Title: Where the norm does not conform: challenging uniformity among low-income settlement type classifications on dolomite

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ABSTRACT

Keywords/key concepts: Low-income settlements, Settlement type, classification, aerial photographs, field work, dolomite

Ground underlain by dolomite may be hazardous to development due to the potential occurrence of subsidence and sinkholes. These potentially disastrous occurrences are in many instances caused by human interaction with the soil through the ponding of water or leaking of wet infrastructure such as water and sanitation services. Construction materials and techniques, as well as effective maintenance of waterborne services have traditionally been acknowledged as having a significant bearing on the level of risk that communities face when living on such potentially dangerous land.

The spatial distribution of settlements on dolomite in the Gauteng City Region (GCR) is already widespread and expected to increase as urbanisation intensifies. Similarly, the challenge of considering the physical vulnerability of low-income settlements is expected to intensify. Well-defined procedures and guidelines govern the development of human settlements on dolomitic ground. However, the classification and characterisation of low-income and informal settlements are not as advanced as that of formal residential developments. In addition, the guidelines regarding management of settlements on dolomite focus significantly on geotechnical interventions, leaving a gap in the influence that human behaviour can play in possible disaster risk reduction on such ground.

The thesis considers the significance of different low-income settlement types on dolomite, relative to perceived human behaviour in association with principles of disaster risk reduction. It hypothesizes that an understanding of settlement type in relation to human behaviour and a stronger emphasis on monitoring via official channels could address some of the conflicts in the development-on-dolomite debate and thereby reduces settlement vulnerability. The research methods included quantitative and qualitative components, commencing with a literature review that spanned multiple disciplines and sectors. Fieldwork included spatial investigation and consideration of low-income settlement types with regard to, for example building material use, dwelling size and dwelling layout, and wet services infrastructure provision and location.

The thesis subsequently identify and explore low-income settlement types in the study area. The research explores a number of sample settlements to consider the physical vulnerability and

potential key areas of intervention and risk reduction, outside of the traditional geotechnical arena. The evaluation then applies the Analytical Hierarchy Process (AHP), a form of Multi Criteria Analysis (MCA), to identify important variables and indicators related to human behaviour and the physical vulnerability of settlements on dolomite that can be harnessed to intervene in the debate, and possible improve the safety of communities living with this risk.

Although not affecting the research outcome directly, a specific observation during the course of engagement with specialists across disciplines was that experts in even closely related practice areas view low-income settlement development and upgrading on dolomite differently. The differences in viewpoints result in contradictions in approaches between housing officials, disaster managers, socio-environmental practitioners, engineers and geologists. Even small differences in approach have been shown to have significant effects on the practicalities surrounding decision making related to low-income settlements and especially informal settlement relocation or upgrading.

The outcome is a set of prioritised indicators that could enable specialists, officials and the public to consider different elements of low-income settlements based on its physical vulnerability. By focussing on the indicators most likely to result in reduced vulnerability, actions that drive settlement development, upgrade and resettlement could be prioritised. Interestingly, one of the findings of the research is that it is not so much the settlement type based on informality that makes a difference in the exposure to risk – physical vulnerability is deemed to be significantly affected by official (municipal-sphere) actions, monitoring and awareness. Finally, the research enables the integration of technical knowledge with behavioural considerations when living on dolomite, thus highlighting opportunities to bring technical and non-technically skilled stakeholders in the debate closer together.

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From the mid-1990s and until the early 2000s I was an active member of the South African Speleological Association (SASA). The primary focus of the Association at that time was exploration and conservation of caves and underground cavities, most of which were located in dolomitic geology or karst environments. At the same time, I was studying towards my undergraduate degree in Geography at the University of Pretoria, which included geomorphology as a subject. During this time through both physical/practical activity and academic studies, I gained a solid understanding of the nature of dolomitic ground and the dangers it may pose. However, I also came to love this sensitive subsurface environment and it being a part of our Mother Earth. By 2004 I completed my masters' degree in Disaster Risk Management at the University of the Free State, immersing myself in the study of disaster risk assessment and disaster risk reduction in particular. These two decades of research as well as practical experience culminated in my PhD thesis.

This thesis came into being not only through personal effort but through collaboration with a variety of individuals and organisations that have supported this effort. Without their professionalism and commitment to contribute comments and recommendations, the thesis would never have realised.

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ACRONYMS

AARSE:	African Association of Remote Sensing of the Environment
AC:	Acta Carsologica
ACC:	African Centre for Cities
ACDS:	African Centre for Disaster Studies
AEA:	American Economic Association
AFD:	Agence Française de Développement
AHP:	Analytic Hierarchy Process
ANC:	African National Congress
ASCE:	American Society of Civil Engineers
APES:	(School of) Animal, Plant and Environmental Sciences (within the Faculty of Science at the University of the Witwatersrand, Johannesburg)
BATNEEC:	Best Available Technology Not Entailing Excessive Cost
BNG:	Breaking New Ground
BPEO:	Best Practicable Environmental Option
CALS:	Centre for Applied Legal Studies (University of the Witwatersrand)
CGS:	(South African) Council for Geoscience
CI:	Consistency Index
CO_2:	Carbon dioxide
CoCT:	City of Cape Town Metropolitan Municipality
CoJ:	City of Johannesburg Metropolitan Municipality
CoT:	City of Tshwane Metropolitan Municipality
CR:	Consistency Ratio
CSIR:	Council for Scientific and Industrial Research
CP:	Cluster Plus
DMA:	South African Disaster Management Act (Act 57 of 2002)
DMISA:	Disaster Management Institute of South Africa
DoH:	See NDH
DoHS:	Department of Human Settlements
DPLG:	Department of Provincial and Local Government
DPW:	Department of Public Works
DRDLR:	Department of Rural Development and Land Reform
DRMP:	Dolomite Risk Management Program
DRR:	Disaster Risk Reduction
DST:	Department of Science and Technology
Du/ha:	Dwelling units per hectare

DWA:	Department of Water Affairs (previously DWAF, now Department of Water and Sanitation)
DWAF:	Department of Water Affairs and Forestry (see above)
DWS:	Department of Water and Sanitation (see above)
EA:	Enumerator Area
EC:	European Commission
EDRS:	Educational Resources Information Center
Eds:	Editors
EERI:	Earthquake Engineering Research Institute
EIA:	Environmental Impact Assessment
EMM:	Ekurhuleni Metropolitan Municipality
EPA:	Environmental Protection Agency (USA)
ETU:	Education and Training Unit for Democracy and Development
Ext:	Extension
FGS:	Florida Geological Survey (USA)
Gauteng:	Gauteng Province, South Africa
GCR:	Gauteng City Region
GCRO:	Gauteng City Region Observatory
GCSRI:	Global Change and Sustainability Research Institute
GDRI:	Groupement de Recherche Internationale
GFDRR:	Global Facility for Disaster Reduction and Recovery
GIS:	Geographic Information Systems
GPG:	Gauteng Provincial Government
GSDRC:	Governance Social Development Humanitarian Conflict
GTI:	GeoTerraImage (Pty) Ltd
H_2CO_3:	Carbonic acid
H:	Hazard
HF:	Hyogo Framework for Action
HDA:	Housing Development Agency
HSRC:	Human Sciences Research Council
IAHS:	International Association of Hydrological Sciences
ICESCR:	International Covenant on Economic, Social and Cultural Rights
ICP:	Imperial College Press
IDP:	Integrated Development Plan
IFRC:	International Federation of Red Cross and Red Crescent Societies
IIED:	International Institute for Environment and Development
IIHS:	Indian Institute of Human Settlements

IPCC:	Intergovernmental Panel on Climate Change
IRC:	Inherent (Dolomite) Risk Class
ISGSR:	International Symposium on Geotechnical Safety and Risk
ISPRS:	International Society for Photogrammetry and Remote Sensing
JEE:	Journal of Earthquake Engineering
KF:	Knowledge Factory
Ltd:	Limited
M:	Manageability
MCA:	Multi Criteria Analysis
MDR:	Mean Damage Ratio
MEC:	Member of the Executive Committee
Merafong:	Merafong Local Municipality
MIG:	Municipal Infrastructure Grant
MIR:	Make It Rational™
Mogale City:	Mogale City Local Municipality
MRA:	Mine Residue Area
MTSF:	Medium Term Strategic Framework (2014 – 2019)
NCEER:	National Center for Earthquake Engineering Research Report (USA)
NDH:	National Department of Housing
NDP:	National Development Plan
NGOs:	Non-Governmental Organisations
NHBRC:	National Home Builders Registration Council
NORSAR:	Norwegian Seismic Array
NSIDC:	National Snow and Ice Data Center (USA)
NRC:	National Research Council
NUSP:	National Upgrading Support Programme
NWU:	North-West University
n.d.:	not dated
OHSA:	Occupational Health and Safety Act
PAHO:	Pan American Health Organisation
PRASA:	Passenger Rail Agency of South Africa
PVC:	Polyvinyl Chloride (synthetic thermoplastic material)
PPP:	Public Participation Process

QUEST:	The quarterly publication of the Academy of Science for South Africa
R:	Rand (South African currency)
RAVA:	Risk and Vulnerability Atlas
RDP:	Reconstruction and Development Programme
Re:	Resilience
Ri:	Risk
RSA:	Republic of South Africa
RWH:	Rainwater Harvesting
SABS:	South African Bureau of Standards
SAGNA:	South African Government News Agency
SANS:	South African National Standard
SASA:	South African Speleological Association
SAICE:	South African Institution of Civil Engineering
SDF:	Spatial Development Framework
SEA:	Sustainable Energy Africa
SERI:	Socio-Economic Rights Institute of South Africa
SPII:	Studies in Poverty and Inequality Institute
SPLUMA:	Spatial Planning and Land Use Management Act (RSA, 2013)
StatsSA:	Statistics South Africa
SUDes:	Sustainable Urban Design Programme
SWOP:	Society, Work and Development Institute
UCT:	University of Cape Town
UK:	United Kingdom
UN:	United Nations
UNISDR:	United Nations International Strategy for Disaster Reduction
UNU:	United Nations University
USA:	United States of America
US$:	United States Dollar (currency)
V:	Vulnerability
VIP:	VIP Ventilated Improved Pit Latrine
West Rand:	West Rand District Municipality
WITS:	University of the Witwatersrand, Johannesburg
WHO:	World Health Organisation

CHAPTER 1: UNDERSTANDING THE DEVELOPMENT-ON-DOLOMITE DEBATE

1.1 Introduction

"…disasters occur at the intersection of environmental hazards and vulnerable people…"
(Bolin and Stanford, 2005: 218)

Worldwide and in South Africa, the integration of economic growth, disaster resilience, and functional urban form often can create turmoil among governments, public and private sector role players, academic disciplines, planners and communities alike (Vale and Campanella, 2005; Berke and Campanella, 2006; Parnell, Simon, and Vogel, 2007; Van Niekerk, 2013). The ideal of the assimilation of goals within human society is further hampered by climate change challenges, community behavioural anomalies, a lack of awareness or integration of knowledge, and resource limitations (Bigio, 2003; CoJ, 2009b; Faling, Tempelhoff and Van Niekerk, 2012; SEA, 2013). In addition, the objective of sustainable earth management, to shift from financial focus as a primary concern towards appreciation of quality of life, presents critical challenges to society and governance systems. This search for balance between the egoistic human condition and sustainable earthbound existence is an ever-elusive objective, resulting in academic research approaches that separate, describe, then analyse and ultimately attempt to assimilate or re-construct the components of our environment and socio-physical interactions. With the increasingly urbanised human settlement landscape, responses to the need for solutions are often fast-tracked and if not carefully considered, result in communities becoming progressively vulnerable in their physical surroundings (Biesbroek, Swart and Van der Knaap, 2009; Van Huyssteen, Meiklejohn, Coetzee, Gross and Oranje, 2010).

In the search towards understanding of earth's geomorphological processes, human behaviour impacts and physical sciences research, academic disciplines tend to disaggregate sectors that segregate the multiplicity of cause and effect. However, when considering human-made and natural disaster risk evaluation, reduction and management, these disciplines have to integrate their outputs and solutions in order to be applicable in the complex context of human society and nature. With increasing urbanisation, especially in Africa, concerns regarding levels of disaster risk conversely increase (Satterthwaite, Huq, Pelling, Reid and Romero Lankao, 2007). The junction of settlement development with natural hazards exacerbates the vulnerability of communities residing in those areas, and is triggering a global focus on Disaster Risk Reduction (DRR) as one of the means to lower the levels of risk (UNISDR, 2005; UNISDR, 2015). DRR forms part of the so-called 'Disaster Cycle' or disaster continuum (elaborated on in Section 2.2.1). The Cycle represents a continuous process before and after disaster strikes. This consists of risk identification and –assessment, mitigation and prevention, preparedness, prediction and early warning (all forming part of the protection phase) before a disaster strikes. After disaster strikes, the Cycle includes impact assessment, response, recovery and reconstruction, the latter often involving reduction of future risk (Warfield, n.d.).

The application of DRR principles enables investigation into the processes that bring about the risk as well as finding solutions to the resultant challenges that communities and governments face, using a multi-disciplinary approach. The multiplicity of human settlement vulnerability as characterised by multi-dimensional and trans-disciplinary components (Council for Scientific and Industrial Research (CSIR), 2009; Van Niekerk, 2013), provides an opportunity to apply a combination of inductive and deductive research approaches towards risk assessment in the context of dolomitic ground as a naturally occurring hazard. I apply both approaches in my research.

1.2 Background

1.2.1 The geology of South African dolomite

Internationally, karst landscapes form due to the presence of highly weatherable dolomite or limestone. The chemical make-up of these formations results in comparable weathering features and resultant hazard characteristics. The older the formation is in geological age, the more prone it is to weathering. Limestone and dolomite are both present in Southern Africa, but this study focuses on dolomite, with particular reference to the area known as the Gauteng City Region (GCR) where the dolomites display particularly high hazard levels. GCR dolomites, estimated to be approximately 2.3 billion years old (CGS, n.d.(a)), represent some of the oldest and most weathered karst landscapes on earth (*ibid.*), thereby elevating the dolomite disaster risk substantially, when compared to other regions in the world.

Figure 1.2.1a shows the distribution of dolomite in South Africa, with the key focus area being in the vicinity of the City of Tshwane and the City of Johannesburg, located in the Gauteng Province.

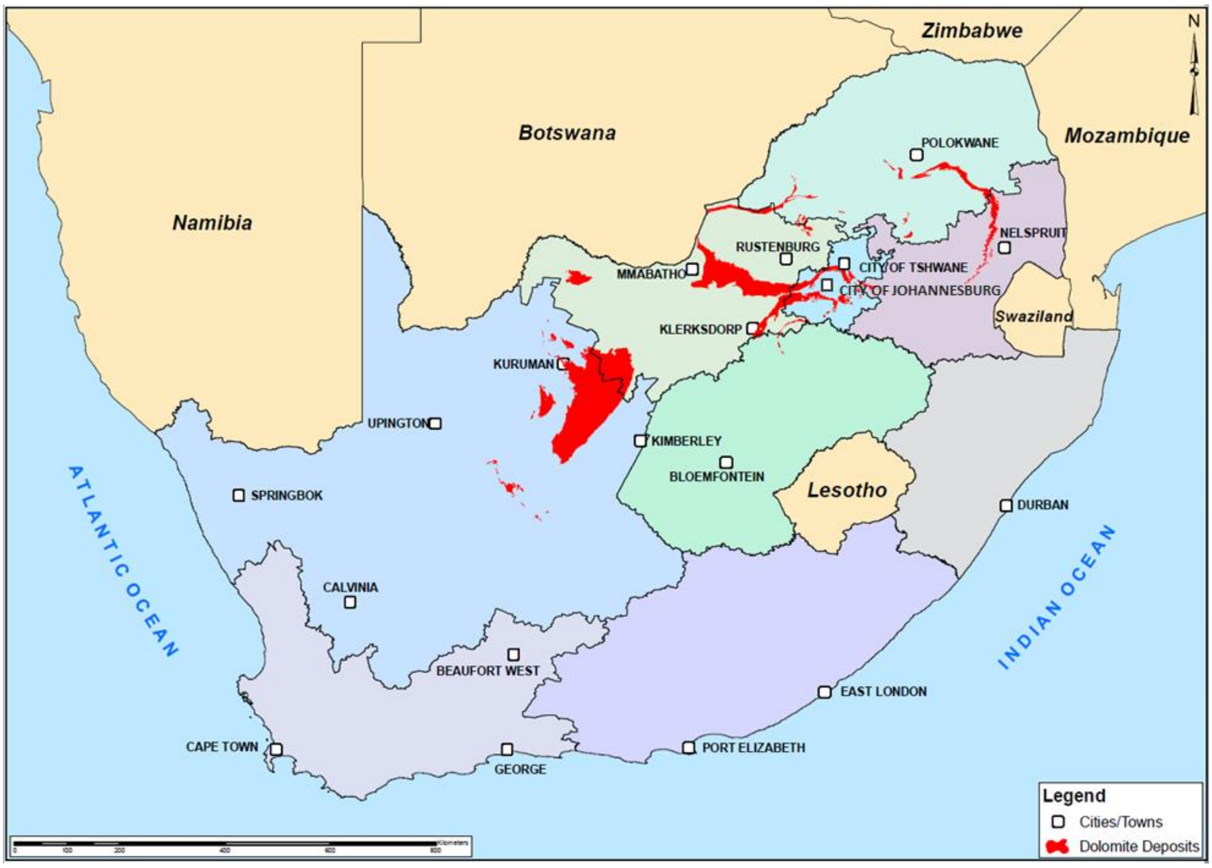

Figure 1.2.1a: The distribution of dolomite in South Africa

Source: Map compiled by AECOM SA (Pty) Ltd, based on CGS (2015).

Ground underlain by dolomite is hazardous due to the potential occurrence of subsidence (*dolines*) and sinkholes (Department of Public Works (DPW), 2010). In South Africa, these potentially disastrous occurrences of sinking ground are affected and often caused by human-induced changes in soil moisture content, for example, due to water ponding or leaking water-bearing infrastructure (Kleynhans, personal communication, 2012). Therefore, conditions of development, construction techniques and maintenance of wet services have a significant bearing on the level of risk that communities face when living on such land. With the South African government supporting sustainable human settlement development (CSIR, 2000; DoHS, 2011), this interaction between geological hazards, development planning and human behaviour calls for consideration. Although the international knowledge base regarding dolomite is relevant to this thesis and the global applicability of the study findings are important, the specific hazard characteristics of the Gauteng dolomites based on their significant geological age, require appraisal of the South African situation and related literature in particular.

Gold-bearing veins that run in an East-West alignment across the GCR led to the establishment of Johannesburg in the late 1800s. Figure 1.2.1b shows the current City of Johannesburg boundary, with the alignment of gold reefs in relation to the dolomite. In this area, the dolomite and gold reefs, as well as the Mine Residue Areas (MRAs) run parallel to each other. MRAs are the tailings residue and waste rock dumps associated with underground mining activities.

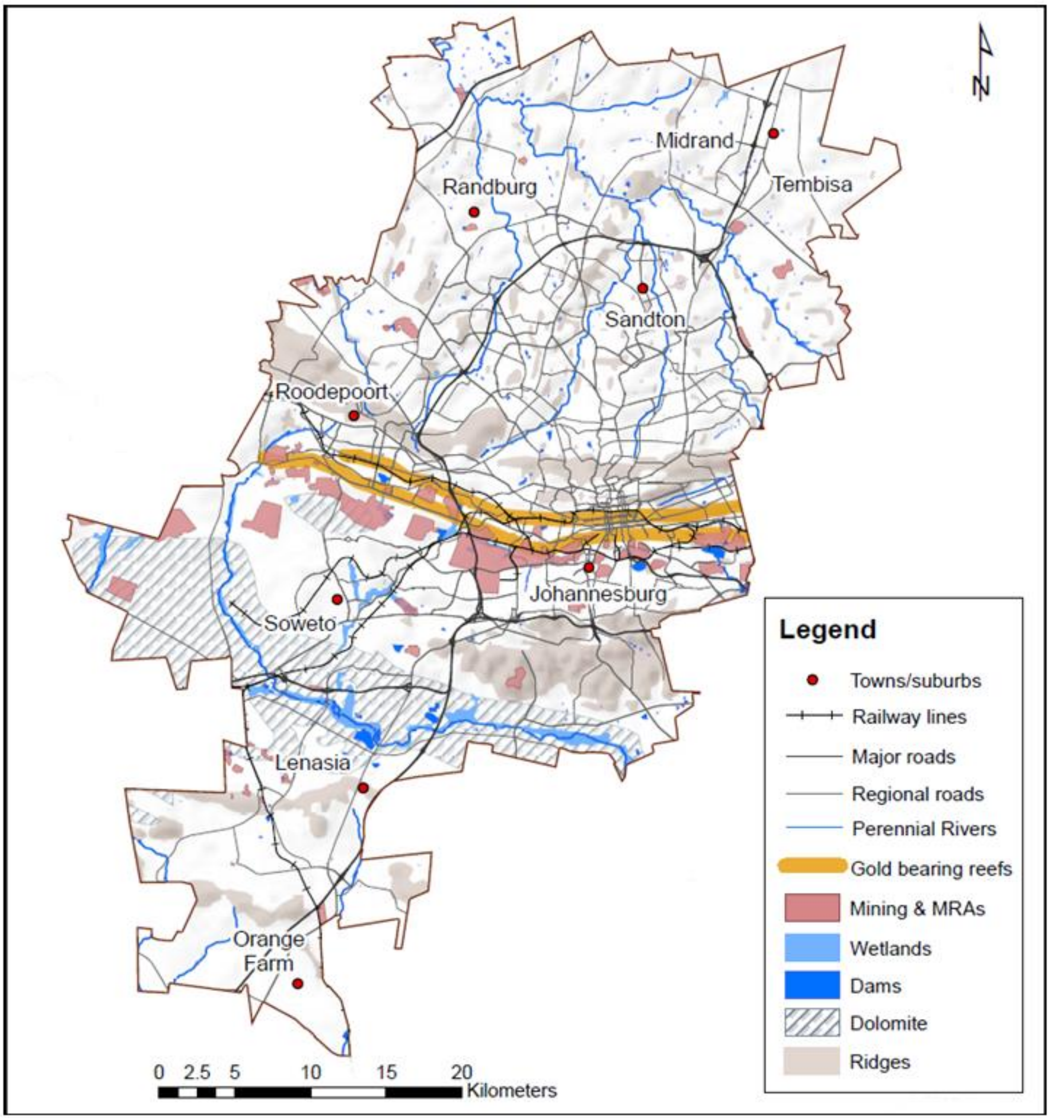

Figure 1.2.1b: Gold reefs in relation to Mine Residue Areas and dolomite in Johannesburg

Source: Map compiled by Gauteng City Region Observatory (GCRO) (2015).

