cities and towns are more likely to be heavily affected by a single event. Local response capacities are not sufficient to deal with a large-scale event due to centralized decision-making and insufficient pre-disaster management. In addition, relatively small populations often lack the political and economic influence of megacities and have less resources available to mitigate risks and to respond to disaster situations (Cross 2001; Porfiriev 2009).

The global increase in urban population has resulted in the biggest construction boom in history. It is expected that the greatest share of future construction activities will take place in smaller cities and towns in countries of the Global South, where building quality is generally lower than in wealthier societies (Jackson 2006; Bilham 2009). Poorly located and substandard housing poses a high risk to resident populations; leading them to be figuratively called "weapons of mass destruction" (Bilham and Gaur 2013) in the event of a major earthquake.

Situated at the centre of the tectonically active Himalayan range, Nepal is one of the countries with the highest potential earthquake hazard (Mosquera-Machado and Dilley 2008). Risk exposure is particularly serious in western Nepal, where the absence of major earthquakes over a long time period has led to a high rate of stress accumulation (Bilham 2004; Fort 2011; Mukhopadhyay et al. 2011; Chamlagain and Gautam 2015). It is not yet clear to what extent this stress accumulation was released by the recent 2015 Gorkha Earthquake.

Nepal has experienced tremendous demographic growth with a more than threefold increase of the population, from 8.3 million to 26.5 million people, over the last six decades (CBS 2003, 2012a). With only 17 % of the population living in urban areas[1)], the country is still the least urbanized in South Asia. Yet, at the same time it is the fastest urbanizing nation of the region with an average annual increase in urban population of about 6 % since the 1970s (Muzzini and Aparicio 2013). While much of this growth is concentrated in the intermontane basin of Kathmandu and in some expanding cities in the lowlands towards the Indian border (called *Terai*), a considerable increase in population numbers and built-up areas has also occurred in numerous district capitals and bazaar towns throughout the hill areas of Nepal (Muzzini and Aparicio 2013).

The Local Self-Governance Act (HMG 1999) defines a Municipality according to the number of people living within the smallest administrative unit, administered by Village Development Committees (VDCs), formerly called *Panchayats*. For hilly and mountain areas this administrative unit is defined as "a population of at least ten thousand and annual source of income of minimum five hundred thousand rupees [...] even if there is no road facility" (HMG 1999, 29). Administrative functions are not necessarily a decisive criteria. In reality, "political ad hocism" in the nomination process is apparent

[1)] There has been a continuous struggle over the definition of urban areas in Nepal. Sharma (2003) provides a comprehensive overview of the definitional complexity. Since 1971, municipalities have been considered urban from a legal perspective, while they commonly refer to areas with more than 10,000 inhabitants and services available like electricity, roads, drinking water, and communication facilities. More recent efforts classify cities according to their population or in terms of shop numbers (DUDBC 2013).

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(SHARMA 2003, 377). In 2014 and 2015, and for the first time since 1996, a total of 133 VDCs were gazetted as municipalities, including Musikot (CHAUDHARY 2014; EKANTIPUR 2014; THAPA 2015). Despite their qualifying population numbers many other smaller towns, however, were not taken into consideration as municipalities (locally called *Nagar Palika*), owing for instance to their low annual revenue or lack of facilities such as public transport or installed piped water systems (cf. PORTNOV et al. 2007). Nonetheless, these towns have significant regional importance as administrative centres or commercial hubs. They offer scarce off-farm employment, which is increasingly important for rural livelihoods that are no longer sustained by subsistence agriculture alone (RAITHELHUBER 2003). In addition, they provide government services or supply their rural hinterland with agricultural inputs and commodities from the *Terai* and, further, from India (BAJRACHARYA 1995; BLAIKIE et al. 2001; PORTNOV et al. 2007). Currently, these regional centres are experiencing rapid population growth due to in-migration from surrounding rural areas, resulting in urban expansion and transformation of the built-up area.

Bazaar towns and administrative centres in the hill areas of Nepal are mostly located on spurs and ridges above steep slopes, with limited suitable space for settlement expansion. This contributes to the decision to construct multi-storeyed reinforced concrete buildings on steep slopes; increasing their susceptibility to collapse during an earthquake (KLEINERT 1983; JACKSON 2006; BILHAM 2009; BILHAM and GAUR 2013). As a result, these small regional centres are further exposed to earthquakes, making the mountain areas of Nepal even more prone to disaster (cf. HOFER 2005; GARDNER and DEKENS 2007), and this also holds true for the wider Himalayan region (HEWITT 1997; HEWITT and MEHTA 2012).

A large body of literature on 'seismic culture', a broad concept that encompasses "a range of cultural adaptations to seismic risk and hazard", exists (HALVORSON and HAMILTON 2007, 322). The concept highlights how previous knowledge of adaptation mechanisms is in danger of being lost through four main processes: deteriorating local knowledge of hazards, demographic dynamics, livelihood transformations, and the concentration of knowledge in internationally well-connected urban agglomerations. These transforming processes hinder the perpetuation of existing local adaptation strategies (cf. DEGG and HOMAN 2005; KARABABA and GUTHRIE 2007). Nepal is an example of a country experiencing a profound loss in 'seismic culture', as manifested through a decline in local building practice in preference to new substandard building, for which this study will contribute quantitative evidence on the degree of building susceptibility to earthquakes.

This paper presents a case study of Musikot, the administrative centre and most important bazaar town of Rukum District, located in the Middle Hills of Nepal. The study examines the rapid urban growth that has occurred in this small town over the past few decades. Special attention is given to the spatial expansion and compaction of the built-up area, and correspondingly, to changes in building structures. These changes are evaluated in the context of high earthquake hazard, building code standards and official regulations on settlement development. Of particular interest is an examination of the dynamics of recent urban transformation regarding its effects on earthquake risk from a structural engineering perspective.

2 Musikot: from a regional bazaar town to a district headquarter

Musikot (28°37'N, 82°27'E) is the headquarter of Rukum District, which is part of the Mid-Western Development Region (Fig. 1). It lies about 300 km northwest of Kathmandu, the capital of Nepal. In physiographic terms, the region belongs to the Middle Hills, a landscape of comparatively moderate altitudes situated south of the High Himalayan ranges (HAGEN 1954; UPRETI 1999). Geologically, the area forms part of the Lesser Himalaya, which is confined by the Main Boundary Thrust (MBT) to the south and the Main Central Thrust (MCT) to the north. It is mainly underlain by meta-sedimentary rocks like slates, shales, and phyllites (FUCHS and FRANK 1970; STÖCKLIN 1980).

Located at an altitude of 1,525 m a.s.l., the study area has a moderate subtropical climate with an average temperature of 19.7 °C. While maximum temperatures may reach more than 33 °C in summer, the winters are usually frost free with temperatures that rarely fall below 5 °C. Precipitation is strongly influenced by the summer monsoon and about 80 % of the annual precipitation of 2,130 mm falls between June and September (SHARMA and JOSHI 2008; DHM 2012).

Land-use in Rukum District is characterized largely by subsistence agriculture. Farmers cultivate paddy rice, wheat, and maize on dry (*bari*) and irrigated (*khet*) terraces at lower slope sections and valley bottoms. Because of the conversion of for-

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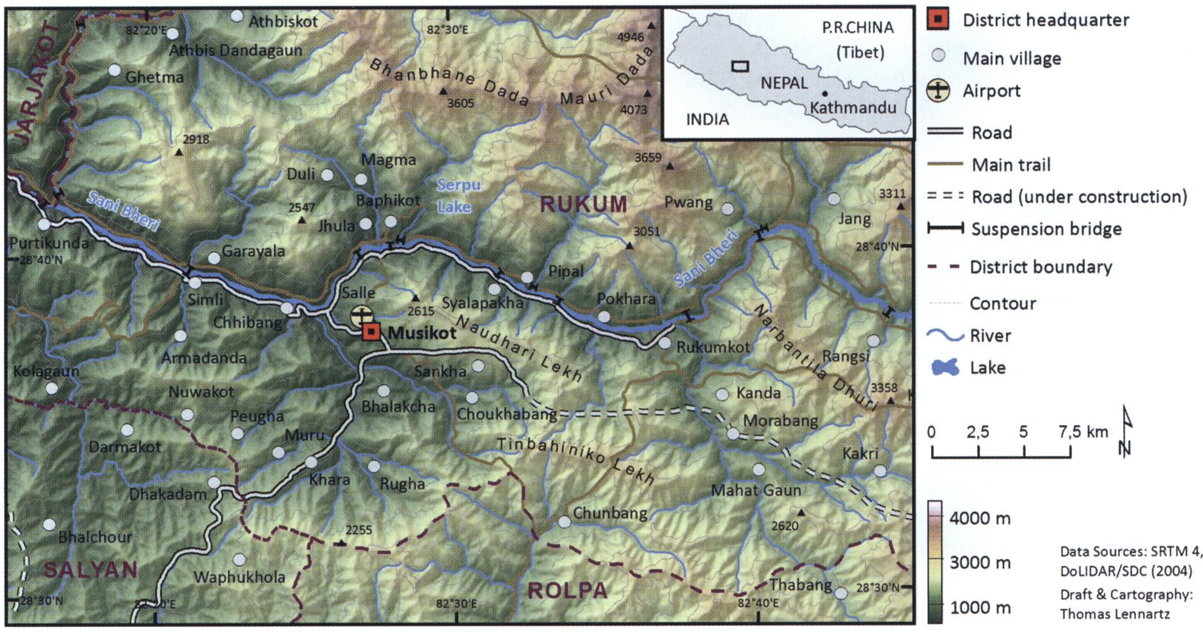

Fig. 1: Location of the district capital of Musikot in Rukum

merly forested slopes into terraces, forest patches composed of Chir pines (*Pinus roxburghii*) and oaks (*Quercus* spp.) are nowadays confined to the ridges and are intensively used and maintained as community-forests (Lennartz 2015). A large proportion of the 211,000 inhabitants are concentrated in the south-western part of the district, where lower elevations, more gentle slopes and abundant water availability allow for higher agricultural yields. People usually live in loosely scattered settlements rarely consisting of more than a few dozen households, which are typical for lower mountain areas in Nepal (Kleinert 1983).

The average population density of Rukum (72 pers./km²) is less than half the average for the entire country (180 pers./km²). However Rukum, and Musikot in particular, is currently undergoing rapid demographic growth, driven initially by the effects of the armed conflict between Maoists and the national government, which ended in 2006 (CBS 2012a). The population of the town has more than doubled from 5,329 to 13,203 inhabitants between 1971 and 2011 (Tab. 1). From 2001 to 2011 the population of Musikot grew by 41.4 %, almost four times as rapid as the population of the entire district (10.7 %), which in itself grew a little slower than the country's average (14.4 %).

Tab. 1: Population growth in Musikot, Rukum and Nepal

YEAR	MUSIKOT		RUKUM		NEPAL	
	inhabitants	annual growth rate	inhabitants	annual growth rate	inhabitants	annual growth rate
1952/54	-		19,985		8,256,625	
1961	-		21,907	1.32 %	9,412,996	1.89 %
1971	5,329		96,243	15.95 %	11,555,983	2.07 %
1981	-		132,432	3.24 %	15,022,789	2.66 %
1991	7,279		155,554	1.62 %	18,491,097	2.10 %
2001	9,336	2.52 %	188,438	1.94 %	23,151,423	2.27 %
2011	13,203	3.53 %	208,567	1.02 %	26,494,504	1.36 %

Source: (CBS 1995, 2002, 2012b)

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The early settlement history of Musikot is not well documented. According to a local legend it was founded by a king who was persuaded by his servant named *"Musi"* to shift his fortress (*kot*) to the ridge on which the current village is situated. After Nepal's consolidation under King Prithvi Narayan Shah and his son Bahadur Shah in the 18th century, people from the Jumla and Jarjakot kingdoms migrated to Rukum and established their local power in Musikot and two neighbouring villages (Gersony 2003).

Musikot gained its regional administrative importance under the *Panchayat* system of governance in the 1970s (cf. Whelpton 2005). In 1973, all administrative functions of the district were shifted to Musikot, laying the foundation for current urban growth (Gersony 2003; Ogura 2007). This shift offered government employment and prioritisation of the town with respect to governmental development projects. The town benefitted from electrification generated at a nearby small hydropower plant (1986), the construction of an airport (1996) and of a road (2003), enhancing the connectivity of the region to the lowlands of Nepal.

Considering the rural character of Rukum District, Musikot stands out clearly in functional and physiognomic terms. With about 13,000 inhabitants it is by far the largest settlement in the district (CBS 2012b). Like many other bazaar towns in the central Himalayas, it is characterized by its compact character (Photo 1). Being the administrative centre and the most important trading hub, Musikot offers more off-farm income opportunities than any other settlement in the district and therefore attracts people from the rural hinterland (Lennartz 2013). However, agriculture continues to play a subordinate role in securing livelihoods for both urban and rural dwellers.