The name "Gauteng" is derived from among others the Afrikaans word "*goud*", which means "gold" – the rationale for much of the human settlement in the region – with the Sotho-Tswana locative suffix "-ng". The early city was less constrained than today's urban expanse by the hazards that dolomite present, since the gold mines were not located on dolomite. Dolomitic risk was also not well known at the time. As the city spread out over the past two centuries, the situation changed radically to its present-day condition where the region is experiencing unrelenting urban development, expansion and densification. Even though the dolomite stretches in a ring around

Johannesburg (Figure 1.2.1c), the gold reefs and dolomite outcrops do not overlap and the presence of dolomite does not determine the presence of gold mining activities (Figure 1.2.1b). However, the proximity of the two in the region in general has inadvertently placed urban development in close presence of dolomitic hazard.

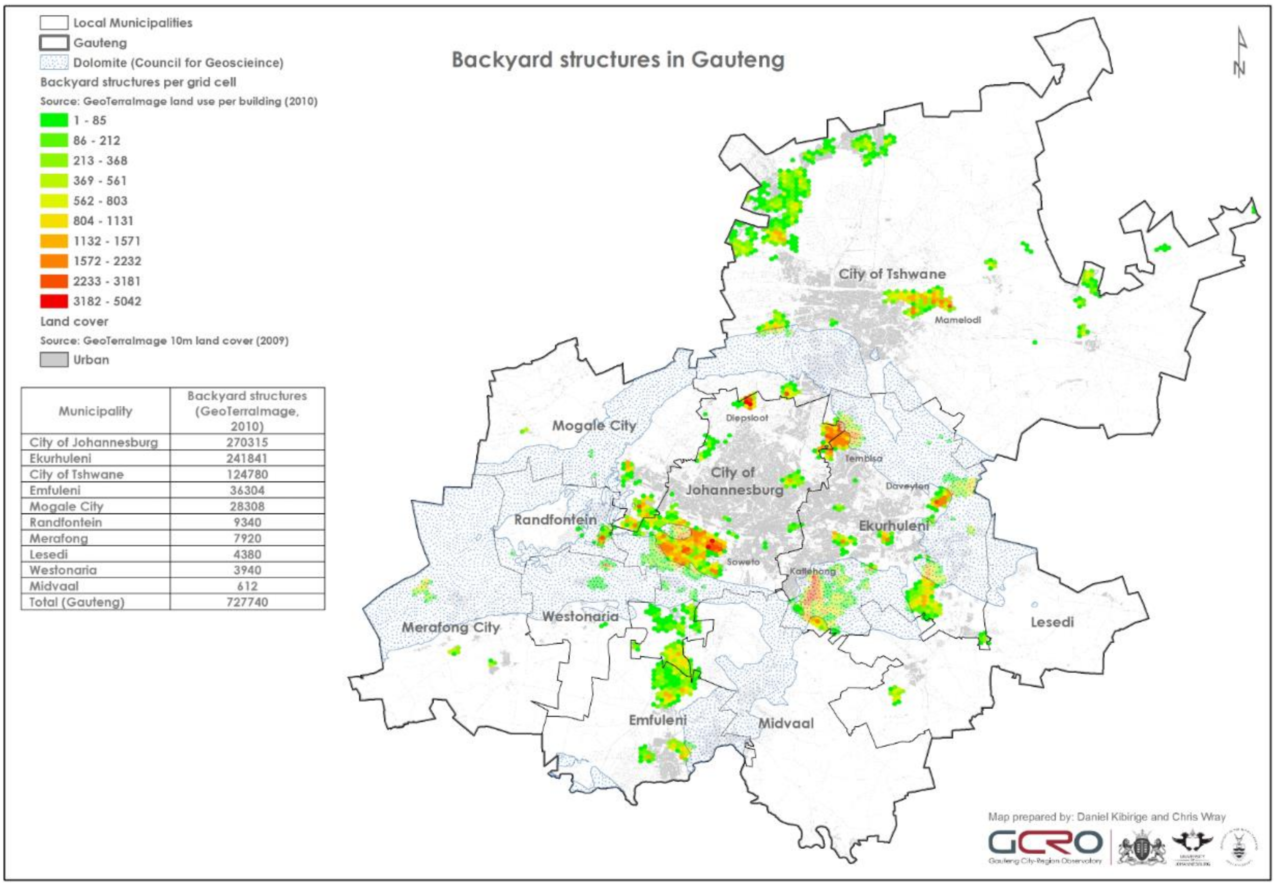

Figure 1.2.1c: Dolomite, urban areas and backyard structures* in Gauteng

Source: GCRO (2013) (*all backyard structures associated with formal housing that may be used for housing purposes (formal or informal), reflected as points, aggregated using a randomly generated hexagonal grid (GTI, (2012)).

This research focuses on the intersection of relatively high levels of dolomitic hazard severity with human settlements, in particular where low-income communities reside in the densely populated Gauteng Province and surrounding areas in South Africa. Figure 1.2.1c also shows the proliferation of backyard structures in Gauteng in 2012 with the count amounting to 727 740 – more than twice that of the census count the year before. “Low-income” in the context of my research is a relative concept that refers to the cost of living in an area in relation to the household size and level of income that households are able to achieve on average. Placing a monetary value on the concept is challenging. However, in general household incomes in these areas would range between zero and R100 000 per annum for a four-member household. Settlement types associated with the context of low-income are generally no larger than 100 m² per family dwelling unit. The challenges of an elevated hazard probability and severity in terms of dolomitic ground, combined with low-income human settlement vulnerability are particularly visible in Gauteng. As such, the region characterises an area where often significant conflict of opinion exists between role players and decision makers in the development-on-dolomite debate.

Varying characteristics of dolomite constituents determine the level of disaster hazard in relation to human settlement development options (DWA, 2009). These characteristics include, among others, the age of the geological form, the underground structure, the make-up of geological strata, the depth at which it occurs, as well as the type and thickness of the overburden (soil covering over the dolomite strata). The older the geo-form and the more weathered it is, the greater the potential for sinkholes or dolines to occur; and the closer to the surface it is, the greater the level of exposure to development (Heath, personal communication, 2011). The uneven distribution of dolomitic hazard patterns across often small spatial expanses, coupled with undeterminable directionality, shape and size of underground caverns and vacant spaces in the dolomite (SASA, 1982) causes difficulty to determine an absolute risk level or location in many areas in and around Gauteng. Hazard zonation for development purposes are therefore an approximation only, based on the best available information gained from drillhole analysis and the like, which attempt to define the irregular subsurface distribution and patterns of underground aquifers, voids, chert bands, weather altered dolomite (WAD) (Avutia, 2014), rock pinnacles and bedrock (Jack, 2011). Regulations, standards and guidelines pertaining to development on dolomite therefore consider relatively conservative options for development on inherently hazardous ground. Figure 1.2.1d shows a site where development along the *Gautrain* route has resulted in removal of WAD and chert, exposing dolomite pinnacles.

Figure 1.2.1d: Exposed dolomite pinnacles (Centurion, South Africa)

Source: Author's photograph (2013).

1.2.2 Development challenges on dolomite

Introduction to challenges

Globally, development often avoids karst ground, the preference being to set it aside for parks, conservation or ecosystem services purposes (Fleury, 2009). Even though avoidance of dolomitic ground remains the ideal, reality shows that the intention of greenbelt restrictions often gives way to urban development pressures (Williams, 2011), both formal and informal. Where development does occur, building regulations, restrictions and planning processes are largely involved (City of Budaörs, n.d.; FGS, n.d.; Kaufmann and Quinif, 2002; Richardson and Brown, 2005; DPW, 2010; Reger, 2010; IAP, 2011; Republic of South Africa, 2011). Even where DRR measures are applied and conservative decisions regarding development choices made, the hazard continues to present a threat to built structures and human safety. Particularly, sudden surface collapse may cause deaths, injuries and damage to property, with reference to such losses in South Africa by Hawke (1975), Brook and Allison (1986), Schöning (1990), Kaytech (2006), Environomics (2012) and Mchunu (2012).

Gauteng experiences a critical juncture between densely populated human settlements and significantly high dolomite hazard levels (Heath, personal communication, 2011). In order to address the development-on-dolomite issue since the 1970s, South Africa has since designed, refined and implemented pre-development assessment and reporting procedures, national standards, building regulations and guidelines. These technical systems govern formally approved development of human settlements on dolomitic ground and have undergone revision in the early 2000s, with specific refinement again taking place since 2010 (DPW, 2010; South African Bureau of Standards (SABS), 2012; Oosthuizen, 2013). Within this framework of governing “rules”, development on dolomite is possible given the implementation of investigations and remedial measures before developments commence (Heath, personal communication, 2011).

Examples of formally approved development on dolomite in Gauteng include Lenasia (Mchunu, 2012), Centurion (CoT) (Kaytech, 2006; Environomics, 2012; Chapman, 2013; Martins, 2013a, b; Oosthuizen, 2013; Velleman, 2013; du Plessis, 2014; Mnguni, 2014), and the Gautrain rail alignment (Gautrain, 2010) that runs between the City of Tshwane (CoT), Johannesburg and Ekurhuleni Metropolitan Municipality (EMM) (Some of these areas are indicated in Figure 1.2.3). By 2001, at least 270 000 formally approved dwelling units (including subsidised low-cost housing) in the province had already been built on dolomitic ground, while between 2001 and 2009, at least another 55 500 new residences were added to this number, on dolomite of varying hazard levels (GCRO, 2011a). In Centurion, in particular, significant densification is occurring, with a number of high-rise commercial buildings proposed and blocks of flats reaching four to five storeys high being constructed (Nene, personal communication, 2014). Ahmad (2013) reported rapid growth in the numbers of backyard shacks across Gauteng over the past two decades, with the trend expected to continue. This occurrence is confirmed by Eskom's spot building count (Eskom, 2013) and the GCRO visualisation of backyard dwellings (2013) (both GIS data sets derived from satellite-image data).

In formalised settings in South Africa, land uses and housing densities have been classified and considered for approval based on a range of dolomitic hazard levels, thereby aiming to provide an acceptable level of "living with risk" to those communities (CGS, 2007). However, the definition of the categories of formal development types on dolomite did not foresee the proliferation of indeterminate settlement configurations which include informally constructed dwellings and un-registered backyard units not approved or registered via formal municipal processes (GCRO, 2013), or even entire informal settlements. Recent amendments and additions to development on dolomite standards (SABS, 2012) address some of the elements of informality and regulate through intensive site investigation. However, potential development of land where funding for such investigations is not available is thereby ruled out, or access for drilling equipment is physically restricted due to narrow pathways.

In Gauteng's urban areas, the proportion of settlements that intersect with hazardous dolomite is increasing, in parallel with the progression of settlement densification. Where large numbers of individuals and households with relatively low-incomes settle in or near these dolomitic-underlain urban areas, the disaster risk is considered to increase dramatically (Kleynhans, personal communication, 2012). It is not only on dolomitic ground that the challenge is taking place. The contestation of space is fuelling an energetic debate throughout the Province, with a number of appeals to allow settlement development and informal settlement upgrading ending in the Courts, a number of which are discussed by Chenwi (2012). As examples, the cases of Bapsfontein and Protea South settlements, both located on dolomite, are highlighted.

Bapsfontein Risk-based Relocation

The case of Bapsfontein informal settlement started around 2004 when the instances of dolomitic sinkholes in the area prompted EMM to commission geotechnical investigations (Pheko v EMM, 2011a, b). Findings showed a depression with perimeter sinkholes as close as 100m to the primary school in Bapsfontein. Sporadic sinkholes, depressions and cracks within the settlement were discovered and the area was deemed unsuitable for "mass housing" based on the geotechnical reports (*ibid.*). By 2009 EMM made the decision to relocate the settlement to a temporary location based on the level of disaster risk, in terms of Section 55 of the South African Disaster Management Act (Act 57 of 2002) (DMA) (*ibid.*). After resistance to relocation, forced relocation took place in March 2011. The North Gauteng High Court (Pretoria) dismissed an application by the community for disaster relief and held that forcible relocation and demolition of their homes by the EMM was lawful. The applicants then turned to the Constitutional Court, which set aside the High Court decision and declared the relocation unlawful. Several issues were identified regarding the interpretation of the Disaster Management Act and the process that the Municipality followed. For example, the evacuation of residents based on the DMA was found not to be equivalent to eviction and demolition of homes, nor of doing so without a court order. The urgency of the matter was also questioned due to the time it took between the hazard being identified and the settlement being relocated (*ibid.*).

From a review of the relevant documentation related to the case, more effective engagement and awareness processes could have alleviated the severity of the situation and improved the level of appropriateness of the actions that were taken. The question arises as to what the meaning of "meaningful engagement" signifies for different individuals or groups. By November 2012 the Bapsfontein community had organised themselves into two groups: the "N12" and the "Mayfield" Communities (Pheko, 2015). The N12 Community were willing to relocate to the Daveyton Farm and parts of Putfontein and Mayfield Extension and confirmed that they were adequately consulted (*ibid.*). However, the Mayfield Community were unhappy with the quality of the consultations (*ibid.*). The Constitutional court ruled in May 2015 that although not found in contempt, the Municipality has not complied with the Court's directions and orders and has breached its constitutional obligations by failing to abide by the orders. The EMM's Mayor, the Municipal Manager and the Head of Department for Human Settlements were called to personally respond to certain elements of the case and the Gauteng Province Member of the Executive Council (MEC) for Human Settlements were joined to the case for the purpose of supervisory implementation (*ibid.*). Throughout the process, the community remained in temporary housing.

Protea South Informal Settlement Ongoing Case

For Protea South (Mnisi v CoJ, 2009 and Mnisi v CoJ, 2014) the situation revolves around the communities request for *in-situ* upgrading, with potential relocation on the cards in order to resolve inadequate housing and basic services access. In this case, the stakeholder consultation process is of specific interest with regard to the manner in which community engagement on dangerous ground is approached. The original township plan (dated 2003) was meant to accommodate about half of the approximately 6000 households in the Protea South location. By 2006 no development has taken place yet and a dolomite geotechnical investigation concluded in that only 583 stands could be developed.

Communication and meetings since then did not result in positive and effective community engagement. Subsequently, *in-situ* development was to be abandoned in favour of relocation of the entire settlement. In this regard the High Court found “a disturbing pattern of official indifference” (*ibid.*: Section 23), lack of meaningful engagement and unilateral decision making. The dolomite situation was noted, but not attended to in detail. The Court found the City of Johannesburg obliged to:

- have a programme to address the situation in a mediated fashion;
- provide immediate basic services; and
- progressively realise the right to adequate housing for the applicants.

The case thus shows the need to implement improved consultation processes to arrive at a mediated solution. The three items listed above is a requirement in terms of Section 26 of the Constitution and Chapters 12 and 13 of the Housing Code (DoHS, 2009) and was as such a key focus of the Court’s decision. It is during these meaningful engagements and consultative processes where awareness of the technicalities involved in development-on-dolomite can potentially be shared with communities. By 2012 the residents were still living in a desperate situation and the matter of understanding the key dolomitic concerns and possible interventions remain contested (GCRO, 2012a) and this remains the case to date.

The cases referred to allude to a critical need for timeous and effective community engagement, towards arriving at a mutually agreed-upon decision when considering development, upgrading or relocation of low-income and specifically informal settlements. The technicalities of dolomitic ground are realised to be of such nature that courts are not in favour of engaging in professional debates or consider differences that may exist between outcomes of geotechnical investigations, and the geotechnical reports are not called into question, even if only submitted or referred to in part. Thus, interventions when settlements are faced with developmental and upgrading challenges may not be served by technical objection, but rather served via behavioural and communicative interventions.

1.2.3 Settlement vulnerability on dolomitic ground

In densifying African cities, increased housing demand arises from among others the perceived ability of urban economic hubs to provide job opportunities as well as perceived ability for improvement of individual and household socio-economic status (Demurger, Sachs, Woo, Bao and Chang, 2002). The influx of residents into urban hubs results in increased pressure for provision of housing to accommodate the populace (Mosoetsa, 2010). There is also an increased tendency for poor communities worldwide to settle on potentially hazardous ground (Yodmani, 2001; Sagala, 2006; Tacoli, 2011), exposing them to additional pressure when climate change is considered (Bigio, 2003; McGranahan, Balk and Anderson, 2007; Satterthwaite *et al.*, 2007). The presence of communities living in potentially dangerous geographical locations is of particular concern since they exhibit lowered capacity to absorb the impacts, and to financially and emotionally manage and physically recover from even minor disruptive events (Storie, 2012b).

In the Gauteng landscape, quartzite ridges are prominent, while rivers, wetlands and floodplains, and gold mining residue areas present additional physical and environmental constraints to the spatial distribution potential of urban development in the region (Storie, 2014). The vast expanse of dolomitic ground, covering 25% of the province (CGS, n.d. (a)) (Figure 1.2.1c and Figure 1.2.3), is therefore increasingly being considered for construction of industrial and residential features. The steady increase of inhabitants per square metre (m^2) in urban densities suggests that development on hazardous ground would be difficult to curb, especially where informality (shack and backyard dwelling construction) is involved.

Figure 1.2.3 shows a map overlaying the Gauteng Provincial Department of Housing informal settlement polygons (areas) and informal dwelling point density data that was developed using high resolution satellite imagery in Gauteng. The figure reflects on the proliferation of informal and backyard dwellings in settlements such as Thembelihle, Protea South, Bapsfontein, Winnie Mandela Park, Khutsong, Thusong and Ivory Park (Figure 1.2.3). These areas are located close to, partly or entirely on dolomite. Thembelihle is an informal settlement where, after initial consideration for relocation to Lehae, formal housing development and service delivery is currently being earmarked (Planact, 2015). Protea South remains engaged in legal processes to determine their future, with possible relocation to an area called Doornfontein. The Bapsfontein settlement was relocated to a site 30km away from its original placement, while Winnie Mandela Park was an informal settlement that was developed cautiously and taking into account geotechnical engineering requirements, despite being underlain by dolomite. Khutsong and Thusong are in various stages of development and provision of services, while some areas are being relocated based on dolomite hazard levels. Ivory Park was partly developed as serviced sites pre-1994 without clear guidelines regarding how dwellings would be constructed on the dolomite, while a more recent housing project approximately ten years ago implemented dolomite-approved raft foundations (Warwick, 2011).

Managing or policing the construction of backyard structures in low-income areas after formal development is completed is a challenge. The most recent South African census data reveals 305 682 households living in informal backyard structures in Gauteng (StatsSA, 2011). However, mapping based on satellite imagery indicate possible undercounting.