Up until the establishment of the first road connection to Musikot, the small airport in neighbouring Salle was the only option to reach the district by public transport. The underlying rationale for the construction of this road was provided by the armed conflict. The district capital of Musikot was the only town that was continuously under government control throughout the decade-long 'Maoist People's War' (Ogura 2008). It served as a base for security forces and as a refuge for government employees and politicians in a time of escalating violence. In order to facilitate the defence of this last government stronghold in the district, the Royal Nepalese Army undertook a major effort to construct a road to link the district capital (Gersony 2003; Stöwesand 2014). Until today, it remains the only road connecting Musikot to the rest of the country. Therefore, it is of critical importance for the recent expansion of the settlement and the modifications of its building structure, as it facilitates the import of new construction material like cement and corrugated iron sheets, necessary for faster building and taller structures.

3 Earthquake hazard in the Middle Hills of Nepal

Situated in the tectonically active central part of the Himalayas, Nepal is one of the global hotspots for earthquake hazard (Mosquera-Machado and Dilley 2008). Historical sources report on major events in the years 1223, 1255, 1344, 1808, and 1934 (Pant 2002). The latter is by far the best-documented and most severe historical earthquake disaster in Nepal. The 8.4 magnitude earthquake destroyed large parts of the cities within the Kathmandu Valley and caused between 8,500 and 10,000 fatalities (Pandey and Molnar 1988; Chamlagain 2009). Due to the lack of exhaustive time series of earthquake records, defining recurrence intervals of major seismic shocks in the Himalaya remains difficult (Paudyal et al. 2010; Bilham and Gaur 2013). However, assuming fairly comparable seismo-tectonic conditions along the Himalayan arc, the possibility of a major earthquake is likely to be highest in those areas where no events have occurred over long periods, as the accumulated compression energy has not been released. There are several seis-

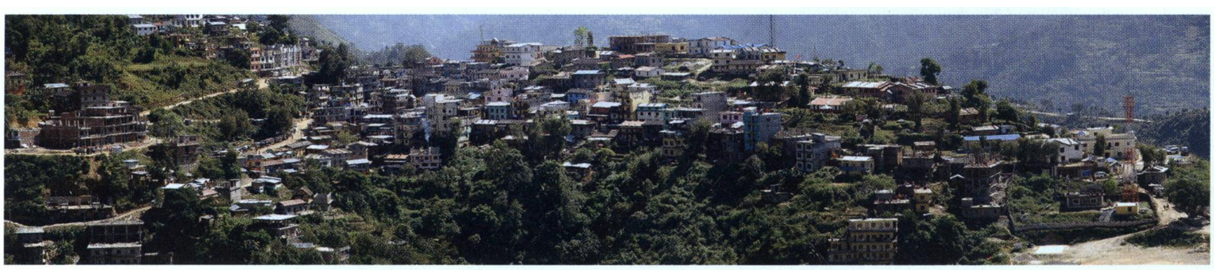

Photo 1: The district capital Musikot in 2012 (Photo: J. Anhorn, 09 October 2012)

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mic gaps along the Himalayan arc (Bilham 2004; Bollinger et al. 2004). One of these gaps, which was sufficiently mature for rupture, was identified in the section between Kathmandu in central Nepal and Dehradun in the Indian federal state of Uttarakhand (Bilham et al. 1995; Chamlagain 2009). This coincides with the location of the epicentre of the 7.8 M_w Gorkha Earthquake on April 25th 2015. This quake led to more than 8,000 fatalities, 18,000 injured and the destruction of more than 400,000 buildings, and left an estimated 2.8 million Nepalis displaced (GoN 2015; Khazai et al. 2015).

While geological and geomorphological factors determine attenuation of Peak Ground Acceleration (PGA) from the epicentre and variations in shaking intensity, direct earthquake damages are a function of both shaking intensity and building fragility. Close to the epicentre, the destruction caused by this earthquake was immense, and it also triggered many large landslides, which further complicated relief-efforts. Despite the fact that the epicentre was located approximately 230 km away from Musikot, government sources (GoN 2015) report on one fatality and 207 damaged buildings in the district (10 damaged and 16 partly damaged government buildings, 61 damaged and 120 partly damaged private buildings). Unfortunately there is no detailed record of the building typology affected by the latest event.

In addition to the risk posed by major earthquake events along the continental collision zone, the local population is threatened by frequent earthquakes of lower intensities (Bilham and Gaur 2013). The people living in Rukum District and surrounding regions have experienced several moderate earthquakes (up to 5.9 M_w mostly below V MMI according to the Modified Mercalli Intensity Scale) over the previous two decades. Nine events are documented for 2012 and 2013, while only three each are recorded for the 1990s and 2000s (Tab. 2). These events caused minor damage such as human injuries and cracks in houses (e.g. The Kathmandu Post 2013).

As in most rural areas of the country, no micro zonation studies or local seismicity data are available. Most earthquake scenarios for Nepal solely focus on the intermontane Kathmandu basin (e.g. Wyss 2005; Anhorn and Khazai 2015). On a national scale, the Asian Disaster Preparedness Centre (ADPC) conducted a hazard risk assessment based on PGA and regional epicentre catalogue data (ADPC and MoHA 2011). That study analysed different scenarios of an earthquake with a Modified Mercalli Intensity

Tab. 2: Recorded earthquakes in Rukum according to the National Seismological Centre

Date	Magnitude	Epicentre	Latitude	Longitude
2013/06/28	5.5	Rukum	28.76	82.40
2013/03/06	5.4	Rukum	28.57	82.27
2012/09/17	4.4	Southern Rukum	28.59	82.41
2012/08/30	4.5	Southern Rukum	28.61	82.43
2012/08/24	5.2	Rolpa-Rukum border region	28.42	82.75
2012/08/23	5.6	Rolpa-Rukum border region	28.38	82.84
2012/07/31	4.2	Southern Rukum	28.55	82.37
2012/07/31	4.8	Southern Rukum	28.53	82.42
2012/07/31	5.0	Southern Rukum	28.58	82.48
2009/10/29	4.1	Rukum	28.73	83.11
2004/11/09	4.4	Rahal Gaun/Rukum	28.77	82.95
2003/07/28	4.5	Rukum	28.75	82.52
1997/10/24	5.2	Rukum	28.66	82.54
1997/05/28	4.5	Rukum	28.68	82.58
1994/12/13	4.6	Rukum	28.70	82.88

Source: DoMG 2015

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greater than VII. This MMI corresponds to severe damage of poorly built or badly designed structures, while moderate damage is expected even for well-designed structures. Their study estimates the extent of the area that is at high and very high risk for different return periods of earthquakes with an intensity greater than VII. Accordingly, more than 97 % of the area of Rukum District lies within the "very high" risk zone for a return period of 250 years and more than 80 % of the area lies within a "high risk" area considering a return period of 50 years (ADPC and MoHA 2011, 42–49).

4 Earthquake risk mitigation in Nepal

In general, risk mitigation comprises of several interrelated areas of intervention. It includes conducting hazard and vulnerability assessments, establishing risk awareness, strengthening institutions, drafting a comprehensive legal framework, making human and financial means available, as well as developing operational skills and capacities in order to lessen the adverse effects of hazards (UNISDR 2009). Nepal has one special legislation promulgated in 1982 that addresses disasters, the National Calamity (Relief) Act 2039 (GoN 1982). A National Strategy for Disaster Risk Management (MoHA 2009) was approved in 2009 and provides a comprehensive multi-risk framework for Nepal (IFRC 2011). The national strategy focuses not only on earthquake risk, but incorporates all major natural and human-caused or technological hazards. Unfortunately, implementation is still lacking due to the ongoing political difficulties. Raising awareness has been on the agenda for many years, with several initiatives trying to: foster public education (e.g. School Safety Program), enhance emergency response capacities of institutions (e.g. through the PEER program), conduct masons training under the Building Code Implementation Program, but also by reaching out to the private sector (Public Private Partnership for Earthquake Risk Management Program).

Implementing building codes is one important measure to mitigate earthquake risk. Most earthquake-prone Asian countries like India, Pakistan, China, or in other parts of the world, such as in the US or Chile have translated knowledge about seismic fragility into practical building codes or construction guidelines (cf. Paz 1994; e.g. Indian Standard IS: 1893 from 1984 or the Seismic Provision of Pakistan Building Code from 2007). The Nepal National Building Code (NBC) of 1994 (DUDBC 1994a) provides four different levels of codes, depending on design sophistication and construction type. They range from international state-of-the-art, professional engineered structures to mandatory rules-of-thumb guidelines for remote rural buildings. Theoretically, the codes must be applied in urban areas for all buildings exceeding a height of five meters and a floor area of 20 square meters. Code compliance is part of the building permit issuing process. In practice however, these codes are hardly ever enforced and municipal administrations have failed to establish subsequent chapters. Even in the main urban centres of Nepal code compliance is hardly ever checked during the construction of new buildings (IFRC 2011). One exception is Lalitpur Sub-Metropolitan City due to a long track of active engagement in risk mitigation and hazard projects sponsored by international donor agencies and mainly implemented through the National Society for Eearthquake Technology (NSET) (Dixit 2009; Giri 2013). Rural areas are even excluded from the building permit issuing process because of insufficient resources of authorities to control construction practices. Therefore, most buildings in peripheral centres do not comply with existing building standards (Dixit 2009). Recommendations to update the NBC of 1994 and include rural areas in this process were published by the Ministry of Physical Planning and Works in 2009 (MoPPW 2009). However, these recommendations have not yet been formalised into legislation.

With respect to small urban centres, Part IV of the NBC addresses traditional buildings, which usually form the largest share of the prevailing building stock in rural areas. NBC 203 and NBC 204 are tailored to meet the requirements of local building material and non-engineered structures (DUDBC 1994b, 1994c). Both are optional for residential buildings in rural areas but mandatory for all public and residential buildings in urban areas. The codes distinguish two different traditional building types: Low Strength Masonry (LSM) buildings are constructed of non-erodible walling units (stones, burnt clay bricks, solid blocks) while Earthen Buildings (EB) are made of mud walls or masonry units that are constructed with unstabilised mud-like adobe blocks, sun-dried clay bricks, etc. In such cases, mud mortar is used as binder. With concrete and corrugated iron sheets becoming available, traditional construction techniques are increasingly being replaced by reinforced-concrete framed (RC-framed) buildings. Usually, they are planned and constructed by mid-level technicians and masons without formal professional training (Dixit 2004, 2009; Chaulagain et al. 2013).

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Specifications for different wall construction types and respective building codes (Tab. 3) limit for instance, the height of LSM buildings to two storeys with an additional attic; while RC-framed buildings are limited to three storeys or a maximum of 11 m.

5 Methods and analytic framework

In order to investigate the interaction of urban transformation and earthquake risk we used an approach that combines terrestrial repeat photography, detailed field mapping, and GIS analysis. Whereas repeat photography has been used as a tool for change detection in various thematic contexts, ranging from vegetation ecology and glacier monitoring (e.g. SCHMIDT and NÜSSER 2009) to land-use patterns (e.g. NÜSSER 2000), it is less common in urban studies, especially in mountain regions (e.g. NÜSSER 2001; DITTMANN and NÜSSER 2002). The method has also been applied in the context of earthquake-triggered landslides (KHAN et al. 2013). In the present study the comparison of two terrestrial photographs, separated by an eight-year period, was used to demonstrate the rapid transformation of the built environment and to provide a visual impression of the limited availability of land suitable for construction. In order to assess the fragility of buildings in Musikot, its entire building stock, comprising of more than 650 buildings, was mapped using high resolution GeoEye data from February 2012. In a second step, the seismic fragility of the complete building stock was assessed through direct inspection during a field mapping exercise in September 2013.

The potential damage to buildings in case of a specific earthquake scenario can be assessed by seismic fragility modelling. There is a great variety of methods which vary in terms of data needed, algorithms applied, and fragility function derived (e.g. ROSSETTO et al. 2013). Especially in less developed and data sparse regions, such methods need to be adapted to site-specific conditions and local construction practices. In this study we took a modified version of practice-oriented guidelines to estimate the seismic performance of buildings developed by NSET (2014) as s reference and starting point. These guidelines for Nepal are based on existing assessment standards from the US and India (e.g. FEMA 1998, 2002; ASCE 2003; BIS 2009) and allow for a rapid fragility assessment through visual inspection. Global or regional studies on the seismic performance of different building types can be found in KORKMAZ (2009), KORKMAZ et al. (2010), JAISWAL et al. (2011) and CHAULAGAIN et al. (2013,

Tab. 3: Building typology and Nepal National Building Code (NBC) compliance

Type	Wall Construction	NBC Taxonomy	NBC
Load Bearing Masonry	Adobe	Earthen Building (EB)	NBC 204 (G)
	Stone in mud	Low Strength Masonry Building (LSM)	NBC 202 (MRT) NBC 203 (G)
	Brick in mud	Low Strength Masonry Building (LSM)	NBC 202 (MRT) NBC 203 (G)
	Brick in lime/surkhi (brick dust cement)	Low Strength Masonry Building (LSM)	NBC 202 (MRT) NBC 203 (G)
	Stone in cement	Low Strength Masonry Building (LSM)	NBC 202 (MRT) NBC 203 (G)
	Brick in cement	Low Strength Masonry Building (LSM)	NBC 202 (MRT) NBC 203 (G)
Reinforced Concrete Frame	RC-frame without masonry infill	Reinforced Concrete Frame Building (RC)	NBC 205 (MRT)
	RC-frame with masonry infill	Reinforced Concrete Frame Building (RC)	NBC 201 (MRT)

MRT = Mandatory Rules of Thumb
G = Guideline

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2014). Another promising tool to understand local decision maker's preferences and resilience goals in complex environments is the Resilience Performance Scorecard, which initiates a contextualized long-term evaluation process and fosters a dialogue among stakeholders at different levels (Anhorn et al. 2014).