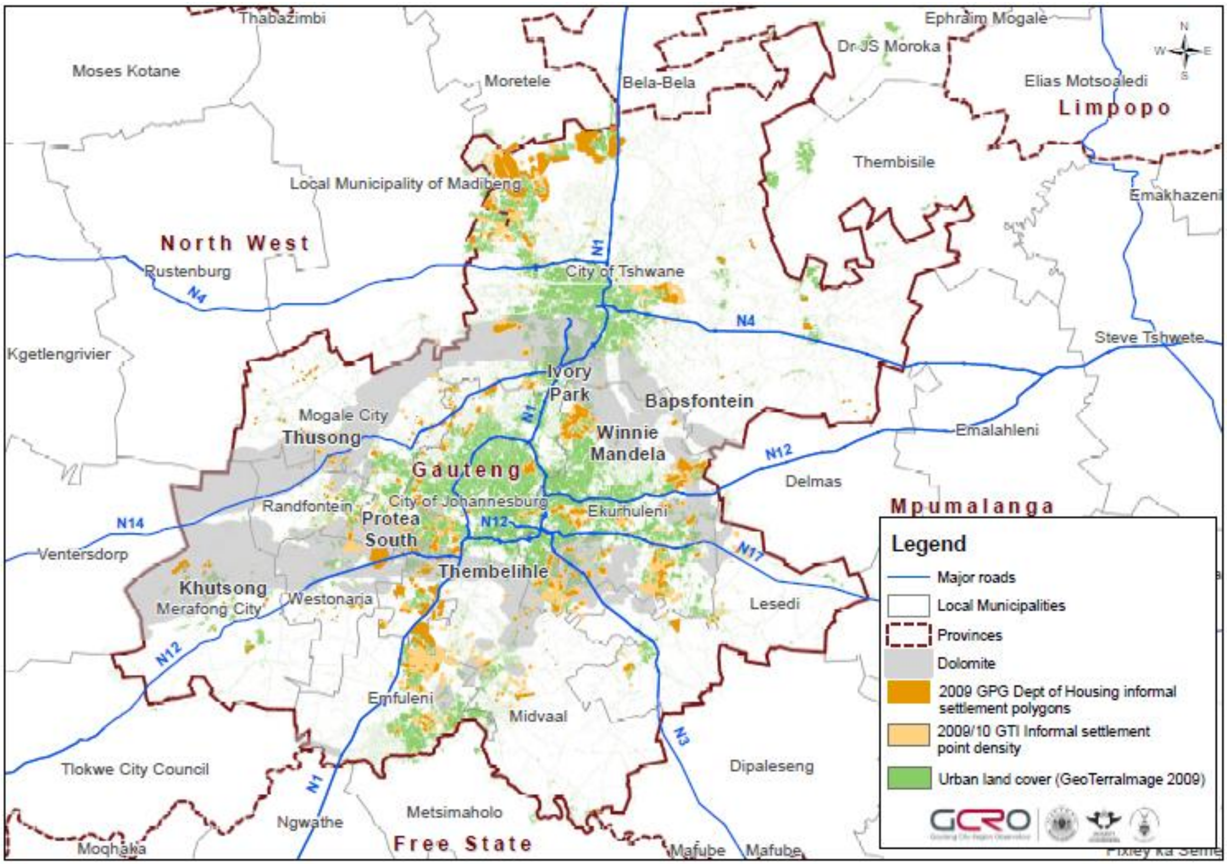

Figure 1.2.3: Urban land cover, informal settlements and dolomitic ground in Gauteng

Source: Map compiled by GCRO (2011a).

The existence of possible undercounting in some informal settlement has to be recognised (du Plessis and Landman, 2002; Turok, 2012). With low-income settlements in the developing world predicted to increase in size, density (Osman and Herthogs, 2010) and level of vulnerability (McGranahan *et al*., 2007), the possibility of undercounting alerts to an ever-increasing fiscal burden on governments to provide basic services (Tacoli, 2011). Where such settlements are located on potentially dangerous ground, especially when service provision is contemplated after settlement establishment, added challenges are expected. This means that settlement development or upgrading on dolomitic land, involving geotechnical investigations, interventions and potential infrastructure construction, would become increasingly costly. The longer decisions regarding development and upgrading are delayed, the more costly interventions are expected to be.

1.3 The research problem

1.3.1 An applied knowledge gap

Assessment of low-income human settlement vulnerability to natural hazards presents opportunities to:

- explore the confluence of human settlement exposure to disaster risk,
- investigate socio-economically driven household behaviour, and
- explore technical requirements designed to guide urban form and function.

Such research enables insight into elements that constitute the disjuncture between uni-dimensional disciplinary research and associated regulatory instruments. An understanding of the fundamentals that underpin settlement vulnerability within a regulative and technical context highlight a necessity for behavioural appreciation and subsequent cognitive public awareness and intervention when pursuing disaster risk prevention, -mitigation, -reduction and -management.

My research considers the significance of low-income settlement types relative to perceived human behaviour in association with principles of DRR. I hypothesise that an understanding of settlement type in relation to human behaviour, based on information sharing regarding technical considerations of DRR could advance decision making policy and processes, thereby addressing conflicts in the development-on-dolomite debate. Subsequently, reduced vulnerability may be possible when living with risk.

The guidelines and physical vulnerability evaluation methods that support geotechnical risk assessment in South Africa address hazard levels for dwellings on dolomitic ground. Low-income human settlements as opposed to medium- and high-income types are not considered in significant detail or categorised in a wide variety of forms within the hazard assessment environment (DPW, 2010). My research addresses this gap and provides an avenue for increased interaction between settlement planning processes and community behaviour, to reduce the vulnerability of residents living on dangerous ground. Since disaster risk assessment does not only consist of hazard investigation but also factors in vulnerability and manageability, an interrogation of elements of settlement type and related human behaviour that influences vulnerability could increase the overall possibilities for low-income settlement DRR.

Throughout South Africa's history, the positioning and development of low-income settlements was multifaceted with complexities rarely recognised in housing and urban planning regulatory frameworks. The assumption was that modest orderly town planning patterns could address housing development challenges (Huchzermeyer, personal communication, 2014). When the first democratically elected government came into power in 1994, it faced challenges of implementing plans to reduce low-income housing backlogs as well as spatial exclusivity resulting from apartheid planning policies (du Plessis and Landman, 2002). More than two million low cost houses were constructed since then (Mosoetsa, 2010) and although a backlog remain in terms of housing provision, varied trends are observed regarding urban migration where some rural areas are seeing residents return from urban areas, thereby reducing rural housing demand.

Changing housing policies, the policy context and the nature and extent of service delivery over the past two decades (Mosoetsa, 2010) shape the current realities of potentially dangerous development on dolomite. As alluded to earlier, with the examples of court cases cited and as presented by Huchzermeyer (2009), the interpretation of legislation and municipal housing and service delivery policies do not align consistently. The Constitution (Republic of South Africa, 1996) states everyone's right to access to adequate housing. Therefore, the State must take measures to achieve the realisation of this right while at the same time not evicting anyone from or demolishing homes without consideration by the Court (*ibid.*). Within this context, geotechnical reasons cited to support removal of settlements are difficult to uphold, since the right to housing then conflicts with the right to a safe living environment.

In addition, the acceptable level of service provision may be interpreted disparately by different municipalities. Considering that some low-income settlements have been located on potentially hazardous dolomitic ground for many decades and backyard dwellings proliferate even in newly planned settlements on dolomitic ground, contestation between housing and safety remain rife. By enabling pragmatic knowledge of the dangers associated with living on dolomitic ground in association with low-income settlement types, my research pursues a method that presents officials, planners and communities with a better understanding of the need for increased participation and

awareness of the risks involved. This may contribute to bridging the gap between demand for constitutionally stated human rights and the hazards associated with dolomitic disaster risk.
With regard to vulnerability on dolomitic ground, medium to large dwelling units, with foundations of on average 13m x 13m, or 170m² or larger (Kirsten, Heath, Venter, Trollip and Oosthuizen, 2009), constructed from brick and mortar with formally designed water-bearing infrastructure (for example piped water and flush toilets), dominate residential geotechnical solutions in South Africa. Few of these characteristics are relevant to low-income settlement types, where structures are small and often informally built, basic services are lacking or provided after initial development took place, and population densities are high. Furthermore, the risk posed by water-bearing infrastructure of formally planned and developed dwellings and the assumed maintenance regime of such infrastructure is significantly different from the informally and sometimes illegally constructed often-leaking and irregularly maintained waterborne infrastructure in lower income settlements (Kleynhans, personal communication, 2012). Only one study thus far investigated the context of low-income settlements on dolomite in South Africa (Buttrick, Trollip, Watermeyer, Pieterse and Gerber, 2011), and this approaches the problem from an engineering perspective where geotechnical design is the key focus with regard to the settlement exposure to dolomite risk. My study creates additional awareness of the need for increased consideration of the behavioural elements related to the physical vulnerability of low-income human settlements on dolomite.

1.3.2 The Problem and Rationale

In South Africa, there is agreement among technical sciences that it is possible, under certain circumstances, when following prescribed procedures and grey or traditional infrastructure interventions (as opposed to green, natural or ecological infrastructure) to develop on dolomite (DPW, 2010; SABS, 2012; Mnisi v CoJ, 2014). These interventions vary, depending on differences in settlement characteristics primarily related to development density. However, since low-income settlements do not conform to formal settlement characteristics and there is varying dwelling density due to its informally developed origins, decision making regarding low-income settlement upgrading on dolomite faces a complex challenge where investigations have to be conducted after establishment. The debate that currently surrounds the challenge alludes to an interdisciplinary approach where different professional areas and transdisciplinary engagements between academia, practitioners, officials and communities involved could be integrated to find a solution to the challenge.

While well-founded evidence-based hazard assessment procedures exist to guide developments on dangerous ground internationally, a number of subjective and scientifically unproven processes are also promoted (Galve , Bonachea, Remondo, Gutiérrez, Guerrero, Lucha, Cendrero, Gutiérrez and Sánchez, 2008). This discrepancy tends to confuse non-technical persons and communities, thus increasing the level of conflict that persists when debates regarding development and upgrading of low-income settlements on dolomite arise. It makes the application of housing and development policies, guidelines, criteria and standards challenging. The unravelling of unique combinations of settlement types implies significant resource expenditure. The dolomite hazard evaluation process applied in South Africa displays variations with regard to distribution sequences of sinkholes (Kirsten *et al.*, 2009), which ultimately affects the uniformity of hazard assessments between settlements. These variances relate to the requirement in drillhole density based on the size of areas investigated. In addition, communities that are the subjects of decision making often have difficulty in understanding not only the decision process itself, but also the reasons for decisions made. As such, communities find it difficult to distinguish appropriate from inappropriate settlement development and DRR behaviour. The emergence of low-income settlements with multi-faceted characteristics and potentially undesirable post-development and post-upgrading resident's behaviour with regard to waterborne infrastructure maintenance therefore pose major challenges for urban planners and regulatory decision makers.

If the highest level of basic infrastructure service provision, such as fully reticulated water and waterborne sanitation to individual dwellings, is the norm for all subsidy-funded developments, elimination of South Africa's housing backlog will be unattainable (CSIR, 2000). Apart from increasing the pressure on existing resources to deliver the promise of such high-level service infrastructure, such a policy direction makes decisions regarding the level of intervention that is applied to different geographical situations a difficult one. Although guidelines such as the Red Book (CSIR, 2000, currently under review) exist, the development or upgrading of low-income settlements on dolomitic ground remains un-nuanced. This lack of clear guidance to inform development decisions effectively on a non-technical basis sometimes results in delays in the decision making process. In addition, there is an absence of consideration of human perception and behavioural elements during disaster risk continuum. These deficiencies call for additional elements to be included in the assessment of physical vulnerability and management of disaster risk. Ultimately, there is a need to inform the development-on-dolomite debate and contribute to decision making that considers alternative options in housing policy development and implementation, from the perspective of settlement type and associated human behaviour (Figure 1.3.2).

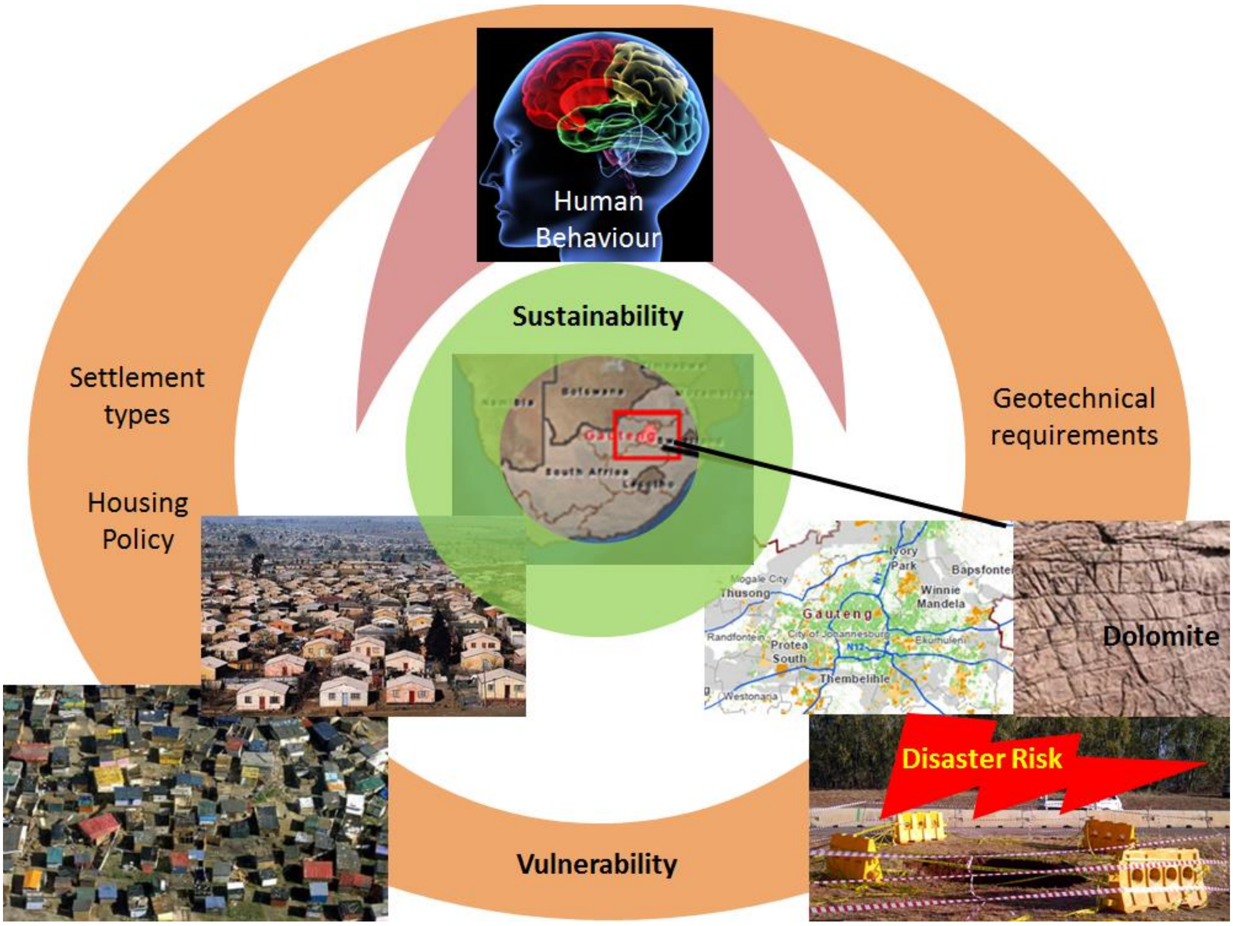

Figure 1.3.2: Elements of the research problem

Source: Compiled by author

1.3.3 The broader context of the research problem

The research is positioned in the broader global context of a need for change in the way that we prepare for, mitigate and respond to physical or "natural" disasters (where natural disasters are often human-induced), and a transition towards more sustainable societies worldwide. The research was initially sparked by the conceptualisation of sustainability and vulnerability in densely populated urban environments, in which I was involved in at the Gauteng City Region Observatory (GCRO) in 2010. I subsequently motivated further GCRO work, the theory and figures of which was primarily used in this thesis.

In an effort to find lasting solutions to challenges, serve human settlements and support livelihoods that provide an acceptable quality of life, disciplines such as engineering, geology, planning, policy making and risk management have to find collaborative solutions to apply the existing knowledge. Since risk is a function of its acceptability by a particular group or groupings of people and their ability to recover or provide assistance for those that need it during the recovery phase to return to normality or a stable state, role players in the process may consider different solutions with varying degrees of approval.

This research spans a number of disciplines and does not aim to exhaust all the possibilities and permutations of the debate that exist. I propose an approach to considering risk based on varying aspects of physical risk, such as vulnerability, manageability and capacity or resilience, which influences community risk related behaviour, as opposed to the hazard itself. The application to the specific environment of low-income settlements on dolomite, with the research focussing on Gauteng as study area, provide the context within which adaptations to the method may be made elsewhere in the world and in different contexts. The study was conducted between 2011 and 2015 via the University of the Witwatersrand, Johannesburg, and reflects a time when the Gauteng region experienced an urgent call from poor communities for the meeting of basic needs and provision of access to land or formal housing.

1.3.4 Research arguments

The research is reinforced by three arguments: First, there is the argument that informal settlements should, wherever possible, be upgraded *in-situ* as opposed to their inhabitants being relocated. Therefore, carefully constructed support tools are required to assess dolomitic risk during the decision making process of settlement upgrading, with relocation as a last resort (HDA, 2004). The research approach suggests that current scientific geotechnical assessment guidelines are not particularly effective when used for decision making in informal settlement upgrading cases. This results in authorities not upgrading settlements where risks could be mitigated effectively and the social structure of communities remain intact. However, informal settlements are not the only ones affected by pre- and post-development concerns when located on dolomite.

This leads to the second argument, which is based on the characteristics of informal settlements, social and subsidised housing development, which in its design at present is not responsive to the geological strata on which they are constructed. Current guidelines for development are very specific regarding the allowed number of dwelling units per hectare (Du/ha) on dolomitic ground, but do not specify unique sizes for such units, especially in the range of small dwellings (approximately 100m² or less). The research argues that the possibility exists to select a range of settlement designs and density characteristics, along with behavioural intervention, to improve long-term viability and safety of government-funded or subsidised housing on dolomitic ground, in a different form from the typical freestanding housing type. The hierarchy of settlement types presented in this research were defined based on a set of variables that form the foundation of the vulnerability evaluation method: it recognises that no one settlement type is perfectly represented in the real world, with permutations and combinations of settlement types existing within suburbs and townships. The hierarchy was considered through an investigation of sample sites across Gauteng as well as some hypothetical settlement types.

The third argument focuses on the likelihood that climate change will cause dolomitic risks to become more severe. With climate change denoting rainfall variances, resultant changes in ground water levels may be expected. Any change (a rise or a fall) in ground water level may increase dolomitic hazard levels (Brackley, Rosewarne and Grady, 1986). Current South African mainstream publications such as the Climate Change Adaptation Plan (CoJ, 2009b) and the CoGTA guide entitled "Adapting South African cities and towns: A local government guide to climate change adaptation planning" (SEA, 2013) largely ignore the risk that ground water level changes may have in relation to an increased risk of doline and sinkhole formation. Therefore, a conscious effort is necessary to tighten planning instruments and increase awareness at community and government level, in relation to dolomite risks, in order to improve an understanding of the possible risks that cities may face because of climate change.

1.3.5 Conceptual framework

A theoretical or otherwise referred to as a conceptual framework is an intermediate theory that attempts to connect all aspects of inquiry of the research. It acts as a *map* imparting coherence to the empirical enquiry followed throughout the research (Maxwell, 2005). There is a variety of elements involved in the intersection of low-income settlement types and infrastructure (Figure 1.3.5) with dolomitic ground as a naturally occurring hazard (the orange block with associated bullet points). The intersection indirectly means that settlement vulnerability is characterised by elements such as loss of assets and injury or fatalities, especially in the case of low-income settlements. Dwelling- and infrastructure design and maintenance affect the risk of subsidence and sinkholes.

Figure 1.3.5 organically evolved during a research writing retreat hosted by the GCSRI. I initially wrote the research concepts and elements involved on pieces of loose paper, which I then shuffled around and arranged according to categories and themes related to my research topic. The element of human behaviour was added towards the end of the research process only. The framework relates to existing international and national conceptualisations of housing risk and vulnerability. These are referred to in Sections 2.2.2 and 2.2.3 of the literature review.