The NSET standards were developed for individual buildings and its compliance assessment requires a detailed investigation and measurements inside each building on all storeys. As this method is not feasible for the assessment of the building stock of a town with more than thousand buildings, this study used modified NSET standards to carry out a simple but robust earthquake fragility appraisal using the parameters *building type*, *number of storeys*, *aspect ratio* and *roof type*. Based on the evaluation scheme (Fig. 2), all buildings were classified into three categories of strength (weak, average, and strong) and the relative likelihood of damage (very high, high, and moderate risk). In a first step, two different building types were distinguished based on the wall construction type as defined in the NBC (*typology*): Low-Strength Masonry houses (LSM) and Reinforced Concrete Framed (RC-framed) buildings (see Photo 2 and Photo 3). A second parameter was the *number of storeys*. In case of LSM buildings, structures higher than two storeys were generally considered "weak", whereas less fragile RC-framed buildings were considered "weak" only if they exceeded three storeys. The remaining buildings were then assessed with respect to the *aspect ratio*, the proportion between the length and the width of a building, as recommended by the NBC. All buildings with a ratio of three or higher were classified as "average". The final parameter for estimating the strength of a building was the *roof type*. The building stock in Musikot shows a large variety of roof types (see Photo 4). Some *lightweight* roofs are constructed of thatch or corrugated galvanized iron (CGI) sheets. These materials were generally considered to be more favourable for the strength of a building. Therefore, buildings with such roofing material were consid-

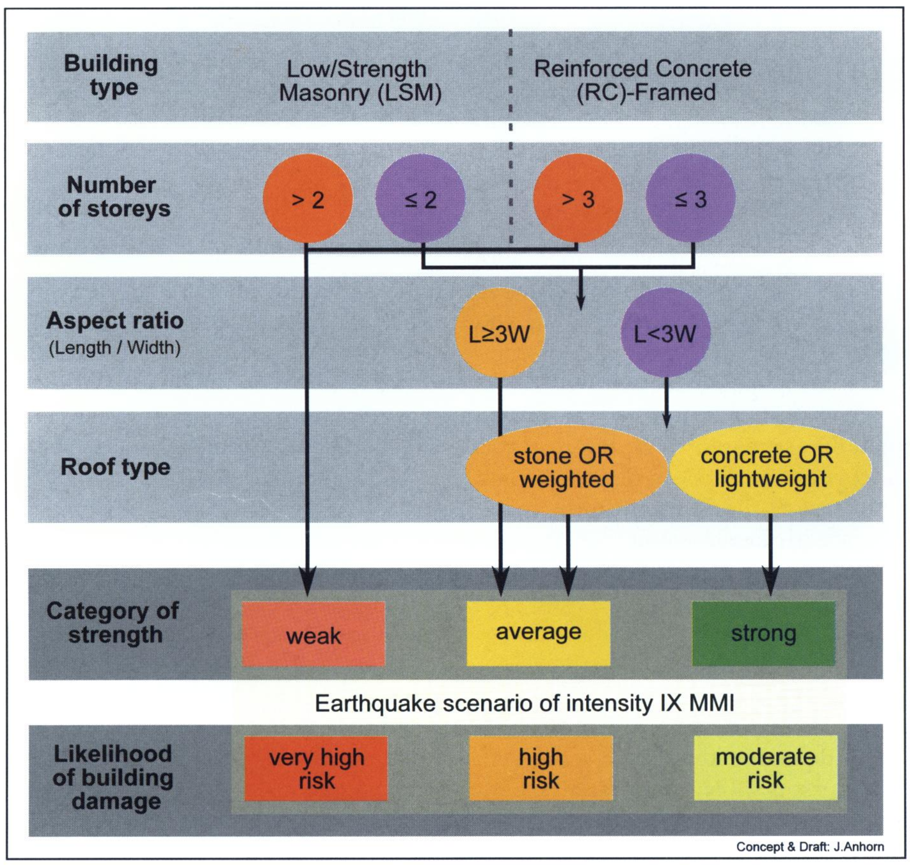

Fig. 2: Structural assessment method for LSM and RC-framed buildings

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Photo 2: Low-Strength-Masonry (stone in mud unfinished without plaster) (Photo: J. Anhorn 2012)

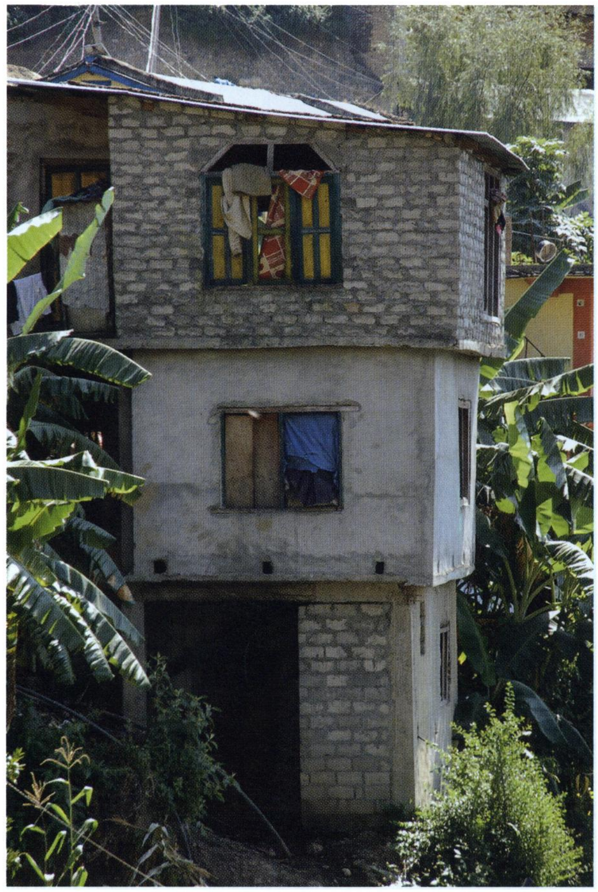

Photo 3: Partly framed Reinforced Concrete with soft storey and vertical irregularity (unsupported columns on upper floors) (Photo: J. Anhorn 2012)

ered "strong" unless the material was loaded with stones or concrete blocks to pin it down (*weighted*). In that case even *lightweight* roofs decrease the stability of structures. Other buildings are constructed with heavier roofing materials with different strengths characteristics. Buildings with *concrete* roofs were generally estimated to be more stable than structures covered with roofs made of *stones*. Therefore, only in case of the former roofing material such buildings with heavy roofs were considered to be "strong."