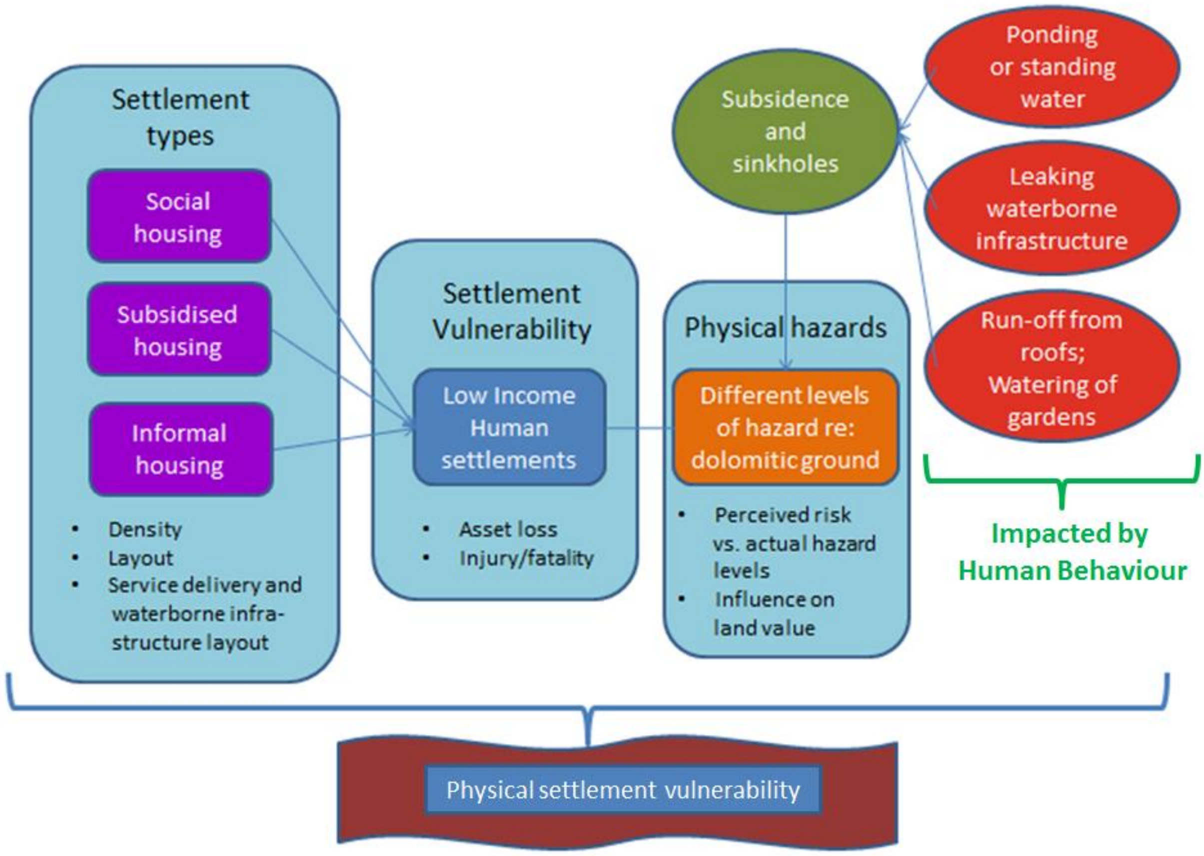

Figure 1.3.5: Conceptual framework of the research

The research promotes the importance of low-cost intervention as a measure to increase the resilience of poor households and improve their socio-economic conditions. Where housing is provided within the larger paradigm of asset-building through home ownership (as is the case with subsidised housing), the aim is to prevent these assets from losing value over time. This value-building process associated with vulnerability should be critically considered when laying settlements over marginalised land.

The interdisciplinary investigation and new knowledge that the research generated culminated in the presentation of a physical vulnerability evaluation tool. It could also be referred to as a *fragility* assessment tool (NORSAR, n.d.) that can be applied in the use of settlement development and upgrading decision making. The evaluation presents an image- and graphically rich and easy to comprehend decision support tool, which development planning officials and other specialists or educators may use to identify the potential applicability or suitability of a selected dominant low-income settlement class with regard to dolomitic ground of specific hazard classification. The tool thus addresses the multi-faceted issue of governance decision making in the face of marginalised land but more importantly, also highlights the need for expanding the application of physical vulnerability assessment techniques worldwide.

1.4 Purpose of the study

1.4.1 Contribution to science

Internationally, especially in developing countries, infrastructure and built environment choices are generally based on short-term horizons and immediate needs, while the infrastructure life generally spans many more years. This means that decisions made with regard to short-term goals have a significant lock-in effect in terms of enabling the transition of the built environment towards becoming more sustainable over time. Similarly, the cost of low-cost dwellings is often considered from an initial investment and development perspective (Davidson and Malloy, 2009) as opposed to also considering future maintenance requirements and reconstruction costs in the event of damage or destruction.

In addition to this global situation, with the allocation of freehold titles in South Africa the government absolves itself of future responsibility for housing that it develops or subsidises once the land has been transferred (with the exception of the National Home Builders Registration Council (NHBRC) warranty period) (Huchzermeyer, 2011a). Hereby, the costs of maintenance and the risk of subsidence transfers to the beneficiary. These beneficiaries may not necessarily understand the complexities of the risks they face. Although the NHBRC provides short-term warranties (from three months to five years) (NHBRC, n.d.(b)), with warranties focused mainly on protection in relation to building quality and not as much clarity in relation to pre-existing ground conditions, it demonstrates a responsive approach towards disaster risk management, as opposed to a DRR, prevention and mitigation tactic.

The contribution is a paradigmatic one that brings together geomorphological conditions, disaster risk assessments, built environment planning and socio-political decision making as they intersect through investigating a global city region shaped by extreme inequalities. The research speaks to a political context where Constitutional rights (Republic of South Africa, 1996) and people's *right to the city* (Lefebvre, Kofman and Lebas, 1996; Purcell, 2003; Harvey, 2008; Gorgens and van Donk, 2011) are often associated with mass political mobilisation (Harvey, 2012), as is the case with

Abahlali baseMjondolo (Gibson, 2008; Patel, 2013). This context is juxtaposed with financial, geological and engineering realities faced by city planners, often rendering officials unable to deal constructively with the issue of communities that live on marginalised land and opening up the decision making process for potential abuse. The research method and the incorporation of multiple viewpoints highlight the forces that drive the establishment of low-income settlements on marginalised land in often unsuitable forms as being typical of developing (or unevenly developing) country contexts.

1.4.2 Contribution to South African communities

Apart from the scientific focus, this research enlightens investigations into global change trends towards a more resilient humanity through consideration of specific settlement characteristics and types suited to dangerous ground. From a holistic perspective, the method presented in this research provides the opportunity to bring different schools of thought together, combining their skills and expertise towards a solution for unique situations where uniform approaches have to date not proven to reduce risk. In turn, it opens the door for a range of solutions to flow from the adaptation possible within each of the variables and each of the indicators, allowing specialists and practitioners to present their inputs and results to a global audience that may not necessarily have the background to otherwise interpret the findings effectively. By presenting technical complexities in a manner that makes logical as well as technical sense, the gap between technical specialists and the average citizenry could be bridged in an effort to change the behaviour of especially urban residents in order to reduce the risk of disaster that they may be exposed to. When the disaster risk is reduced less resources have to be channelled into re-building or re-storing when disasters strike. This in turn allows for not only a safer and happier humanity, but improved quality of life overall. This notion supports the principle that “it is essential that resources be used as efficiently as possible” (CSIR, 2000).

1.4.3 Research application

As far as I am aware, there has never before been an attempt to bring the diverse disciplines and practicalities that relate to each element that forms part of the debate in South Africa (for example, risk management, geology and geotechnical elements, and settlement theory) together in this manner to find a solution to a very pressing challenge. As I show throughout this thesis, this research subject has traditionally been fraught with difficulties of applying complex geotechnical theories and practicalities that exist in the physical environment to fast-changing and complex fluxes in human habitation.

In a time of intensified urbanisation, considering rural-urban interactions and livelihood strategies especially in the developing world (Tacoli, 2011), research of this nature opens up the scope for increased urban densification in the face of potentially dangerous living environments. The application of the method hopes to promote sustainability in urbanised living spaces by advancing our understanding of the interactions between the physical space we inhabit (such as geology and settlement type), and the way in which we maintain it (related to for example infrastructure design, management and operational behaviour). The evaluation method applied in this research could be utilised further than the field of dolomite and low-income human settlements; for example to determine the measure of sustainability that an existing or planned low-cost housing development portrays in relation to other types of hazards posed by geographically marginalised land. It has the potential to be extended to urban areas with similar characteristics worldwide, thereby supporting the knowledge base for sustainable development on a global scale.

1.5 Process, methods and materials

1.5.1 Research question

In the framework of this research, societal change over time (*temporality*) gives rise to different settlement patterns and community behaviour, which in turn affects how settlements respond to vulnerabilities related to their living environment (*spatiality*). With regard to human settlement on dolomitic ground, temporality reflects changes that may take place over time in relation to the perceived dangers associated with specific dolomite hazard classifications (such as when classifications across geographical space differ, depending on the hazard classification method based on accessibility of areas or budget-availability that may influence the drillhole sampling process during geotechnical assessments). Temporality also reflects changes in hazard evaluations when new or additional geotechnical knowledge or tools for sampling or assessment become available. Furthermore, there is a significant dependence on the management and maintenance of water-bearing services (for example, pipe leakages), and physical fluctuations such as changes in rainfall patterns and infiltration rates, or the lowering of the water table.

The major knowledge gap that this research proposes to bridge is that, especially in the face of major urban growth and densification with associated spatial development planning, there is no clearly defined method to consider the vulnerability of low-income settlements already located on the vast tracts of dolomitic ground that stretch across urban environments locally and internationally. In addition, where greenfield development takes place and geotechnical investigations are applicable, the socio-economic environment and community behaviour may in retrospect endanger low-income settlements that may originally have been considered and developed as *safe* – either via poor water infrastructure maintenance or through densification via backyard dwelling unit infill. The central research question is thus: "How can low-income human settlement types and related variables be considered during physical vulnerability assessment, in addition to existing dolomite hazard classification?" Sub-questions included:

- What different low-income settlements types can be identified?
- What variables influence low-income settlement vulnerability on dolomite beyond strict building regulations and guidelines?
- How do these variables relate to each other in terms of its perceived importance by specialists in the field of development on dolomite?

1.5.2 Underlying research assumptions

Initially, the research proposal identified an assumption that guided the research exploration: the assumption was that it is possible to identify and investigate characteristics of low-income settlements, and that their potential vulnerability can be established in relation to marginalised (that is, potentially dangerous) geographical locations, dolomitic ground in particular. Furthermore, the hypothesis was that a physical vulnerability assessment protocol, in the form of a vulnerability curve, could be defined which could enhance decision making when applying the existing dolomite hazard classification and development guidelines and regulations when investigating settlement relocation, development or upgrading scenarios. Thus, the notion existed that when viewing varying settlement characteristics and dolomite risk criteria collectively, from a purely technical perspective, the result could provide a supporting methodology when making developmental decisions. Such a tool would be an enabler of developmental and governmental policy making, enhancing the understanding of the impact that selected settlement development or upgrading choices may have in terms of long-term sustainable livelihoods and community stability. The application of the method would be of particular interest where densely populated urban areas occur or where settlements are located on potentially dangerous ground.

The mere provision of basic water and sanitation services significantly increases the potential for dissolution of soil and the subsequent formation of dolines and sinkholes. This is particularly true in an uncontrolled and unmonitored environment as is characteristic of informal settlements (Kleynhans, personal communication, 2012). In addition, such service provision, although enabling basic human needs to be met as stated by the Bill of Rights (Republic of South Africa, 1996), formalises and sanctions community exposure to increased disaster risk. The conundrum clearly highlights the opposing standpoints that form the core of the debates around basic service delivery, safe housing provision, sustainable development and what constitutes acceptable levels of "living with risk". The contribution to knowledge which the research provides is an addition to the growing body of literature addressing the broad understanding of the intersection between disaster risk and human settlement sustainability. Dolomite assessments currently interrogate only hazard levels.

The rationale of the proposed research is to investigate the risk of low-income settlement types on marginalised dolomitic ground, and propose an evaluation method that can be used to present elements in the risk equation, other than only hazard, in relation to dolomite. Thus, I aim to include elements of risk such as vulnerability countered by manageability and capacity, into the dolomite risk assessment. A complex set of factors in the form of indicators was combined into the evaluation process for it to add value as a decision support tool for government officials, planners, geologists and engineers alike, as well as for academic teaching purposes in a multitude of disciplines (for example Geo-Informatics, Disaster Risk Management, Geology and Engineering).

This process enhanced the knowledge and understanding present in the drive that currently is taking hold worldwide towards increasing the sustainability of human settlements. The physical vulnerability evaluation method could furthermore provide insight into the situation of different low-income settlement types, thereby potentially addressing some elements related to the creation of sustainable human settlements worldwide in the face of global change, including increased urbanisation and climate change. The evaluation method may also apply in *in-situ* upgrading of informal settlements to help determine what settlement or tenure type could be provided so as to enable such upgrading, rather than falling back on relocation as a solution (Huchzermeyer, 2011a). This would help unlock *in-situ* upgrading on what often is considered to be *unsuitable* land.

1.5.3 The aim and objectives of the research

The research aims to provide a basis for an improved understanding of the long-term sustainability implications of low-income settlement development or upgrading on dolomitic ground. It supports the reduction of human settlement vulnerability, with associated increased sustainability, while considering interventions that is not limited to hard infrastructure and technical mediation. In addition, the importance of the need to consider the repercussions of locking an urban region into a potentially unsustainable built environment trajectory is highlighted. In its totality, the research reflects on the sustainability of the urban environment with regard to global changes and local challenges.

The broad objectives of the study are:

- To compile spatial data of the selected marginalised land types, to support the thesis discussion;
- To investigate the characteristics of low-income settlement related to its design and density in correlation to dolomitic ground;
- To investigate methods of assessing physical vulnerability and presenting related research outputs;
- To establish the relative importance of criteria of vulnerability, manageability (such as municipal intervention) and capacity (of inhabitants) for low-income settlement types on dolomite; and
- To consider conditions that influence low-income settlement vulnerability on dolomitic ground as related to human behaviour, and determine the relevance thereof in decision making related to settlement development and/or upgrade.

Although the initial notion of my research was to develop a physical vulnerability curve on which to plot low-income settlement types, this proved ineffective. Instead, I applied a Multi Criteria Analysis (MCA) method called 'Analytic Hierarchy Process' (AHP) to allow for the analysis of the multiple, not always directly related, technical and non-technical criteria involved in the research question. The assessment protocol is based on variables that directly influence the physical vulnerability of low-income settlements on dolomite, with the resultant product enabling greater insight into the nuances of these settlements and the differences that developmental and upgrading decisions, as well as human behaviour may have on the sustainability of such settlements on dolomitic ground.

1.6 Outline of the thesis

When investigating residential development on dangerous ground, the challenge arises as to the delineation of the boundary of the research. There are many potential variables that may influence the physical vulnerability of such settlements, and when low-income settlements in particular are considered, complexities increase. In the light of these intricate relationships between the physical environment, human behaviour, policy and development guidelines and provision of basic services I constrain the research output to focus on the benefits it may hold with regard to ultimate DRR in the urban environment.

Chapter one of this thesis provide an overview of the development-on-dolomite debate in the context of South Africa and in particular in relation to the Gauteng Province and surrounding urbanised and peri-urban areas. The debate engages in particular low-income settlements, whose vulnerability to disaster risk related to the geological subsurface is under scrutiny. The problem statement, research questions, conceptual framework, research rationale and aim and objectives for the research was defined and elaborated on. The thesis content from here onwards probes literature, reality, sample sites and statistical outcomes towards the research conclusion. Chapter two follows a process of literature exploration and interrogation of the facts and factors that play a role in the vulnerability of low-income settlements on dolomite in the study area. Specific attention is given to disaster risk vulnerability in relation to low-income housing development, processes of low-income settlement upgrading, dolomite as a geological substrate that present a natural hazard, and technical responses to the risk it poses, in relation to low-income settlement types.

The research methodology, including research phases, each consisting of a number of steps, is set out in Chapter three. Phase one of the method involved the pre-feasibility investigation for the study, during which engagement with specialists in the debate, initial site visits and literature readings informed the research questions and assisted in defining the research focus areas. Phase two of the research method consisted of intensified field work, during which selected sites across Gauteng were visited a number of times to collect data and subsequently identify variables for settlement type characterisation and parameters for analytical assessment of vulnerability of these settlements on dolomite. Interviews and workshops with specialists continued during this research phase. The chapter also describes the statistical assessment process employed to evaluate the data that gathered during the course of the research using the Analytic Hierarchy Process (AHP), a multi criteria analysis tool.

Chapter four considers low-income settlement types and categorises these in the context of the study area and dolomitic ground. The settlements investigated during the course of the study are identified and described, and the parameters that influence disaster risk on dolomitic ground are designated and explained. These parameters or variables were used to construct a questionnaire that was employed to obtain information from specialists in the development-on-dolomite debate.

The information was then captured, normalised and analysed using AHP software. Chapter five presents the research results and contemplates the outcomes of the assessment.

In light of the research method and outcomes, chapter six contemplates the implication and relevance thereof in terms of the study and the multiple disciplines involved in the research. Challenges encountered and the relevance of these challenges are embellished on. The chapter also reflects on the overall research objectives, process and outcome and provide a glimpse into the way forward for future ongoing research in this regard.

CHAPTER 2: LITERATURE REVIEW: UNDERSTANDING THE PAST AND EXPLORING THE PRESENT

2.1 Introduction

In 2014, an estimated 828 million people globally resided in informal settlements and slum conditions (WHO, n.d.(b)). These settlements are often located on unsafe or less than ideal ground such as alongside or on waste sites, river banks (Ngie, 2012; Weakly, 2013), steep slopes and other undesirable areas (WHO, n.d.(b)). Climate change is likely to exaggerate the exposure of the inhabitants of such areas to potentially dangerous conditions, thus magnifying "the brutal urban forces that have pushed the poor to the shadows of life" (Nenweli, personal communication, 2012). Where low-income communities are wedged in marginal spaces across increasingly densifying urban areas, in particular in developing regions of the world, the incidence of disaster is therefore likely to increase. The consequences of disaster is also often more severe than in wealthier urban areas, where disaster risk prevention, mitigation and insurance is more prevalent.

In Africa, where political, social and economic shocks are wide-spread (Pelling and Wisner, 2009), high levels of urbanisation significantly decrease the resilience of human settlements to cope with disasters. In this context, resilience can be defined as the ability to "bounce back or return to normal functioning after adversity" (Headington Institute, n.d.). With the increasing complexity of urban influx, strained management capacity, and with minimal resources available to build human security, local governments are considered a key actor in decreasing urban risk and increasing urban resilience (Pelling and Wisner, 2009). However, associations between urban risk and resilience have in some instances been described as opposing. For example, Shumow, Vandell and Posner (1999) noted that urban integration of low-income areas (with neighbouring areas) fostered risk as opposed to resilience, thereby decreasing the level of resilience that such urban areas could achieve. This points to behavioural consideration when considering design and implementation of interventions in urban risk and resilience.

Recent research with regard to urban risk and resilience and focuses increasingly on multi-disciplinary initiatives towards exploring sustainable urban futures (Singh, 2015; Mauser and Prasch, 2016). In the same vein, UN-Habitat (2012) puts forward a rationale that incorporates:

- the built environment;

- physical and social infrastructure;
- the natural environment;
- the administration of land;
- urban economic capacity; and
- vigorous participation by ordinary citizens (Pelling and Wisner, 2009).

Each of these elements are functional as well as primary to the capacity of urban profiles that increase resilience and thereby promote disaster risk reduction (*ibid*). Thus, the urban environment is deemed to function as a system, as opposed to individual components to be addressed separately. Unfortunately low-income communities often lack not only one or two, but in some cases most or all of the listed elements above, thus facing an almost impossible situation of ever-decreasing resilience and facing increasing levels of risk.

This situation of vulnerability-upon-vulnerability of poor communities is likely to "push their lives into a permanent state of emergency" (Nenweli, personal communication, 2012), with little hope of extraction from their physical location or social position of residence. This chapter provides a literature review regarding research and multiple disciplinary approaches involved in the low-income settlement development-on-dolomite debate. The review includes disaster risk assessment, decision making processes related to development of residential settlements, sustainable development in relation to settlement vulnerability, and dolomitic ground as a specific hazard that intersects with human settlements.

2.2 Evaluating disaster risk

"The past few decades have witnessed the emergence of a new field of research concerned with assessing and managing risks to health, safety, and the environment."

(Glickman and Gough, 1995: 3)

2.2.1 Disaster risk management

According to the South African Disaster Management Act (Act 57 of 2002) and reflected on similarly by the United Nations International Strategy for Disaster Reduction (UNISDR, 2009) a disaster can be classified as an immediate or a slow-onset event which is beyond the capacity of local resources to handle (Republic of South Africa, 2002). The risk that stems from such disaster risk is the result of the interaction of hazards and vulnerabilities, countered by measures to manage these hazards and vulnerabilities (UNISDR, 2009). The calculation of disaster risk can be presented as Risk (R) being the result of the mathematical calculation of a Hazard (H) multiplied with Vulnerability (V), in turn being divided by the multiplication of Manageability (M) and Capacity (C) [R = (HxV)/(MxC)].

Man-made as well as natural hazards only pose a threat to a receptor of impact due to the existence of a vulnerability of some kind (Erickson, 2006). Thus, if the hazard can be known, monitored or controlled and the vulnerability reduced or removed, the impact of disaster may be lessened or removed in totality. Unfortunately, total removal of a hazard or vulnerability is often impossible, and therefore an acceptable level of risk (Fell, 1994) needs to be defined and agreed to by all parties involved. DRR therefore refers to all the elements necessary to minimise vulnerabilities and disaster risks throughout a society or geographical area. It includes the core DRR principles of prevention, mitigation and preparedness (Republic of South Africa, 2005). My research investigates potential options that may be included when addressing vulnerability of settlements on dolomite by considering a combination of approaches that go beyond geotechnical science alone.

The frequency, intensity and spatial distribution of natural hazards play a role in the estimation of risk and classification of hazard perimeters, hotspots or zonings (Schöning, 1990; UNISDR, 2014). Along with the vulnerability and potential variability in manageability of hazards, the level of risk changes over time. Thus, the risk may potentially never be eliminated and the objective for risk reduction is therefore to reduce the risk to an *acceptable* or *tolerable* level (Morgan, 1995b). Ultimately, the management of dolomite risk in relation to human settlements depends on the level of risk that is acceptable to the role players in the situation. Currently, stakeholders in the development-on-dolomite debate, especially in South Africa have different understandings and interpretations of the risk and acceptable tolerance levels (GCRO, 2011c). In addition, the position of Government does not consider the need for risk acceptance or taking of responsibility for risk by communities themselves even when they choose to live in potentially dangerous locations. For example, Habitat III National Report (Republic of South Africa, 2014) does not mention the consideration of risk acceptance or responsibility as an option to include in DRR strategies. This lack of integration of stakeholder engagement and subsequent acceptance of living with certain levels of risk reduces the opportunities to reduce disaster risk and disaster impacts in society.

According to the South African Department of Provincial and Local Government the term “disaster risk management” refers to integrated multi-sectoral and multidisciplinary administrative, organisational and operational processes and capacities aimed at lessening the impacts of natural hazards and related environmental, technological and biological disasters (Republic of South Africa, 2005). As noted in Chapter 1, the disaster management continuum (also referred to as the 'Disaster Cycle') includes:

a) identification of risk and risk assessment;
b) preventing or reducing the risk of disasters;
c) mitigating the severity or consequences of disasters;
d) emergency preparedness and early warning;
e) rapid and effective response to disasters; and
f) post-disaster recovery and rehabilitation (Republic of South Africa, 2002).

This study focuses in particular on the prevention and mitigation elements in the continuum and distinguishes between social and technical perspectives on vulnerability.

Physical vulnerability is often scenario-specific, as highlighted by Fell (1994) and Uzielli, Nadim, Lacasse and Kaynia (2008). Thus, technical risk reduction perspectives regarding human settlements on dangerous ground usually pay attention to non-social elements of the risk equation. During such studies, assumptions are based on increased external management, design, planning, and infrastructural components of settlements. However, the behaviour and influence of individuals within communities living on dangerous ground is not included. I hypothesise that risk reduction may be improved if the latter engagement is included. Such reduction could be used to augment the current regulatory environment that focuses primarily on geotechnical investigation, infrastructure and building guidelines based on dolomite hazard levels.

2.2.2 Disaster risk evaluation for low-income settlements

A substantial body of research proposes a variety of methods to conduct disaster risk, hazard and vulnerability assessments and evaluation of human settlement resilience. Methods range from general natural vulnerability assessment methods such as those presented by Adger (2006) and van Westen and Kingma (2008), to specific natural hazard vulnerability assessment such as flood assessment methods by Sagala (2006) which can be adapted to other natural hazard types, and Uzielli *et al.* (2008) who propose a specific method for geotechnical landslide assessment. Brody, Zahran, Vedlitz and Grover (2008) consider the matter of public perception quantification in physical vulnerability considerations – a deliberation that is of interest in the case of development-on-dolomite due to the current uncertainty in awareness by the public regarding the risk that living on dolomite holds. Some of these methods are compiled into international and local guidelines such as the Pan American Health Organisations' guidelines for vulnerability analysis in terms of water and sanitation systems (PAHO, 1998) and the South African National Disaster Management Framework (Republic of South Africa, 2005). An increasing number of methods apply the use of Geographic Information Systems (GIS) to map, overlay and spatially analyse elements involved in assessments, such as the dolomite disaster risk assessment methodology applied by Coetzee *et al.* (2010) and remote sensing application presented by Busgeeth, Brits and Whisken (2008). Others propose risk quantification by plotting graphs or designing matrixes or indexes in an attempt to normalise and logically explain the elements of risk (Douglas, 2007). Although these methods interrogate the formal and informally built environment to provide insight into the physical, social and environmental risks associated with natural hazards and its delineation, there is little interrogation of the intersection of geotechnical hazards with low-income areas and informal settlements.

To understand risk, hazards and vulnerability in terms of the tools and methods available to assess it, the meaning of these terms should be understood: Hazards denote a source of potential harm and/or injury or the level of potential harm and/or injury itself (Jha, Barenstein, Phelps, Pittet and Sena, 2010). This explanation of what a hazard is often results in the confusion of what causes a hazard and what the effect of a hazard is. The cause of a hazard may even be directly related to the vulnerability of those affected, and the hazard may as a resultant effect even increase the vulnerability. Thus, in order to differentiate risk from a hazard it should be noted that a hazard always denotes the possibility or probability of a specific severity, spatial distribution and return period or frequency (Erickson, 2006). Vulnerability refers to factors that weaken the ability of people or an environment to cope with hazardous events (GCS, n.d.), and is affected by the level of sustainability that exists within environments, individual households and communities. In this function, dolomitic ground presents a natural hazard affected by geological characteristics and human interactions. In order to understand the risk that this hazard poses, it is important to understand the vulnerable settlements.

Informal settlements and backyard structures do not conform to regulatory standards and certification requirements of planning authorities (Heath, personal communication, 2011). This situation creates difficulty when the riskiness of low-income and informal structures is evaluated using normalised matrixes or rules in relation to physical disaster hazards, as is the case with, for example, standards for development on dolomite (SABS, 2012). Risk evaluation criteria for disaster assessment purposes are suited to situations where regulations and standards are applied; however the site layout, site investigation (if any), building design and building materials of these settlements often do not conform to standard features and makes risk assessment particularly challenging (Heath, personal communication, 2011). For example, dwellings made from cardboard, wood or chipboard, metal sheeting or shipping containers are excluded from the ambit of the building regulations and standards guiding development on dolomite, and unless the owner of a residential stand formally applies for permission to build and submit plans for the construction of a backyard dwelling or "granny flat", there is little control over such development or upgrading. Even in cases where vulnerability assessments consider low-income dwellings, as presented by Kirsten *et al.* (2009), the research does not take into account the vast range of potential settlement types or structures that may be encountered outside of the formal building construction domain.

Although municipal requirements attempt management of new urban development or upgrading of existing developments on dolomite, for example via the "Site Specific Dolomite Risk Management Program" (DRMP) which the City of Tshwane introduced, the programme remains limited to formal development applications (CoT, n.d.). With increased calls by communities and officials for of *in-situ* upgrading of informal settlements (Kornienko, 2013; Republic of South Africa, 2014: 65) and relentless proliferation of backyard structures even in formal low-income settlements (Martin, 2014), there is a need to consider a possible settlement hierarchy or settlement type definition for low-income human settlements within the context of dolomite disaster risk.

2.2.3 Integration of disaster risk management with housing policy in South Africa

Risk assessment involves evaluating the amount and magnitude of risk to which an environment or community is exposed (Morgan, 1995a). Hazard rating, hazard level determination and hazard zoning play an important role in the first phase of the disaster management continuum (Strydom, 2003). When vulnerable receptors intersect with hazards, a risk can be assessed. Disaster risk assessment is especially useful in urban development planning projects where the planner or decision maker has control over the development area and the planning process right from the start - from pre-feasibility or conceptual investigations and site selection, until implementation and even operation and regulation of maintenance. Where settlements are established *before* their hazard exposure is investigated and determined, difficulties arise when making decisions regarding implementing risk-mitigation measures (which may include relocation) or service delivery upgrades.

The right to housing is the most adjudicated socio-economic right before the Constitutional Court (Dawson and McLaren, 2014). As such, the need to consider "retrogressive measures and decision making" (*ibid.:* 15) as part of "reasonable policy" (*ibid.:* 16) during a process of "progressive realization" (*ibid.:* 16) while ensuring "meaningful engagement" with communities (*ibid.*: 16) is increasingly emphasised. The key findings and obligations that courts place on the state and its agents during the housing debate require significant consideration since it stretch much further than building standards and technical regulations. However, the realisation of a right to adequate housing (ICESCR, 1976; Republic of South Africa, 1996) does not specify or deliberate the level of disaster risk that may be involved or accepted by residents and officials alike, during site selection for development or upgrading.

The International Covenant on Economic, Social and Cultural Rights (ICESCR) (1976) to which South Africa is signatory, stipulates key criteria for what constitutes adequate housing, but none of the criteria mentioned consider disaster risk. Dawson and McLaren (2014: 17) also list aspects to assess housing typologies in South Africa in terms of adequacy of housing, but again no reference is made to disaster risk, exposure to hazard, vulnerability or resilience. Although the National Development Plan (NDP) (The Presidency, 2011; Republic of South Africa, 2013a) broadly considers disaster risk, its vision does not include consideration of the *acceptance* of risk. Outcome 8 of the Human Settlements Medium Term Strategic Framework (MTSF) for 2014 – 2019 (as referred to in Dawson and McLaren, 2014) which aims to operationalise the NDP also does not integrate disaster risk acceptance levels in its consideration of adequate housing. Although reference is thus made to adequate housing, better living environments, affordable services and spatial targeting, the notion of a community taking responsibility for or accepting certain conditions or levels of disaster risk in order to gain access to certain socio-economic or related benefits remains unaddressed.

The principles reflected in policies and legislation regarding housing in South Africa include the Reconstruction and Development Programme (RDP) (Mandela, 1994; Lodge, 2003), The Housing Act, No 107 of 1997 (Republic of South Africa, 1997), the White Paper on Housing (NDH, 1994), The People's Housing Process (1998), The revised National Housing Code (DoHS, 2009), the Social Housing Policy (2005), the Inclusionary Housing Policy (2007), Breaking New Ground (BNG) (HDA, 2004) and Integrated Development Plans (IDP) (ETU, n.d.). These approaches strive towards defining, refining and achieving acceptable living conditions for the citizens of the country. In particular, the RDP is a socio-economic framework based on human rights, and which has as one of its first priorities to provide housing for the homeless (Mandela, 1994). The BNG takes the RDP further to

denote a comprehensive plan for the development of sustainable human settlements in the country (Tissington, 2010) and the IDP is related to these as a strategic development plan that guides the activities, budget priorities and decisions of a municipality for a period of 5 years at a time, in terms of Chapter 5 of the Municipal Structures Act, No 33 of 2000 (WLM, 2010; CoCT, n.d.).
Within this plethora of Acts, guidelines and policies that exist regarding housing development, the only clear direction regarding disaster-related safety specifications comes via the environmental sector. In this regard, the waste management sector set minimum requirements for hazardous and landfill waste, aiming that "the present generation should not leave the future generation with a poor safety legacy" or with solutions that impose an unreasonable risk or cost to future generations (DWAF, 1998a,b). This view requires the identification of long-term solutions that can be implemented at an acceptable level of risk as well as acceptable cost, within the approach of Best Practicable Environmental Option (BPEO) and Best Available Technology Not Entailing Excessive Cost (BATNEEC) (DWAF, 1998b). These principles are reflected in the disaster management continuum, to identify, prevent and minimise disaster risk. Considering this current lack of a vision towards implementation of risk reduction-based housing development, the country's housing policy and implementation may benefit from an approach where risk reduction and risk acceptance forms an integrated part of the policy and planning process.

The legal framework for planning in South Africa is governed first of all by the Constitution of South Africa (1996), as mentioned earlier. Thereafter, the Municipal Systems Act No 32 of 2000 (Republic of South Africa, 2000) specifies the development and implementation of Integrated Development Plans, encompassing Spatial Development Frameworks and making provision for guidelines for land use systems in municipalities (DRDLR, n.d.). In addition, approved planning legislation such as the Development Facilitation Act (No 67 of 1995) emphasises a planning framework and process based on need, interaction and community participation (*ibid*; CSIR, n.d.(b)). Another set of legislation, namely the Less Formal Township Establishment Act No 113 of 1991 provides for shortened procedures for township establishment, less formal forms of residential settlement and regulating the use of land by tribal communities for communal forms of residential settlement (DRDLR, n.d.). These are all national Acts, guiding settlement design and development countrywide. On provincial level there are Planning Acts and Ordinances that reflect to a large degree pre-1994 legislation and land use management schemes (*ibid*). In Gauteng there are two particular sets of regulation that govern land planning within the national setting: the

- Transvaal Town Planning and Townships Ordinance No 15 of 1986; and
- Gauteng Planning and Development Act 3 of 2003.

These aforementioned formal urban planning systems are governed by processes that consider local spatial settings and interactions, as well as municipal administrative and budgetary processes. The spatial frameworks and plans drawn up in this manner for most urban areas are not only open for public scrutiny, but there are active engagements with communities at defined times during the development of these planning tools. As such, the current trend in planning is based on the satisfaction of fundamental human needs (CSIR, n.d.(b)) (often inferred as "rights"). As part of this process, there is a move away from "blueprint planning" as well as a shift away from non-participation and token processes to a more inclusive and interactive planning process (*ibid*). These processes aim to harness the wealth of local knowledge as well as assist in official understanding of community needs, requirements, local conditions and relationships (*ibid*).

In addition to the formal and participatory processes, the nature of South African housing policy is such that current or new planning legislation does not exclude existing planning legislation and reference to previous legislation such as guide plans, zoning schemes and ordinances (*ibid*). An example of this is where the Spatial Land Use Management Act (SPLUMA) (Republic of South Africa, 2013b) provides an additional land management tool, focussing on integrated urban development framework establishment and aiming among others to improve and standardise land planning.

In addition to these ones mentioned above, there is a plethora of Acts, Bills, White papers and guidelines that reflect on sectors within land management and settlement design and development, including for example water resources and environmental management. As such, the Disaster Management Act No 57 of 2002 (Republic of South Africa, 2002) and the Disaster Management Framework of 2005 (Republic of South Africa, 2005) fulfils a function to place responsibility on South African Government, organisations and industries to cater for, among others the provision of integrated and co-ordinated disaster management policies that focus on preventing or reducing the risk of disasters and mitigating the severity of disasters. The regulations focus on development of local municipal, district and provincial disaster management plans that are founded on the often unique spatial elements of the area which it is designed for. Risk assessment is thus intended to play an important role in the development planning, DRR and disaster mitigation process. Informed decisions are therefore also required early in the development planning process to ensure that DRR measures are financially viable, effective and appropriate.

However, as alluded to earlier, there is an uncertain and unstated linkage between housing policy and the right to adequate housing *versus* DRR. The question arises as to whether a crossing of the divide between human rights and acceptance of risk in the development-on-dolomite debate could moderate the current conflict.

Ultimately, few geographical locations on earth are entirely without any risk, and therefore it is the *level of acceptable risk* and thus also *acceptance of a certain level of responsibility* for that risk that remains uncontended and undebated when development or upgrading of low-income settlements are considered. It is important that the intersection between housing policy and regional planning, technical and engineering standards and guidelines, and disaster risk management including acceptance of the risk and responsibility for risk management is considered.

2.3 On risky ground: unpacking the debate

2.3.1 Geology in relation to human habitation

Physical disaster risk from the perspective of the environmental landscape considers hazards to be forces of nature (Blaikie, Cannon, Davis and Wisner, 1994, Smith, 2004). These hazards existed for millions of years and were the drivers that shaped the Earth (Dekens, 2007). Geological processes in particular continue unabated regardless of human existence or interaction (Galavovic and Smith, 2014). Where the changes are prominent in terms of frequency and severity, the disaster risk is higher (Strydom, 2003). Thus, humans should consider their vulnerability to so-called "natural" disasters in relation to their right of choice to inhabit locations where the environmental landscape is invariably changing – whether though landslides, earthquakes or sinkholes as examples. Ultimately, the ability of societies to mitigate the impacts that Earth processes have on them depends on their capability to adapt their living environment, technology and infrastructure to withstand or change along with nature. In addition, their behaviour and relationship with natural hazards define their level of exposure and govern their resilience, and ultimately their safety.

In an effort to improve understanding of human habitation in relation to ground-based disaster risk, geologists and geotechnical engineers investigate the interaction of long-term geomorphological processes with relatively short-term human intervention. Urbanisation patterns and infrastructure development forms part of the process (Gogu and Dassargues, 2000; Kaufmann and Quinif, 2002; Zhou, Beck and Adams, 2003) while rules and guidelines are implemented in an attempt to manage the disaster risks incurred. Research in the ground-based risk domain remains largely explanatory (Buttrick and van Schalkwyk, 1998; Trollip, 2006; Galve *et al.*, 2008; Oosthuizen, 2013) while the influence of developmental behaviour on the resultant level of risk remain limited (Brody *et al.*, 2008). The result is a body of research regarding potential and probable disaster occurrences and causes based on reflections *vis-à-vis* understanding of urbanisation and geological processes, without integrating the understanding or perception and risk-related behaviour of communities who inhabit dangerous areas. Rapidly changing urbanisation patterns and the relatively uncertain influence of climate change further restricts pro-active engagement with the research content, and urban development policy thus remains largely devoid of association with human behaviour (*ibid.*).

As stated in Chapter one (Sub-section 1.2.1), the Gauteng dolomite represents one of the oldest karst environments on Earth (Health, personal communication, 2011a). Influences from early-world meteorite strikes formed craters such as the Vredefort dome and Tshwane impact crater, and tilted the geological strata in the study area. Apart from revealing the gold bearing seams that lead to settlement in Gauteng, geological layers of varying erosion sensitivity were exposed. When considering human settlement patterns in the study region, from as far back as the Stone Age (JCP, 2008) the speed and impact of geological change is insignificant. Instead, it is the large-scale settlement of communities on this land in recent history that caused increased exposure to disaster risk. With relentless urbanisation, the amplification of interference with geologic strata intensifies. Where dolomite is present, the intensification of water ingress associated with urban development dissolves the soil at faster rates than natural processes would do (Kleynhans, personal communication, 2012) and exposes residents to disaster risk which would otherwise not be as concerning if dwelling densities were lower (*ibid.*). The exposure of communities to "natural" dolomite hazard risk is therefore exaggerated, while the regulatory framework remains constrained to hard or 'grey' infrastructure interventions, standards and guidelines in an attempt to reduce the disaster risk.

2.3.2 Development approaches

Technical evaluation of dolomitic ground and the resultant application of development guidelines, standards and risk management programmes dominate the development-on-dolomite debate in South Africa (GCRO, 2011d). Associated and often costly engineering solutions may reduce the risk of subsidence or sinkholes where developmental necessities exist (*ibid.*), and where funding is available, significant intervention towards settlement development and upgrading is possible (Health, 2011). However, practical development implementation is constrained by financial resource availability. In addition, face-to-face stakeholder interventions require additional time and resources.

While Environmental Impact Assessments (EIA), Public Participation Processes (PPP) and similar engaging practices are geared towards ensuring integration of knowledge between disciplines during development, (Webler, Kastenholz, and Renn, 1996; Hartley and Wood, 2006; O'Faircheallaigh, 2010), the consideration of behavioural intervention requires additional effort during the development process (Pelling and Wisner, 2009; Fischhoff, 2013). Identification of the drivers and enablers of behavioural change that guide community adaptation to risky living environments is needed (IFRC, 2011). Bradley, McFarland and Clarke (2014) investigated cases of disaster risk communication intervention and analysed the reported effectiveness. Of the cases considered, *all* of the studies falling into the *mitigation and preparedness* category reported that the interventions were effective at the least to some extent. On the other hand, in the cases where *response*- and *recovery* interventions were applied, not only did the studies report little behavioural change, but some reported no change at all and one even showed a negative post-intervention behavioural change. Their research highlights the need to intervene in disaster risk awareness programmes *before* development and upgrading takes place, in order to change community behaviour and increase effectiveness.

Behaviour-supported development solutions remain elusive as communities and authorities continue to wrestle with resource constraints that tie them into demand-driven infrastructural-focussed procedures that follow proven technical pathways (CNT, 2010). In addition to the difficulties that communities face in understanding the technical complexities of building on dangerous ground, in-depth behavioural or societal mediations are time-consuming, costly and complex to undertake (Lupala, 2002; Involve, 2005). The reality of development-on-dolomite thus continues to revolve around technical interventions and so-called hard- or grey infrastructure solutions (GCRO, 2011c). Hard and grey infrastructure such as piping, steel reinforcement and foundation design and construction remains firmly in the structural, geotechnical and civil engineering domain and thus invariable exclude behavioural interventions towards DRR. Development standards are well suited to implement in formally structured settlements (Mdakane and van den Bergh, 2012). However, when settlement types do not conform to a recognised or formally planned shape and form and do not follow the formal development application processes applicable, the relevance of infrastructure-based DRR measures become contested.

Internationally, city planners grapple with the need to design spaces that serve not only specific purpose, but allow enhanced performance and networking, or double-up to serve a variety of urban system functions (Siöström and Sternudd, 2011; Wang and Gao, 2012). The complexities of urban

component interaction in land use planning and development intensifies in areas characterised by high levels of social inequality and spatial disparity (Hui, 2011). This makes the ideal of improved urban networking and enhanced performance of the city scheme difficult to achieve.
In developing countries, populated cities face continued growth in both spatial extent and concentration (Jenks and Burgess, 2000). These heterogeneous and complex urban systems are often characterised by vast social inequalities across the cityscape (*ibid.*). In an effort to address socio-spatial inequalities and settlement networking solutions that connect these fast-sprawling and densifying cities, planners grapple with policy constraints and environmental pressures (Harrison, Todes and Watson, 2008).