6 Results

Two photographs of Musikot, taken in 2004 and 2012, allow for detecting changes in settlement pattern. The comparison shows the spatial expansion and the increasing density of buildings on the small ridge, indicating the process of rapid urban transformation (Photo 5).

Musikot is situated at a very exposed location: on a mountain ridge between deeply incised valleys. The top of the ridge is occupied by larger public buildings, which host educational facilities and offices of the district administration. Below, most multi-storied buildings are arranged in rows along two parallel bazaar streets. They are home to dozens of small retail shops, restaurants, hotels and the only internet café of the town. The western extension of the ridge is occupied by a large open space, which is used as a schoolyard and assembling place (right side). Other open spaces formerly used for horticulture and grazing have been transformed into densely built-up areas. The availability of modern construction material due to the new road connection has led to unprecedented building activity, resulting in a concentration of three storey-buildings. In the centre of the bazaar, buildings of even up to seven storeys can be found. This construction activity has to be seen as a drastic modification of the existing urban structure and needs to be contextualized against the prevalent earthquake hazard.

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In 2012, the building stock of Musikot main bazaar comprised 658 buildings of which 635 were assessed during field mapping in 2013. These are mainly LSM buildings using stone walls and mud-mortar as binder (48 %, n=319, Photo 2) and RC-framed buildings (31 %, n=207, Photo 3). Another 17 % (n=109) are small buildings made from lightweight wooden frames without stone walls, which are used either as shops or as toilet buildings in the backyards (Type 3). Many of the buildings show different structural weaknesses such as vertical irregularities and discontinuities (Photo 3) or lack of proper foundation.

The map resulting from structural assessment (Fig. 3) shows a concentration of *very high risk* buildings along the main bazaar road.

The distribution of different risk categories for LSM and RC-framed buildings (Fig. 4) shows that 17 % of all LSM buildings in Musikot are at *very high risk* of damage due to seismic events. For RC-buildings the share is even higher, with almost one quarter (24 %) of them at *very high risk*. Further, 23 % of all LSM buildings and 7 % of all RC-framed buildings are considered to be at *high risk*. The remaining buildings, 60 % of the LSM buildings and 69 % of the RC-framed buildings and all lightweight wood-framed buildings are at *moderate risk*.

The rationality behind the *very high risk* classification is mainly due to the fact that many buildings in Musikot exceed the recommended maximum number of storeys. The NBC recommends a maximum of two storeys for LSM buildings and three storeys in the case of RC-framed buildings. Many structures, especially those along the main bazaar road, contravene this rule. In total, 56 LSM buildings (18 %) and 50 RC-framed buildings (24 %) are higher than recommended. A small number of seven houses were considered to be at *high risk* because of an aspect ratio greater than three despite the fact that they did not exceed the maximum number of storeys. Another 66 LSM buildings and 6 RC-framed buildings were downgraded due to unsafe roof construction, even though they were within the vertical limits and had an appropriate aspect ratio.

7 Discussion

Over the past decades the combination of road construction and expansion of administrative functions has been a major driver for the rapid development of urban centres in Nepal (Blaikie et al. 2001).

Photo 4: Different roof materials (painted corrugated galvanized iron, straw, slate) and typical building types in Rukum (Photo: J. Anhorn 2012)

Population growth is frequently accompanied by the expansion of transportation networks and settlements into hazardous areas (Gardner and Dekens 2007). Even if the frequencies and magnitudes of current hazards were to remain stable, our case study suggests that the level of risk will continue to increase (cf. Gardner 2002). The observed rapid and largely unplanned urbanization is strongly driven by external factors, such as infrastructure investments, development projects, and the flow of remittances from migrant workers. The long-term benefit of remittances in Nepal is controversial (cf. Pant 2011; Le De et al. 2013) – a study by Practical Action and the Nepal Risk Reduction Consortium (NRRC) indicates that remittances function as a form of investment fuelling unsafe construction practices, thereby increasing earthquake risk (Practical Action and NRRC 2014). The interaction of the geophysical setting with specific demographic and socioeconomic processes have transformed the Middle Hills of Nepal into high-risk