The socio-political, economic, cultural and physical nature of the city, as well as historical development patterns focus development corridors and location of land use clusters into particular forms, based on what is formerly directed and physically possible (Halpern, 1995; Fainstein, 1999). The need to balance connectivity, functionality and safety often proves difficult in light of the needs and demands of a growing urban population. In addition, when informal, unplanned and unregulated settlement development occur, planners and engineers alike struggle to ensure continuity towards implementing well-intended plans and official standards (GCRO, 2011c).

2.3.3 Participation during decision making

As mentioned before, formal construction on dolomitic ground requires implementation of stringent measures in terms of site investigation, building standards and maintenance (CGS, n.d.(a); CoT, n.d.; SABS, 2012) designed to reduce disaster risk. As a result, the process is costly and introduces options of avoidance of development on dolomite as opposed to incurring costs that would not be applicable when developing on non-dolomitic ground (Huchzermeyer, 2011a). In this configuration, the argument supports low-risk low-resource decision making. The same argument also supports decisions opting for relocation of, for example, informal settlements, rather than *in-situ* upgrading or provision of wet services (*ibid.*). This manner in which the decision making is approached causes social conflict, especially where other development is subsequently approved in the same location or close to where informal settlements previously existed (Hathorn, personal communication, 2012).

In addition to social conflict, financial affordability, technical intricacies and an inability to manoeuvre large drilling equipment in and around existing densely spaced dwelling units add to the complexity of issues surrounding settlement upgrading on dolomite (Kleynhans, personal communication, 2012). Low-income communities are usually unaware of these technical requirements which approved dwellings are subjected to on dolomite (GCRO, 2012a). The situation is often exacerbated by lack of engagement via participative processes (GCRO, 2013) and suspicion regarding the reasons given for decisions made (GCRO, 2012a). This is not to say that dolomite has not been used in the past as a pretext when informal settlements required relocation, nor should the validity of community suspicion be questioned. The Bapsfontein relocation referred to in Chapter one (Pheko v EMM, 2011a, b), provides an example where community suspicion is compelling, since as mentioned, the children are being transported in busses over 30km to the Primary School that remains in the area from which the community have been evicted.

Regardless of the appropriateness of the action, the question arises as to whether information regarding, for example, the reason for school premises or building foundations being considered safe in terms of dolomite disaster risk have been shared effectively with or understood by community members. The result of the lack of sharing of information in an effective manner highlights a disjuncture where low-income communities are unable to interface constructively with technical reasoning or even Court decisions and *vice versa*. When a community is intellectually isolated in this manner it fuels their concerns that dolomitic hazard levels suffice as an excuse to remove them from a geographical location due to their presence being undesirable by surrounding suburbs. (Huchzermeyer, 2011a; GCRO, 2012a). This perception raises the need for significantly increased participatory processes and a focus on awareness of dolomitic disaster risk.

Even though development strategies require sharing of information and public participation (Webler *et al.*, 1996; Hartley and Wood, 2006; O'Faircheallaigh, 2010), low-income communities often are excluded from the actual decision making methodology (GCRO, 2013). As such, they do not engage significantly in behavioural risk-reduction strategies, nor is their potential willingness to live with a certain level of disaster risk taken into account. Since there is no imposition in the development-on-dolomite regulatory framework that forces public participation processes to consider DRR measures and options for risk acceptance (Kent, 2005), the participative strategies remain superficial. Although information sharing with communities is included in development procedures, the lack of engagement focussing on DRR in particular infringes on elements of the Hyogo Framework for Action 2005 – 2015: Building the Resilience of Nations and Communities to Disasters (HFA) to which South Africa is signatory (UNISDR, 2005). In particular, Priorities 2, 3 and 5 of the HFA are applicable, namely:

- Priority 2 that focuses on identification, access and monitoring of disaster risks and enhancement of early warning systems;
- Priority 3 which revolves around the use of knowledge, innovation and education to "build a culture of safety and resilience at all levels" and places "a legal obligation on the State" to provide access to information to populations at risk (*ibid.*). This includes the raising of awareness and empowerment of communities to "build (their own) resilience to disasters" through in-depth understanding, as opposed to mere information distribution; and
- Priority 5, requiring the strengthening of "disaster preparedness for effective response at all levels" (*ibid.*). This inclusion raises the importance of accountability mechanisms that take cognisance of a need for public responsibility at an individual and community level.

On 18 March 2015, the Sendai Framework for Disaster Risk Reduction: 2015 – 2030 was adopted at the Third UN World Conference held in Sendai, Japan. South Africa is also signatory to this successor instrument to the HFA and therefore the following priorities all have a bearing on the South African approach towards DRR:

- Priority 1: Understanding disaster risk;
- Priority 2: Strengthening disaster risk governance to manage disaster risk;
- Priority 3: Investing in disaster risk reduction for resilience; and
- Priority 4: Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction.

The Frameworks set the baseline for considerations regarding disaster risk management and are therefore expected to find its way increasingly into regulations and guideline documents at Provincial and Municipal level. In addition, human rights law requires Governments to present how DRR fits into the overall development strategy of a country (WaterLex, 2011). The notion denotes a measure of choice between levels of risk faced *versus* location to live on. Of course, associated responsibility and acceptance of certain levels of living with the risk is required. With the emergence of mixed-housing developments (Osman and Herthogs, 2010), the right of choice raises challenges for integration and management of acceptance of levels for disaster risk between different income groups who are bound to share the same cityscape.

2.3.4 The influences of practicalities and perception in decision making

"The Gauteng government could, in a desperate move,
build houses on land deemed unsuitable for construction of homes."
(Nhlabathi and Xaba, 2015: 4)

Worldwide, low-income communities have difficulty accessing resources and support for development, upgrading and service delivery (Govender, Barnes and Pieper, 2011). In addition, information regarding hazards that may affect their livelihood, health and safety is slow to reach them via official channels (Bradley *et al*., 2014; Kheva, personal communication, 2014). Where information does reach them, the specific content of hazards may in some instances be poorly understood (*ibid.*). Occasions where dolomite risk was explained during intervention via a legal and geotechnical awareness platform, resulting in individual behavioural change is uncommon (Bradley *et al*., 2014). The disjuncture between settlement type, community behaviour, geotechnical engineering, urban planning and judicial language creates a barrier to community engagement in disaster risk management and risk reduction. Increased community awareness, individual knowledge and household acceptance of disaster risk are therefore desired. Creating such understanding and inducing behavioural changes is, however, a challenging task (Heath, personal communication, 2011).

In the case of low-income settlement development or upgrading on dolomite, the task is especially daunting due to the highly technical nature of the information involved (Coetzee, van Niekerk and Annandale, 2010). The other aspect to consider is that of vulnerability, poverty and the real absence of alternatives. It is near impossible to set up a new informal settlement in a bottom-up fashion away from risky dolomitic land (Huchzermeyer, personal communication, 2015). Thus, it is recognised that knowledge sharing and awareness of risk will not solve the dilemma on its own.

While greenfield settlement development on dolomite carefully considers housing development policy, spatial development plans and regulatory standards for development on dolomite, the upgrading of existing settlements is unable to undergo the same processes. Greenfield developments on dolomite benefit from settlement design, construction and urban planning strategies that take into account frontward knowledge regarding hazard levels (Heath, personal communication, 2011). When low-income or informal settlements require post-establishment upgrading and wet services, reactive engineering interventions challenge DRR options. As mentioned earlier, it is often impossible to manoeuvre drilling machines in-between established dwellings, leading to limited application of exploratory ground assessments. Thus, inadequate raw data is available to estimate the dolomite hazard level (*ibid.*) and additional restraint is applied to allow for the unknown hazard potential and severity.

Even when geotechnical investigations determine substrata characteristics, limited policy directions exist to help deal with the variety of low-income settlement types encountered. The level of informality of dwelling construction that is prevalent in low-income settlements (Brite, n.d.; Lupala, 2002; Busgeeth *et al*., 2008) presents challenges since there is little common form applicable to address the vast differences encountered between and even within settlements.

Regular investigation and monitoring programmes are key to reducing disaster risk and promoting safety margins on dolomite (Kleynhans, personal communication, 2012). However, there are no requirements for backyard- and informal dwellings built on potentially dangerous ground (SABS 2012) since it is not subject to formal approval processes. Even though the Upgrading of Informal Settlements Programme and approach to development of sustainable human settlements by means of South Africa's National Housing Code (DoHS, 2009) include consideration of land rehabilitation for purposes of allowing formalisation of previously informal settlements, the measures excludes dolomitic ground (*ibid.*). Thus, incremental upgrading programmes designed for informal settlement improvement remains largely out of reach for the majority of informal and backyard dwellings already built on dolomitic land. The situation results on lengthy case-by-case decision making for those settlements already established on dolomite (Ndaba, 2011; Stoch, personal communication, 2012). As shown in Chapter one, development and upgrading considerations shy away from engaging with such compromised locations or tend to propose removal of residents from such locations altogether.

In an effort to enable impoverished and vulnerable communities living in potentially dangerous locations with improved quality of life, legal representatives and humanitarian activists focus their efforts on achievement of constitutional basic human rights (Hathorn, personal communication, 2012). This focus results in some instances in commitment to investigate the feasibility of *in-situ* upgrades even on potentially dangerous land. For example, CoJ has undertaken to consider the possibility for upgrading in Thembelihle (Planact, 2015). Although constitutionally founded, the intentions attract resistance (Hathorn, personal communication, 2012). Prioritisation of administrative resource allocation and a need to balance capital budget expenditure with operational and maintenance costs when deciding on service delivery priorities prevail (CoT, 2013b). When intervention is successful, community expectations regarding service delivery is raised not only in the affected community but with similar communities elsewhere in Gauteng (Nokotyana v EMM, 2009; GCRO, 2012a), thereby placing additional pressure on authorities.

Ultimately, conflict arises between the right to basic services and the right to a safe living environment, due to the services potentially reducing physical community safety. Where development and upgrading of housing and wet services on dolomite is considered, debate continues (GCRO, 2011c). Due to the reality of conceivable increase in disaster risk as explained earlier, large tracts of land may be deemed unsuitable for development and upgrading based on technical constraints, and planning and decision making regarding such development and upgrade takes years (Kleynhans, personal communication, 2012). A recent decision by the Gauteng human settlements MEC to provide housing upgrades and basic services to Thembelihle (Figure 1.2.3a) (Nhlabathi and Xaba, 2015) is intrepid. The plan is similar to that proposed for Vosloorus Extension 28 (EMM, 2012), where multi-storey units with open spaces in areas with high hazard levels are considered.

Although this presents a case for community engagement and paves the way for future similar upgrades elsewhere, the planning and decision making process remain a lengthy (and costly) one and the acceptance of dolomite disaster risk by the municipality and community alike remains a concern. Attention should also be paid to changes in community make-up, and ongoing awareness interventions since new community members in a few years' time may now know the dangers of the land they live on when entering the settlement. The implementation of housing and service delivery alone therefore does not eliminate the potential for increased risk where unremitting wet services monitoring and maintenance is needed. Behavioural considerations of communities living on such dangerous land (Kent, 2005) may thus unknowingly expose them to increased health and safety risk.

Brody *et al*. (2008) present a compelling argument for the inclusion of public perception in the consideration of physical vulnerability. According to their research, the role of personal proximity to a hazard is key to shaping risk perception in a community. Thus, closeness and personal experience with a hazard increase one's perceived level of future danger. When sinkholes and subsidence are not present in an area the public perception of exposure is therefore expected to be low. Their research (*ibid.*) expands on the need for academia and officials alike to understand the role of human perception and behaviour in relation to natural hazards and the associated risks, as opposed to technical solutions only, to address risk reduction. The foundation of dolomite risk perception lies in the uncertainty of predicting hazard occurrences on such ground. This underpins nervousness around potentially placing communities in harm's way and having to take responsibility for decisions regarding their safety.

2.4 Considering affordability and sustainability

2.4.1 The price of land and services

"When space is profit, the question of how to use land … becomes …
a matter of social struggle, which is partly regulated through urban planning"
Ernstson (2012: 3)

Ernston's statement effectively highlights the juxtaposition between the increased need for space for development and the socio-economic needs of society. Current urban planning processes attempt to relieve social requirements through the allocation of land for residential development as one component of the space-profit interaction. Although attempts are made to alleviate the disparity, land allocation remains to a large extent based on the space-profit interaction (*ibid.*). The provision of subsidised housing, usually on municipal or state -owned land, often prevails long distances away from city centres, amenities and employment opportunities. In order to gain access to such opportunities some residents locate closer to urban hubs but forego access to formal housing and instead settle in informal settlements.

In the case of informal communities the space-profit juxtaposition reaches a climax where communities confront municipalities and politicians to gain access to housing and basic services such as water and sanitation. Where relocation of settlements are on the cards, communities do not hesitate to even call on the Courts to consider their plight. Considering the significant effort that is expended during these processes, many times without coming to closure (Hathorn, personal communication, 2012), a finer balance should be struck between provision of housing and services to low-income residents and what is spatially and economically feasible. In terms of the difficulties faced when attempting to satisfy all role players involved, a challenge occur when land is potentially risky or unsafe for human habitation (WHO, n.d.(b)). The encounter places an administrative and financial burden on politicians, municipalities, developers and communities alike.

2.4.2 The link between risk, sustainable development and vulnerability

For human settlements to be sustainable, the prioritisation of the factors that determine sustainability should be deliberated. One of the elements of sustainability that needs to be gauged is vulnerability (Adger and Winkels, 2007; Agyeman, 2007). Vulnerability is a parameter in determining disaster of risk (as noted earlier: R = HxV/MxC) as well as ascertaining sustainability. The vulnerability of human settlements is determined by interdisciplinary factors including but not limited to, environmental, economical, structural and social components (Slaymaker, 1999). When considering maintainable development through its linkage with ecological degradation and poverty (Reid, 1995), it becomes increasingly important to consider the specific characteristics of vulnerable settlements since low-cost housing sectors in developing countries often face pronounced exposure to natural hazards, in turn bringing about additional environmental deterioration. The approach towards addressing the duality of vulnerability (being a determinant of both risk and sustainability) requires housing development and service delivery to particularly consider the lock-in effect that short term decisions have on long term urban transitions toward sustainable urban development (Ernstson, 2012).

Arguments supporting settlement upgrading or granting of long-term tenure rights along with basic service provision in locations that are informally or illegally settled (Huchzermeyer, 2008; Selebalo, 2014) deliberate that confirmation of tenure is more desirable than relocation. This is due to increased community stability and household security since they are able to consolidate and invest in formal structures. The process has additional positive employment, educational, health and developmental spin-offs, allowing long-term decision making, leading to increased quality of life (UN-Habitat, 2003). However, people’s living behaviour, which influences their future exposure to disaster risk when living on dangerous ground, needs to be included in the decision making process when considering upgrading or relocation (Stoch, personal communication, 2014). In situations where rehabilitation or upgrading of settlements is indeed possible, such considerations become critical in the debate around promoting societal stability and increased sustainability.

Although not only the poor are vulnerable to disaster risk (Yodmani, 2001) their housing conditions and level of income may expose them to higher levels of risk than would otherwise be the case. In addition to their socio-economic disposition, their location on often marginalised and inappropriately located land (WHO, n.d.(b)) begs the question whether the provision of services to such areas should be done by means of *in-situ* upgrading of the existing settlement or rather removing them from the location altogether. Ideally, such decision should consider the goal of promoting sustainable human settlements. However, in practice, sustainable settlement objectives cannot be fully achieved and the decision making process remain biased due to political principles taking precedence (Huchzermeyer, 2011a). The options of settlement upgrading *versus* relocation are riddled with constraints and contradictions when considering the aforementioned issues, which make decisions in this arena contentious.

2.4.3 Upgrading towards sustainable urban living

In South Africa, Government's informal settlement upgrading programme provides for phased, area-based development with community participation and project management forming an integral part. "Eradicating or upgrading all informal settlements by 2014/15 is the prime target" (DoHS, 2011). With this target in mind, communities actively participate in calling for the provision of basic services such as waste removal, electricity, water and sanitation services (Nokotyana v EMM, 2009; Mnisi v COJ, 2014). Within this framework, the National Upgrading Support Programme (NUSP) attempts to establish a common understanding of the meaning of *in-situ* upgrading with regard to the delivery of these services and promotes *in-situ* upgrading as opposed to relocation when settlements are in dire need of improved living conditions. Other options such as rollover upgrading and relocation should be, in terms of NUSP, a last resort if the former option is not technically possible. Supporting th approach approach of the DoHS, the Housing Development Agency (HDA) has also refined their consideration of settlement upgrading to consider the need for maintaining community cohesion during development and upgrading processes (HDA, 2015). During this transformation, the consideration of sustainability and the implementation of green infrastructure in particular has not yet received as much attention as it does in formal urban development deliberations.

The intersection between temporality and spatiality is based on the assumption that in the exploration of sustainable urban transitions, a move is made from less to more sustainable built environment form and function (Revi, 2011). In this transitional process the potentially most vulnerable communities include poor populations and communities living in marginalised areas (*ibid.*). However, they are also to a large extent excluded from the transition (Kent, 2005). This places a double burden on them where they remain in a dangerous situation while not keeping up with the urban sustainability drive. Madden (2010) argues for an approach to integrate grey infrastructure solutions (for example, that made out of concrete and steel) with ecologically sensitive options and green infrastructure to overcome the financial resource challenge which faces urban administrations. These natural and semi-natural systems require less maintenance and future capital outlay and play an increasingly important role in providing sustainable urban development solutions (ASCE, 2010; TNC, 2013).

Examples of green infrastructure include grassed embankments and vegetated channels to capture stormwater, thereby dispersing infiltration, while at the same time reducing flood risk and serving to filter certain contaminants from polluted water (Madden, 2010). These solutions may not be ideal on dolomitic ground since the infiltration of the water could in fact elevate the dolomite hazard level. Thus, even though green infrastructure solutions may not be applicable to all upgrading programmes, the ecologically sensitive approach provides insight into the need to consider alternative options of interacting with an inherently dangerous natural environment. In addition, the inclusion of human behaviour considerations in DRR involves a combination of grey and green infrastructure solutions, and works towards a resilient urban system approach that enhances long-term settlement sustainability (Allen, 2012).

Considering the large proportion of low-income communities in and around Gauteng, some which live on dolomitic land (GCRO, 2011a), a blanket approach towards infrastructure transitions aimed at supporting sustainable urban living may not be appropriate. Where development options influences stability on dolomite, *in-situ* upgrading, for example, should consider interventions that do not increase the risk of dolomite subsidence and sinkholes in future. Since infrastructure choices lock the city and its administration into a long-term development trajectory that internalise maintenance costs or reparations to the inhabitants of settlements, there is a need to ensure appropriate intervention and future vision consideration regarding which infrastructure to implement. In order to evaluate the cumulative and often hidden costs that only become apparent in future time, the probability of the physical vulnerability of settlements therefore needs consideration.

2.4.4 Risk insurance

Homeowners are responsible to insure their own properties, or in the case of sectional title, collaboratively (Cooke Fuller Garrun (CFG), 2014) via underwriting or self-insurance (meaning they save money in a separate account or investment for use in case it is needed). When a property is enrolled at the NHBRC and newly built, NHBRC Warranty Cover is applicable and provides structural guarantees applicable to residential dwellings built and registered by developers, contractors or prospective home owners (NHBRC, n.d.(a)). The warranty covers minor defects identified within the first three months of occupation, roof leaks within one year from date of occupation, and major structural defects identified within the first five years after occupation (NHBRC, n.d.(b)). The cover extends to building materials and the structural integrity of the home in particular (*ibid.*) and not dolomite subsidence risk. Where dwellings such as backyard dwelling units, “granny flats” or even entire houses are built without the NHBRC’s approval or involvement the structure is not covered and the owner is not allowed to sell the property within a period of five years after completion.

For low-income government subsidised housing, the NHBRC, through the Housing Consumers Protection Measures Act No 95 of 1998 (Republic of South Africa, 1998), provides warranty for “the super structure, floor slabs and roof up to a maximum amount of R500 000” (in 2014), for five years from date of initial occupation (NHBRC, n.d.(a)). With the floor slabs listed in particular, it is expected that if dolomite subsidence occur, the warranty will hold. Thus, the financial implication of disaster risk such as widespread subsidence or sinkholes in a subsidised housing settlement may pose a threat to the financial viability of institutions such as the NHBRC. Where low-income settlements are developed through government intervention (such as the so-called RDP or BNG projects, the recipients of such properties are accountable for maintenance, damages or costs incurred once the property has been transferred into an individual’s name. With the large backlog and delay for transfer in terms of government-funded developments, many residents in these dwellings do not own it and remain merely beneficiaries (Huchzermeyer, personal communication, 2015). Thus, in all cases – whether privately bonded, bank-guaranteed, or via government subsidies, where citizens live on dolomite they (knowingly or unknowingly) accept the disaster risk for their personal and property health and safety, even if accountability may be lagging in terms of official transfer processes.

In the cases elaborated on above, there is no requirement for regular monitoring or maintenance in general once property deeds have been transferred. Apart from the resultant lack of maintenance of wet services in wealthy and poor communities alike (Heath, personal communication, 2011), a challenge permeating the matter is that most homeowner insurance usually excludes or significantly reduces underwriting for “acts of God” (CFG, 2014). These challenges exacerbate the dolomite hazard level in areas underlain by dolomite. In addition, the formation of dolines and sinkholes is sparsely covered, if underwritten at all, for both private and government owned and -maintained residences (*ibid.*).

Owners of properties in formal suburbs exposed to natural disaster risk may have the financial ability to adhere to development and maintenance requirements that may support underwriting of damage, and if disaster strikes, they may be able to recover financially from the impact (Sartain, Mian, O'Riordan and Storry, 2011). Their socio-economic standing enables them to potentially manage, monitor and reduce risk to their properties and recover if disaster occurs (Heath, personal communication, 2011). However, a dual burden faces low-income communities on dolomite where they are troubled by lack of funding to ensure wet services maintenance as well as an inability to insure against or recover from damage caused by subsidence.

While only 38 fatalities caused by sinkholes and subsidence occurred in South Africa over a period of 50 years (mainly in and around Gauteng) (CGS, n.d. (a)), the figures do not reflect the substantive financial damages caused over the same period in the region. Even conservative estimates of the efforts that have gone into sinkhole and subsidence reparation are vastly under-counted since many small depressions are filled in without being recorded (Kleynhans, personal communication, 2012). Future infrastructure losses and associated financial and insurance costs are therefore a concern when considering the potential for increased risk through additional densification of settlements and human interaction with the dolomitic ground.

Informal settlement residents do not engage in formal insurance activities that protect them in case of damage or loss (Stoch, personal communication, 2012). Government-based insurance and commercial insurance industries cater to a limited extent for the formal low-income settlement market, while commercial insurance particularly targets the medium- and high-income market (CFG, 2014). The low-income sector therefore has limited options in regards to alleviation of damages in the event of natural hazards resulting in disaster. Their main measure of protection against disaster is thus prevention, which is in turn, related to their understanding or perception of their hazard exposure.

Dolomite hazards are a problematic concept for many low-income residents to engage with, not only because of the technicalities involved in hazard level determination, but because it is an unseen and unknown hazard (Stoch, personal communication, 2012; Davis, personal communication, 2013). Even in areas with a high probability for large sinkholes to form, there may not have been any sinkholes in decades since original occupation. The non-existence of sinkholes can also be attributed to no or very limited waterborne reticulation being present in the area. The possibility of a sinkhole developing is therefore not only often misunderstood or not even considered, but also understood as a foreign force, sometimes-attributed to unnatural origins (Mmemezi, 2011). Insuring against dolomite risk in a formal financial system therefore becomes challenging.

In the past two decades, CGS has recorded at least 2600 sinkholes in Gauteng (Health, 2011b). With many of these, occurring in or near informal settlements (*ibid.*) the non-availability of insurance for informal settlements will likely remain as is in the near future. In addition, government subsidies for informal settlement upgrading and improvement also do not cover sinkhole and subsidence formation. The provision of budget for basic water and sanitation services is in many cases barely able to cover the infrastructure required for upgrading on dolomite since it is much costly than provision of wet services on non-dolomitic ground, let alone insurance against the possible occurrence of dolines and sinkholes (*ibid.*).

2.5 Dolomite as potentially dangerous ground

2.5.4 Availability and use of information

The extent to which human behaviour causes sinkholes varies between geographical locations. In Missouri in the United States of America (USA), only 49% of sinkholes are human-induced (Reger, 2010). The prevalence of human-induced sinkholes on dolomite in South Africa is significantly higher. Schöning (1990) presents a comprehensive compilation of empirical results that shows a high correlation (94%) between the incidence of poor maintenance and waterborne infrastructure leakage with the incidence of sinkholes and subsidence. Although exact figures are not currently available, this finding was indicated to remain valid in the context of dolomite in Gauteng, as confirmed during separate interviews with Heath, Kleynhans and McLuckie (Health, personal communication, 2011; Kleynhans, personal communication, 2012; McLuckie, personal communication, 2015). Human behaviour in regards to infrastructure maintenance should therefore be deemed of importance when considering the debate in South Africa.

Although some sinkholes observed during my research were seemingly caused by improper installation (for example Figure 4.2.3a where sinkholes existed at almost every manhole along an entire stretch of pipeline), the vulnerability of settlements to dolomite is perceived to be related socio-economic situations of its residents (Heath, personal communication, 2011). Although statistical information is not available to prove the predicament, higher income households are expected to be able to mitigate runoff stress via installation or redirection of gutters, storm water drainage maintenance, and high quality plumbing, whereas socio-economically distressed communities do not necessarily have alternatives.

Data collection regarding dolomitic investigations emerged when the first guidelines for development on dolomite in South Africa evolved in the 1970s. During initial development and implementation of standards and guidelines, reports and investigation results were not kept as diligently as is currently the case (*ibid.*). As guidelines evolved (NDH, 2002; CGS, 2007; DWA, 2009; SABS, 2009; DPW, 2010) requirements for reporting and record keeping increased in parallel. The most recent standards (SABS, 2012) require not only the results of investigations and risk assessments but also risk management plans to be maintained for all development on dolomitic ground. The result is that a vast number of geotechnical risk assessments and records of construction interventions, monitoring and maintenance programmes being archived. The CGS has a databank where many of these site investigations and reports are being archived (CGS, n.d.(b)). However, report submission remains voluntary since there is no legislation that compels record submission of dolomite assessments to a centrally accessible location. In addition, some private developers and companies require confidentiality of the reports to be maintained and thus refuse access to their reports (Warwick, personal communication, 2011).

In addition to the difficulties related to availability of and access to information, occasionally subjective interpretations have been found to be done in the past (Heath, personal communication, 2011), exacerbated by private interest in the funding of investigations (Davis, personal communication, 2013). Changes to regulations and guidelines over time makes historical comparison of research and reports difficult. A large number of engineering reports and a smaller number of academic research reports and publications that interrogate settlement development on dolomite (Wagener, 1982; Brown, 1985; Roux *et al.*, 1998; Trollip, 2006; Kirsten *et al*., 2009; Coetzee *et al*., 2010; Oosthuizen, 2013) also focus primarily on middle- to high income developments. Buttrick *et al*. (2011) is the only published article that specifically considers the low-income settlements-on-dolomite conundrum. This places low-income settlements in a precarious situation where the subject not only remains under-researched, but un-nuanced, since different make-up of settlements is not considered.

Galve *et al*. (2008) proved that an array of qualitative and somewhat subjective classification processes exist internationally for natural hazard investigations. In South Africa, even though regulations and guidelines changed over time, the dolomite assessments have been standardised as best possible, as confirmed by Buttrick *et al.* (1993), Van Schalkwyk (1998), and Buttrick, van Schalkwyk, Kleywegt and Watermeyer (2001). Currently, the assessment of dolomitic ground stability is done via multiple tabular references and matrixes (SABS, 2012), the interpretation of which often confuses persons who are not familiar with the assessment process and relationships between the tables and matrixes.

In addition, the classification system is not always applicable to low-income settlements that are already located on dolomitic ground, since the assessment process may, as noted earlier, not be feasible. In the South African National Standards (SANS) 1936: 2012, the Inherent Risk Class (IRC) characterisation ranges from Class 1 to 8, with 8 reflecting high inherent risk of very large sinkholes and doline formation. Some of these classes are further defined to reflect differences in the mobilisation potential of the dolomite. Then, building classes (A to J, with sub-classes) are associated with the IRC's, with no development allowed on IRC 8 and residential development only allowed up to IRC 5 (IRC 6, 7 and 8 allows no residential development). Each building class is defined in terms of its characteristics as well as occupancy. This is where the Standards are un-nuanced in regards to low-income settlements. Table 2.5.4 presents a summary of the building classes. Type H refers to residential occupation; however, there is insufficient characterisation of non-site or stand-based dwellings as found in low-income settlements and particular in informal settlements. The design population for building type H1 and H3 is two persons per bedroom and H2 is one person per 5m² (*ibid.*).

Table 2.5.4: Summary of classification for buildings on dolomite

Class	Description
A1 to A5	Entertainment and public assembly, theatrical and indoor sport, places of instruction, worship and outdoor sport
B1 to B3	High, Moderate and Low risk commercial services
C1 and C2	Exhibition hall and Museum
D1 to D4	High, Moderate and Low risk industrial, and Plant room
E1 to E3	Place of detention, Hospital and other residential-type institutional occupation
F1 to F3	Large and Small shops, and Wholesale store
G1	Offices
H1 to H4	Hotel, Dormitory (where groups of people are accommodated in one room), Domestic residence (occupancy consisting of two or more dwelling units on a single site), Dwelling houses (a dwelling unit on its own site, including garage and domestic outbuildings)
J1 to J4	High, Moderate and Low risk storage, and Parking garage

Source: SANS (2012).

The guidelines with respect to density of residential development to a large extent do not accommodate low-income settlements. Residential types are referred to in terms of gentleman's estates, residential type 1, 2 and 3 (as per town planning terminology), and affordable housing. Stand sizes of 300m² to 1000m² consider largely single dwellings on stands and not where for example hundreds of informal dwellings could exist on large non-proclaimed spaces. The affordable housing type considers one dwelling per 300m² or larger (*ibid.*). This lack of distinction is evidence to the complicated decision making process when considering upgrading of existing informal settlements on dolomitic ground in particular.

Dolomite hazard classification and risk analyses for development purposes are typically done on a site-by-site (usually a stand or erf) basis. Different stand owners could very likely get different experts to conduct surveys at different times. Therefore, the evaluation of two adjacent sites may not match due to differences in survey technologies and analysis techniques available or used at the time. Even if the same methods and drillhole data is used for a property, experts may disagree regarding the interpretation (Heath, personal communication, 2011) especially where, as explained earlier, access to historical reports are a challenge. In addition, a zone classified as high dolomite hazard may lie directly alongside a zone classified as low hazard and they may both occur on a single erf (*ibid.*). This adds to the challenge already alluded to, of applying traditional standards and guidelines and engaging in drawn-out deliberations when considering low-income settlement development or upgrades.

2.5.5 Responses to human settlement dolomite risk

In Gauteng, scientific research regarding settlement infrastructure development on dolomite is widespread (Wagener, 1982; Brown, 1985; de Beer, 1987; Buttrick *et al.*, 1993; Roux, Warwick and Meintjies, 1998; Brown and de Beer, 1989; DPW, 2003). These research outputs do not consider small sized dwellings that exist in low-income settlements. Kirsten *et al*. (2009) proposed a method to consider dwelling risk exposure on dolomite, based on individual dwelling characteristics and assuming the size of a dwelling to be at least 13mx13m. They include parameters such as:

- a household consisting of five persons;
- the space inhabited at any given time covering an area of 5mx5m of the total dwelling surface; and
- the proportion of the household that may be fatally injured when the dwelling collapses into a sinkhole.

Their proposed method is useful to consider safety risk to the inhabitants of a dwelling and could be adapted to smaller dwellings. Unfortunately, one limitation remains, namely unit density considerations, where in low-income settlements the dwelling density is significantly higher than what is covered in SANS 1936 (SABS, 2012). Thus, the suitability of their proposed method remains inapplicable to informal settlements.

Kesten (2005) and Coetzee *et al.* (2010) aimed to integrate dolomite risk technicalities with disaster risk management as considered by the Disaster Management Act (57 of 2002) (Republic of South Africa, 2002). However, they have not had a significant influence on the consideration of low-income settlement development on such ground. Furthermore, sinkholes do not dominate the disaster prevention, mitigation and response literature due to their relatively small extent (at stand level) and random occurrence. Apart from a number of headline-making sinkhole and subsidence occurrences in the 1960s and 1970s (cited in Geocaching, 2014), and again since 2000 (cited in Kaytech, 2006; Heath, 2011, quoted in *News24*; Chapman, 2013; Martins, 2013a, b; Ndaba, 2013; Velleman, 2013; du Plessis, 2014; Greve, 2014; Mnguni, 2014; Meijer, 2015), sinkholes have not received much attention in the media. The type of 'sinkholes' that tended to reach news headlines were in some cases not related to dolomitic soils but rather to infrastructure inadequacies on other types of geology (Hlubi, 2011).

Municipalities acknowledge the pressure that settlement densification is placing on wet services infrastructure and ultimately community safety on dolomitic ground (CoT, n.d.; Grobler, personal communication, 2014). To this end EMM implemented key interventions and processes involving specialist staff and pre-approved consultants, thus pre-empting response to dolomite dangers in their area of responsibility (Kleynhans, personal communication, 2012), and CoT instituted a guideline for implementation of disaster risk management programmes on developments and property upgrades within their jurisdiction (CoT, n.d.; McLuckie, personal communication, 2015).

Uncertainties related to the probability of dolomite hazards manifesting in urban areas are highlighted when the impacts of global climate change and subsequent changes in rainfall patterns are considered. Changes in water volumes, run-off and ponding regimes (SEA, n.d.) signify a potential increase in subsidence and sinkhole occurrences since these are often generated by a change in the soil moisture regime (DWA, 2009; DPW, 2010). Therefore, dolomite disaster impacts are far from being understood in totality even when existing standards and technical guidelines are applied to low-income human settlements.

2.6 Settlement characteristics

"Understanding different settlement types in South Africa … becomes crucial to the sustainable development debate in this country"

(CSIR, 2007: 18)

2.6.1 Settlement classification for vulnerability insight

Urban structure and morphology research started in the 1930s with academic and scientific investigation into what was then considered modern city planning and development processes (Christaller, 1933; Lynch and Rodwin, 1958; Chinitz, 1960; Warner, 1962; Alonso, 1964; Glaab and Brown, 1967; Moses and Williamson, 1967; Mills, 1967; Muth, 1969; and Fales and Moses, 1972 in Anas, Arnott and Small, 1998). Since then, urban structure and morphology research have seen changes in form and scale, including association from city-wide to sub-nodal scale based on changes over time in economy, communication and transport options. The latter changes are especially notable during the 1980s and early 1990s (Thomas, 1981; Getis, 1983; LeRoy and Sonstelie, 1983; McDonald, 1987; Cronon, 1992; and Garreau, 1992; in Anas *et al.*, 1998). From this basis, a focus on urban analysis emerged that support the delineation and classification of settlement types and -settlement characteristics, from suburb-level to building footprint analysis. This *zooming-in* process was facilitated by increased availability of remote sensing data such as high resolution aerial photography and satellite imagery, with associated hardware and software such as those provided by GIS that facilitate high-volume spatial data analysis. Research presented by Herold, Liu and Clarke (2003), Steiniger (2006), Banzhaf (2007), Blum and Gruhler (2010), Jiang and Yao (2010), Meinel (2010), Herold, Roehm, Hecht and Meinel (2011), Blanco and Schanze (2012), Herold, Meinel, Hecht and Csaplovics (2012), and Meinel (2012) provide a glance at the development and improvements that have been made over time in this regard.

The UNISDR defines vulnerability as the degree to which a settlement, individual, household, community, area or development may be adversely affected by the impact of (such) hazard(s) (UNISDR, 2004). The concept of human settlement vulnerability, linked to low-income and needs-driven settlement growth patterns, is defined in different ways (van Westen and Kingma, 2008), based on the hazard(s) present in that settlement (Storie, 2012a). The factors or processes that drive this inter-related hazard *versus* settlement relationship require an in-depth evaluation in order to achieve a conclusive vulnerability assessment (Storie, 2012b). Such an evaluation requires accurate spatial data, both for the settlement and in regards to the hazard.

Huchzermeyer, Karam and Maina (2014) investigated informal settlement forms in Johannesburg using GIS and satellite imagery. They highlighted that the magnitude of settlement informality is less than what official figures of the City of Johannesburg represented. They also found that vector-based spatial data, aerial photography, satellite image interpretation and catalogued databases of informal settlements show significant differences in the way in which such settlements are identified, classified and treated from a developmental perspective. This alludes to not only the important role of timeous and accurate data, but also the methods of analysis or interpretation of raw data, thus so-called "metadata" related to the source and creation method of data. Often, by the time that development decisions are made or upgrading is due to take place, settlements may not have the same spatial layout, extent or dwelling types as was present when data collection and image analysis which informed the process was done (*ibid.*). Thus, settlement studies based on spatial data or municipal databases from even a year or two before studies are completed, may not be valid unless field investigations and adjustments are made based on ground-truthing shortly before the development or upgrading begins. In response to this situation and with input from the National Upgrading Support Programme (NUSP), the City of Johannesburg in particular, has changed its methods of engagement with informal settlements to ensure that development and upgrading is relevant by the time that it commences.

International research regarding low-income settlement types place a significant focus on the location-based component such settlements, as alluded to by Birkmann and Fernando (2008), Bostrom, French and Gottleib (2008), Glade *et al*. (2005), Birkmann (2006), McGuire (2004), Merriman and Browitt (1993), Mitchell (1999) and Smith (2004). However, the physical characteristics of settlements in relation to location-based vulnerability have been less explored (Pascual, Garcia-Montero, Manzanera, Arroyo-Méndez, Beltrán and Caballero*,* n.d.). The key elements of settlement type consideration for physical vulnerability assessment appear to include at least dwelling type and average settlement density (Bunce, 1982; Alexandrova, Hamilton and Kuznetsova, 2006; CSIR, 2007; Pillay, Rule, Rubin and Ntema, 2010; Pascual *et al*., n.d.).

In the referenced literature, dwelling type commonly refers to individual dwelling units that may differ in form, construction method and fabrication materials. Density considers the size of units in relation to stands, as well as distance between units, thus translating into a percentage difference between built-up ground surfaces *versus* that which is left open. Additional elements taken into account when estimating physical vulnerability of settlements include:

- geographical location, which can be determined using, for example, remote sensing and aerial photography making use of GIS software (Pascual *et al.*, n.d.; Busgeeth *et al.*, 2008);
- dwelling design, type and material (CoJ, 2000);
- dwelling unit density in relation to each other (Glass, Morkel and Bangay, 2006);
- proximity and type of service infrastructure or resources; and
- socio-economic elements of the individuals and households (GCRO, 2011c).

Although these characteristics differ among settlements, the physical vulnerability that it translates into is pronounced in low-income areas. The financial status of low-income residents and their often compromised educational background further exacerbates the resultant disaster risks to which they are exposed (Stoch, personal communication, 2012).

2.6.2 Low-income settlement classification for dolomite in South Africa

Settlement studies are commonly based on theoretical exploration that has a spatial and practical component (Mdakane and van den Bergh, 2012). In South Africa, settlement classification systems follow this trend and rely significantly on spatial density classification via the use of cartographic maps, aerial photographs and remote sensing in GIS and mapped formats. The South African Human Settlements Atlas (CSIR, 2009) uses the same base data types and provide significant insight into, among others:

- spatial representation of residents' quality of life (via an index based on productive life, shelter, safety and health);
- spatial quality of place (via an index based on viability, diversity, accessibility, efficiency and protection of resource use);
- differentiated settlement investment potential; and
- profiles based on the quality of life and of place index of areas, linked to recommended types of housing and supportive service investments per type.

The Atlas aims to provide decision makers with categories of settlements that relate to development and investment potential across South Africa. Density considerations from the Atlas that are relevant to low-income settlements in the context of dolomite hazards include areas of *very low*, *low* and *medium* density. In these three categories the following is covered:

- single detached units that may include government-subsidised or privately funded dwellings;
- single detached units with backyard dwellings;

- semi-detached units such as duet houses and detached duplexes; and
- cluster housing such as townhouse complexes, detached triplexes and low-rise apartments (three to four storeys high);

all which have a wide array of tenure types (*ibid.*). These categories and descriptions are to some extent reflected in the settlement types covered in my research.

Glass *et al.* (2006) explored informal settlement layout patterns in settlements using aerial photography and satellite imagery, combined with procedural techniques. Their assessment focussed on spatial classification of some of the typical informal settlement layouts in South Africa, in accordance with geographical modelling processes. They proved that it is possible to generate graphical settlement layout models and digitally simulate some of the patterns found in informal settlements. They classified informal settlements into clusters (types), however did not include topographic influences which may influence settlement form, thus limiting the application of enactments of their spatial distribution method to individual settlements on level ground. Nevertheless, their study provides insight into the spatial form of low-income settlements and the manner in which dwelling density can be considered when using aerial photography.

An example of a “toolkit”, appropriate for settlement type assessment in South Africa, was produced through collaboration between the Human Sciences Research Council (HSRC), CSIR and Department of Science and Technology (DST) (Cross, 2008b). Their settlement survey results were based on demographic and socioeconomic factors, migration elements, spatial planning elements and the density of populated areas, “as a new kind of applied demography aimed at delivery planning” (*ibid.*: 3). It was subsequently used to further develop the Human Settlement Atlas (CSIR, 2009) which was described earlier. The classification aims at “effective spatial planning at municipal level” (*ibid.*: 7) and identification methods are suitable for differentiating the variety of settlements that exist throughout the country, based on service delivery and economic elements as well as the density of dwellings. Even though the study is in-depth and may be applicable to the low-income settlement investigation, it does not consider the potentially hazardous ground on which some settlements are built, as a reason for differentiating between settlement forms.