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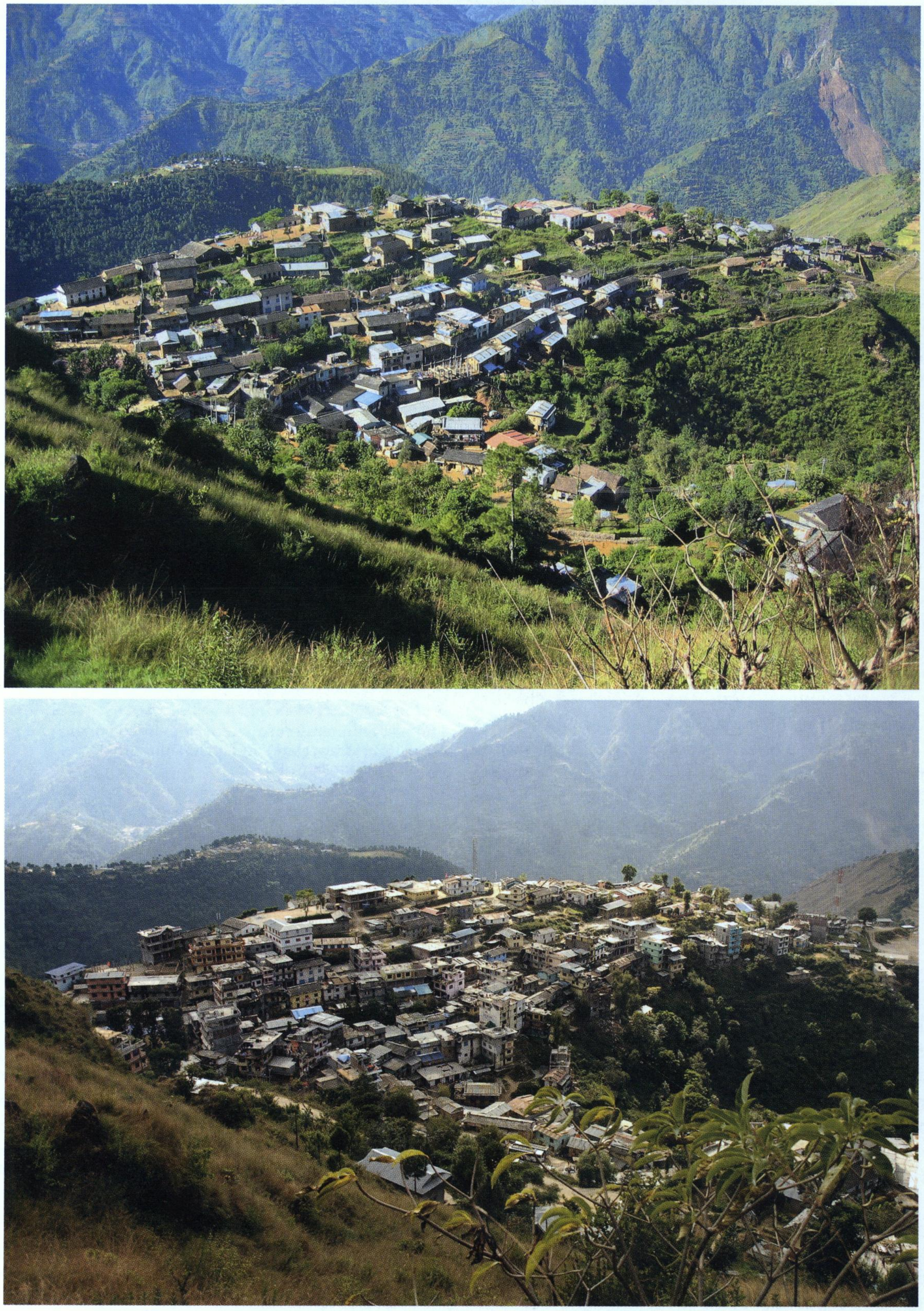

Photo 5: Repeat photography of Musikot in 2004 (upper photo P. Pun 2004) and 2012 (lower photo, J. Anhorn 22.10.2012)

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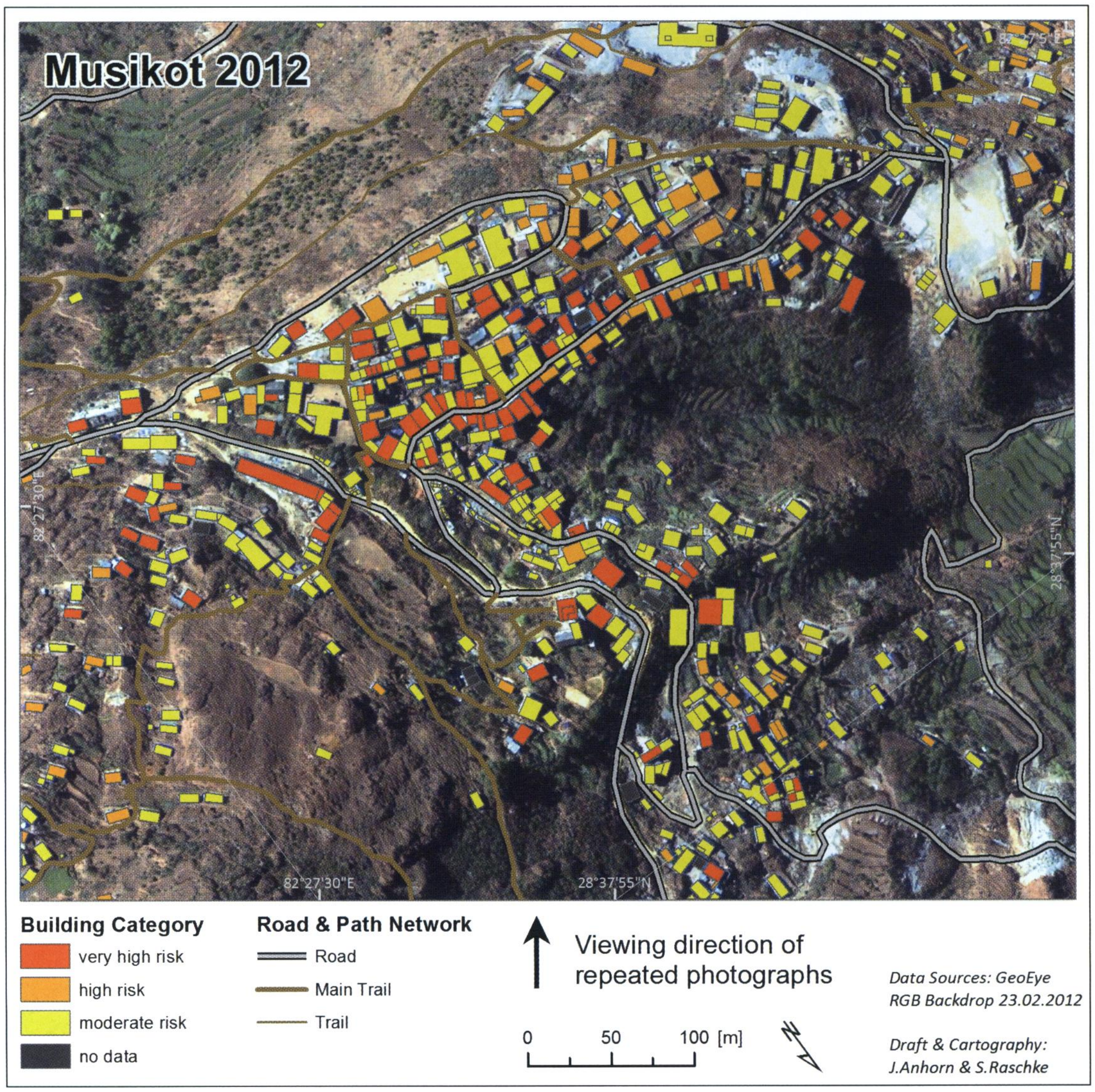

Fig. 3: Map of building risk

environments, making them increasingly disaster-prone. On the individual level, the use of modern materials symbolising strength and "higher status" is considered a "false perception" (Jigyasu 2002, 269). The author provides insights from Bungamati, a small town in the Kathmandu Valley, concluding that most of the recent spatial development is taking place in a haphazard manner, increasing the vulnerability of rural communities, destabilising cultural practices, and decreasing the level of cooperation among residents (Jigyasu 2002).

Typically, house owners in Musikot design and construct their houses with help of family members, neighbours and local masons. As shown in our analysis, traditional house-types are being replaced by multi-storey buildings constructed with "modern" materials, creating a mismatch between the experiences of the builders and changed construction practices. This points to the great necessity for training in the proper use of these materials, especially where they have only recently become available, taking seismic performance into consideration. So far, such training in earthquake-safe building techniques has not been conducted in Musikot. Therefore, measures such as corner bands or vertical enforcements at corners and junctions are neither known nor applied in RC-framed buildings (pers. comm. Local Development Officer 19.10.2012; cf. Dixit 2009). This ought to be considered as another proof of the decline of knowledge of local construction techniques, techniques which are

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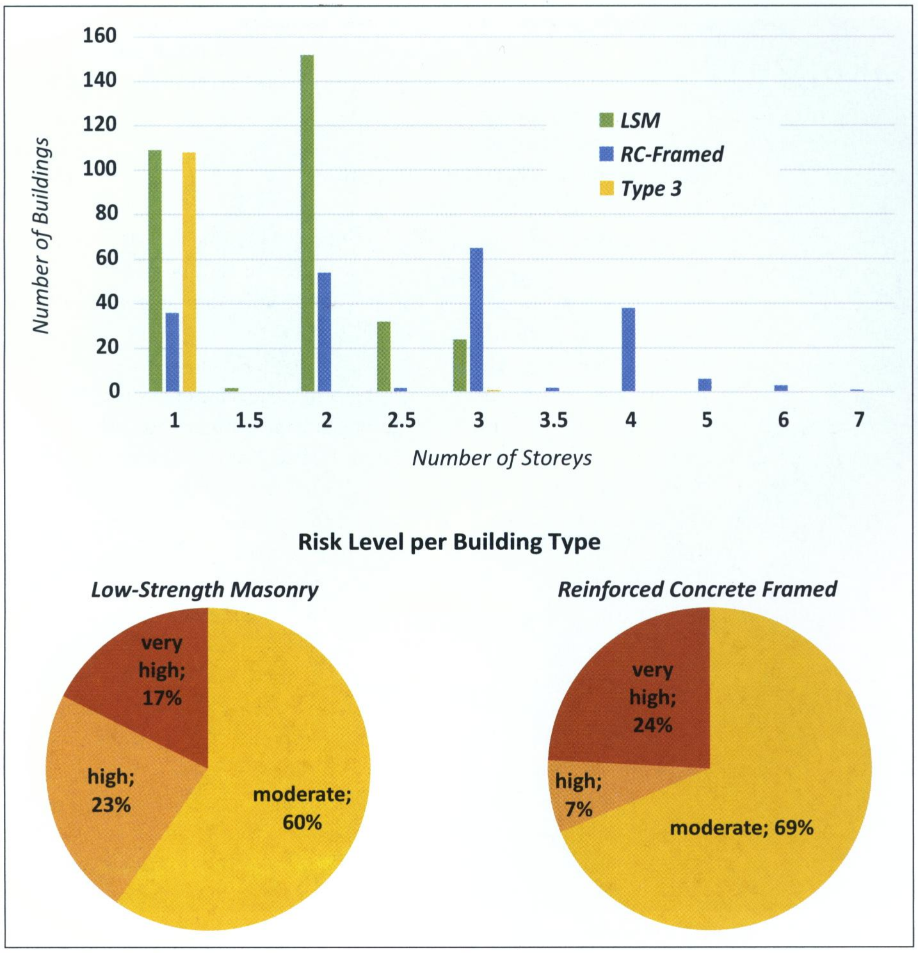

Fig. 4: Distribution of building categories in Musikot

common throughout Nepal. Dixit et al. (2004) indicate the existence of a multiplicity of traditional construction techniques and building designs which need to be explored scientifically and mainstreamed in the curriculum. Disclosing the former knowledge base might revoke any existing seismic culture and support the individuals' contemplation of earthquake risk.

From a legal point of view, the current NBC does not allow for a more rigorous implementation of existing building codes in rural areas, simply because they are not intended to be used in areas not designated as urban. According to the Local Development Office, none of the public buildings are built by professionals and there is no building permit issuing office in place (pers. comm. Local Development Officer 19.10.2012). The same holds true for private buildings. The current political deadlock with no local elections since 2002, hinders further development, implementation and enforcement of existing regulations due to the absence of political incentives and limited funds (cf. IFRC 2011). Positive experiences from elsewhere, such as a building code implementation project in Lalitpur Sub-Metropolitan City could serve as a positive example (Ando et al. 2009; Dixit 2009; Burton et al. 2015). Although, cost-efficient seismic retrofitting methods for local building types exist, they require further dissemination (Macabuag et al. 2012).

As Musikot is developing in a very unplanned and haphazard way, earthquake risk is not the only concern of local dwellers – the availability of daily goods and services, healthcare and food security are equally important for them. This is similar to the capital Kathmandu, where, besides unreliable daily services, the encroachment of potentially lifesaving open spaces point to a problematic lack of planning and consequent consideration of resilience performance (Anhorn and Khazai 2015). While many (international) development projects solely focus on the Kathmandu basin, fast growing towns in the periphery of Nepal develop unrecognized into high-risk cities.

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8 Conclusion

The Gorkha Earthquake of April 2015 has revealed the fragility of the built environment and the resulting social vulnerability in Nepal. Rukum District, despite its distance from the epicentre, sustained considerable damage to its built-up area (71 damaged, 136 partly damaged buildings, according to GoN 2015 as of 12.5.2015). The continuing risk of large earthquakes in the future requires the Government of Nepal to make serious efforts to implement spatial planning tools beyond the Kathmandu basin and enforce updated building codes. Risk-sensitive land-use planning, as recommended by the Earthquakes and Megacities Initiative for the Kathmandu Valley (EMI 2010), needs to be developed and enforced for a multitude of small and rapidly urbanising towns throughout the country. Such endeavours require sufficient financial means, government enforcement and active involvement of local residents; all of which are lacking so far. Over and above changes in the legal and administrative framework, there is an urgent need for raising the awareness of earthquake risks and for transferring knowledge of low-cost earthquake-proof building techniques (Halvorson and Hamilton 2007). This would stimulate positive development, foster a 'seismic culture' (Degg and Homan 2005), and allow for "adaptive and integrative risk governance for urban planning" (Renn and Klinke 2013), ranging from the large urbanized areas to peripheral small mountain towns. A rapid urban appraisal of building susceptibility, using the simplified scheme presented in this paper can help in appropriate mapping and more focussed interventions based on spatial distribution of buildings and populations at risk.

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