Even though it is “very difficult to separate settlement and housing types” from each other (CSIR, 2007: 19), there has been a steady increase in research related to settlement types (Blum and Gruhler, 2010; Meinel, 2010; Knowledge Factory (KF) n.d). In South Africa, the Knowledge Factory’s *Cluster Plus* (CP) 34-class categorisation (KF, n.d.) is useful for distinguishing income and density variations. Although approximately seven of these classes could be useful for purposes of my research, CP focusses on providing commercial businesses with profiles of their potential customers and therefore remains somewhat off-target for low-income communities. CP does, however, provide insight into settlement income levels, for considering the potential for household-level wet services infrastructure maintenance regimes.

The consideration of settlement types, dwelling design and settlement density classifications are defined in a variety of literature that relate to South African conditions (KF, n.d.; CSIR, 2007; Cross, 2008a; CSIR 2009; Pillay *et al.*, 2010). However, each classification has its specific aim and does not consider parameters that relate to potential danger from a physical disaster perspective. When dolomite is the hazard, there is little literature that considers low-income settlement type classification. As mentioned before, urban density related to dolomite-underlain land for middle- and high-income residential dwellings, large complexes and commercial developments are well researched (Wagener, 1982; Brown, 1985; de Beer, 1987; Roux *et al.*, 1998; Trollip, 2006; Kirsten *et al.*, 2009) and strict guidelines and requirements exit as to wet services infrastructure provision, monitoring and maintenance (CoT, n.d.; SABS, 2012). However, the same rules do not hold true for settlements where low-income households and informality in housing structures dominate.

The situation makes the provision of basic waterborne infrastructure to low-income communities, especially in respect of historical settlement, a highly contested arena (EMM v Dada, 2009; Nokotyana v EMM, 2009; Pheko v EMM, 2011a; Mnisi v CoJ, 2014). In the struggle for legitimisation of settlements on dolomitic ground opposing parties tend to argue their case from dissenting platforms that do not necessarily consider settlement typology. For example, the Bill of Rights (Republic of South Africa, 1996) stands in opposition to Geotechnical regulations (SABS, 2012) regardless of settlement characteristics or inhabitant awareness or behaviour. Where no common ground exists, the disparity results disable the achievement of mutually beneficial solutions for all parties concerned. My research aims to assist in addressing this information gap that exists regarding low-income settlement types and the vulnerability of low-income settlements on dolomite.

2.7 Conclusion

The literature review provides insight into the key features that form part of the development-on-dolomite debate. As a primary focus, disaster risk assessment and disaster risk reduction is pursued in the international context of settlement vulnerability. With low-income settlement development and housing policy approaches in South Africa ever-evolving there is sometimes a disjuncture between the focus areas of housing or planning experts, *versus* engineering and geotechnical responses to the reality. Even though all the approaches seek to achieve sustainable urban development, the outcomes may be aimed at different outcomes and methods of achieving those outcomes.

The challenges associated with development on dolomitic ground are internationally and locally well-known. In the South African context, research, policy and guidelines regarding development on dolomite are usually directed by practitioners who operate in the geotechnical and engineering field. This makes the application of development standards on dolomite practical. However, where informal settlements are concerned, the situation remains un-nuanced, with physical constraints related to risk assessments, as well as potential to interpret some of the contents of guiding documents differently. The challenge results in contested and drawn-out responses to developmental challenges related to low-income settlement development and upgrading, as well as proliferation of informal backyard densification in formal settlements.

In response to the gaps identified in existing research and literature, Chapter three presents the research method employed to investigate and address some of these gaps. The chapter introduces the pre-feasibility investigation and literature review for the study. Thereafter, continued literature review and fieldwork, consisting of interviews and workshops as well as field observations and site visits deepened the investigation. The analysis included result data capture and analysis, using analytical process software. Section 3.3 provides the literature review of the analytical method used as well as challenges that were experienced during the process, and how it was overcome.

3.1 Introduction

Natural hazard risk assessment research shows a preference for quantitative as opposed to qualitative analysis techniques, since it allows for "more … objective output and an improved basis for communication between the … categories involved in technical and political decision making" (Uzielli *et al*., 2008: 251). In contrast, human behaviour investigations commonly engage in qualitative techniques (Tesch, 1990; Kvale, 1992; Amaratunga, Baldry, Sarshar and Newton, 2002). The cusp between multiple disciplines and the resultant complexities of my research calls for a dual approach that includes both quantitative and qualitative research elements. The quantitative component engages statistical assessment techniques, supported by qualitative research related to human behavioural elements. In this manner, investigations into decision making guide the development and maintenance of the urban space cross the boundary between qualitative and quantitative research.

To a large extent, the research evolved organically after my initial interest in low-income settlements on dolomite was piqued in mid-2010, by in-office discussions at the GCRO regarding planning and development concerns in Gauteng. The initial interest evolved into a literature review, which supported the research proposal compilation. The literature review also provoked visitations to areas where low-income settlements existed on dolomite in and around Gauteng. During this time I met a number of community members from low-income settlements on dolomite, as well as specialists from different disciplines who had interests in the development-on-dolomite debate, who enabled insight into their respective viewpoints. The next step was to select sample sites where in-depth observations could be made and information could be gained to develop a research questionnaire. I soon realised that my aim of developing a settlement vulnerability curve based on individual comment and inputs from geotechnical specialists who could be identified or quoted on their inputs was not feasible. Instead, as mentioned in Chapter two, I applied a Multi Criteria Analysis (MCA) method, namely the Analytic Hierarchy Process (AHP) to gain anonymous inputs from the specialists.

The research has been categorised into three phases, the activities and methods within each phase being detailed in Section 3.2. The research phases and steps in phases overlap, since availability of specialists for purposes of engagement could not be determined or confirmed for specific dates during the course of the research and had to be adapted based on their availability. Availability of financial resources further required flexibility in the timing of activities across research phases. Phase 1 commenced in mid-2010 and continued until May 2012. Phase 2 commenced in November 2011 and continued until January 2013, and Phase 3 started in August 2012 and continued until mid-2015. During Phases 1 and 2, I interacted with over 60 specialists in the field of development-on-dolomite in Gauteng. Of these, eight agreed to participate in Phase 3. Their expertise ranged across the fields of geotechnical engineering, civil engineering, geology and environmental science. The use of the AHP method accommodated the need of specialists to provide anonymous input into the research, while gaining effective and appropriate research results. Chapter four presents the research results for Phase 1 and 2 of the study, focussing on the characterisation of settlement types. Chapter five presents Phase 3 of the study, which is the analysis of the identified settlement types integrated with dolomite vulnerability considerations. Chapter six concludes the research methodology by discussing the significance of the findings.

3.2 Method

3.2.1 Phase 1: Pre-feasibility investigation

Phase 1 of my research involved an in-depth literature review of the multiple components involved in the research topic. As mentioned earlier, this process started in mid-2010. The main part of Phase 1 concluded in May 2012, however refinement continued until mid-2015. The literature review included but was not limited to dolomite as geological formation, technicalities of dolomite risk assessment, approaches to characterise human settlements, housing policy, disaster risk management and -assessment methodology, as well as methods of doing statistical analysis especially where multiple variables are involved.

Between January 2011 and May 2012, I conducted preliminary investigative field visits to over 40 low-income settlements in and around Gauteng. The locations were chosen based on the literature review, opportunity for site access during study leave, and discussions with specialists and informed stakeholders that were involved in the development-on-dolomite debate at the time. Based on the nature of urban development and dolomitic ground, I often encountered sites and suburbs that were of relevance to my research, unintentionally, when I travelled to and from selected sites. The visits provided insight into the reality and potential characteristics of low-income settlements in the study region. This first phase of the research allowed me to develop and refine my initial research methods.

3.2.2 Phase 2: Fieldwork

Field visits and sample site observations

I designed a field observation form (Appendix E) based on the pre-feasibility site visits and literature review. The form was adapted after pilot visits to three of the sites, to test its suitability when used during sample site visitations. The testing ensured that the capturing of observations made during sample site visits were more focused, thus better achieving the research objectives. The site visits also enhanced my understanding of human behaviour related to wet services on dolomitic ground.

My research investigated settlements as units with similar characteristics, defined by viewing high-resolution aerial photography. I considered that erf or stand-level changes may exist within settlements or suburbs, for example: it is possible that individual dwelling units may differ in form and function from one stand to the next, or a large stand may contain 30 to 90 sectional title units of the same form, or an informal settlement may span thousands of m² with no relationship to cadastral boundaries. This difference in the contextualisation of low-income settlement types resulted initially in 38 different settlement classifications. The classifications were reduced and grouped into ten types reflecting real-world scenarios and enabling differentiation between these settlements on dolomite.

To date, research that aims to find suitable methods, processes and data to use when conducting settlement classification remains lively. The active pursuit of classification methods and subsequent development of products are discussed in detail in Section 2.6.2. Based on this section of the literature review, it is noticeable that different methods of data collection and analysis provide different perspectives and type classification for settlements even if they are located on similar topographical locations. My research considered settlement types based on spatial density and housing materials, culminating in low-income settlement type classification for purposes of this research. The resultant settlement groupings present an assembly of manageable types taking into consideration the variance in housing form, material, structure and layout that is commonly found on dolomitic ground in Gauteng. The primary concern of settlement type identification and classification in this context is based on the potential spaces perceived to be open between units in a sample plot, along with the level of formality and building materials/construction methods used.

From the pre-feasibility investigation site visits, I selected eight sample sites for further assessment, using the form described above. The following criteria guided the sample settlements most suitable for purposes of this research:

- Location of the settlement on dolomite (based on spatial information regarding the general areas underlain by dolomite, as per CGS);
- Type of dwellings being subsidised housing, informally built or having a presence of backyard dwellings (using the identification of dwelling types according to the GCRO 2011 Quality of Life survey);
- Homogeneity of dwelling density (as visible from aerial photographs or satellite imagery);
- Accessibility of the site and elements of personal safety that would allow visits to the sites numerous times;
- Availability of a specialist or person who is knowledgeable to provide insight into settlement and community details with regard to their residing on dolomite; and

- Existence or evidence of past or present development or upgrade conflict or debate.

The settlement type identification involved spatial identification and delineation of potential settlements based on location on dolomitic ground, as well as the visibility of dwellings of a similar density within an approximately 1kmx1km radius. The process employed the use of GIS software, including distance measuring between units and features visible on digital maps. This selection was deliberate to allow an attempt at settlement type classification on dolomite. High-resolution aerial photography (2.5m x 2.5m) (for example, for the City of Johannesburg (CoJ)) and satellite images was employed to do the visual spatial delineation. The eight sample settlement locations are presented in Figure 3.2.2.2a, with a more detailed view of each provided in Figures 3.2.2.2b to 3.2.2.2i.

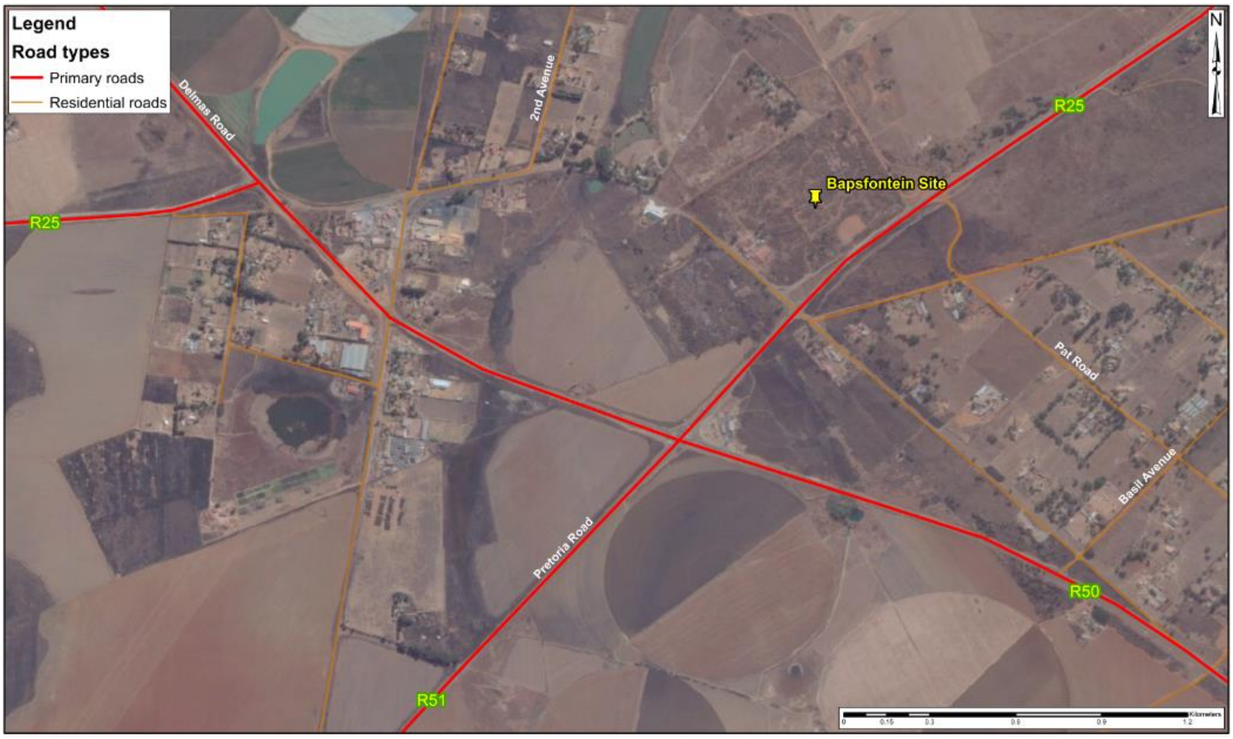

Figure 3.2.2.2b: The Bapsfontein area

Source: Map compiled by AECOM SA (Pty) Ltd, service layer credits: Esri, DigitalGlobe, GeoEye, icubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

As described in Section 1.2, the Bapsfontein settlement (Figure 3.2.2.2b) consisting of just under 800 individuals was relocated during the course of my research, while smallholdings remain in the vicinity. At the time that it existed, its structure and type was typical to informal settlements located on dolomite elsewhere in the province. This site was selected as a sample settlement for purposes of the research primarily due to its critical timing in regards to court proceedings (between 2011 and

2015), and consideration of the National Disaster Management Act (Republic of South Africa, 2002) as a driver for relocation.

Winnie Mandela Park (Figure 3.2.2.2c) used to be partly formally developed and partly informal, with subsequent development and upgrading taking place during the late 1990s and after 2000. This suburb is selected as a sample site since even though it is underlain by dolomite, formal development continues and the prevalence of backyard dwellings is increasing. The intersection of formal development, RDP-style housing and densification due to backyard dwellings is of particular interest in relation to development on dolomitic ground, where the original dolomite risk assessment did not envisage the subsequent dwelling densification (Warwick, personal communication, 2011).

Figure 3.2.2.2c: Winnie Mandela Park (near Tembisa in the North-East of CoJ)

Source: Map compiled by AECOM SA (Pty) Ltd, service layer credits: Esri, DigitalGlobe, GeoEye, icubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Geotechnical dolomite risk reports regarding the informal settlement of Thembelihle, in the formal suburb of Lenasia, was reviewed by Warwick and Roux (2004) to consider the potential upgrading of the settlement. Figure 3.2.2.2d shows Thembelihle in the centre of the map, located in a North-south configuration between the primary roads indicated in purple and towards the east of the M10. The Figure indicates some of the stands that form part of Lenasia, towards the far North-east corner and the South of the map. As can be seen, these two locations are in close proximity to each other.

At the time, advisors and geotechnical engineers engaged the community in workshops where they were alerted to the risks related to and cautions that they should follow when living on dolomite. Although formal street layout plans are visible for Thembelihle, the dwellings remain informal, with residents not having access to the full extent of basic services that they request (CoJ, 2012). Service delivery protests are common in this community. Upgrading of this informal settlement is currently being considered (Nhlabathi and Xaba, 2015), with a proposal to reduce the coverage of the settlement and develop multi storey units to accommodate the residents on the area with lower dolomite hazard levels. This settlement is of interest as a sample site since it is surrounded by formal development, has a formal street pattern, but dwellings are informal in nature.

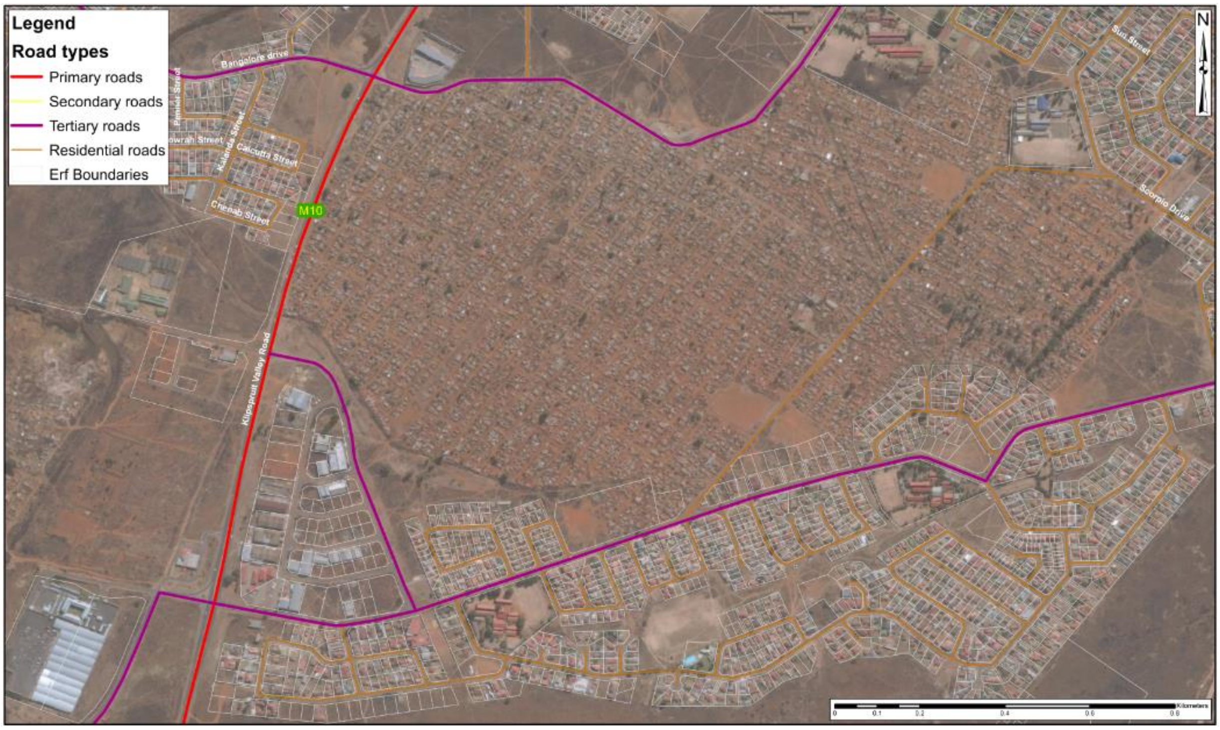

Figure 3.2.2.2d: Different settlement types in close proximity to one another: Thembelihle as an informal settlement, surrounded by the suburb of Lenasia (CoJ)

Source: Map compiled by AECOM SA (Pty) Ltd, service layer credits: Esri, DigitalGlobe, GeoEye, icubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Protea South, the case of which is covered in Chapter one, shows the informal settlement with minimal structure in stand layout (Figure 3.2.2.2e). As with Thembelihle, it is surrounded by formal suburbs and industries. This site is also of interest due to its ongoing engagement with the Court, resisting relocation.

Figure 3.2.2.2e: Regional view of Protea South (in Soweto, CoJ)

Source: Map compiled by AECOM SA (Pty) Ltd, service layer credits: Esri, DigitalGlobe, GeoEye, icubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Goudrand East (Figure 3.2.2.2f) was selected to be part of the research sample sites since it displays a formally developed area with a long history of inhabitance. In particular I visited a small area (similar to a “complex” but without entry and exit gates or a name) where approximately 18 dwelling units have been built on shared foundations. These dwellings are bank-guaranteed and privately owned residences, originating from a need for housing for workers in the mine industry. Its exact date of origin could not be establish, but based on the architecture and design is expected to have been developed around the 1970s.

Figure 3.2.2.2f: Goudrand East (Mogale City)

Source: Map compiled by AECOM SA (Pty) Ltd, service layer credits: Esri, DigitalGlobe, GeoEye, icubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Figure 3.2.2.2g: Kagiso/Goudrand West (Mogale City)

Source: Map compiled by AECOM SA (Pty) Ltd, service layer credits: Esri, DigitalGlobe, GeoEye, icubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

In the area known as Goudrand West, Kagiso, in Mogale City towards the West of CoJ, there are a number of RDP-type developments along the southern side of Randfontein Road (the R41) (Figure 3.2.2.2g). The history of establishment of the area could not be confimred. However, discussions with residents confirmed their RDP origin after 1994. The dwellings are somewhat smaller than average RDP-size houses, with stand-level basic services provision.

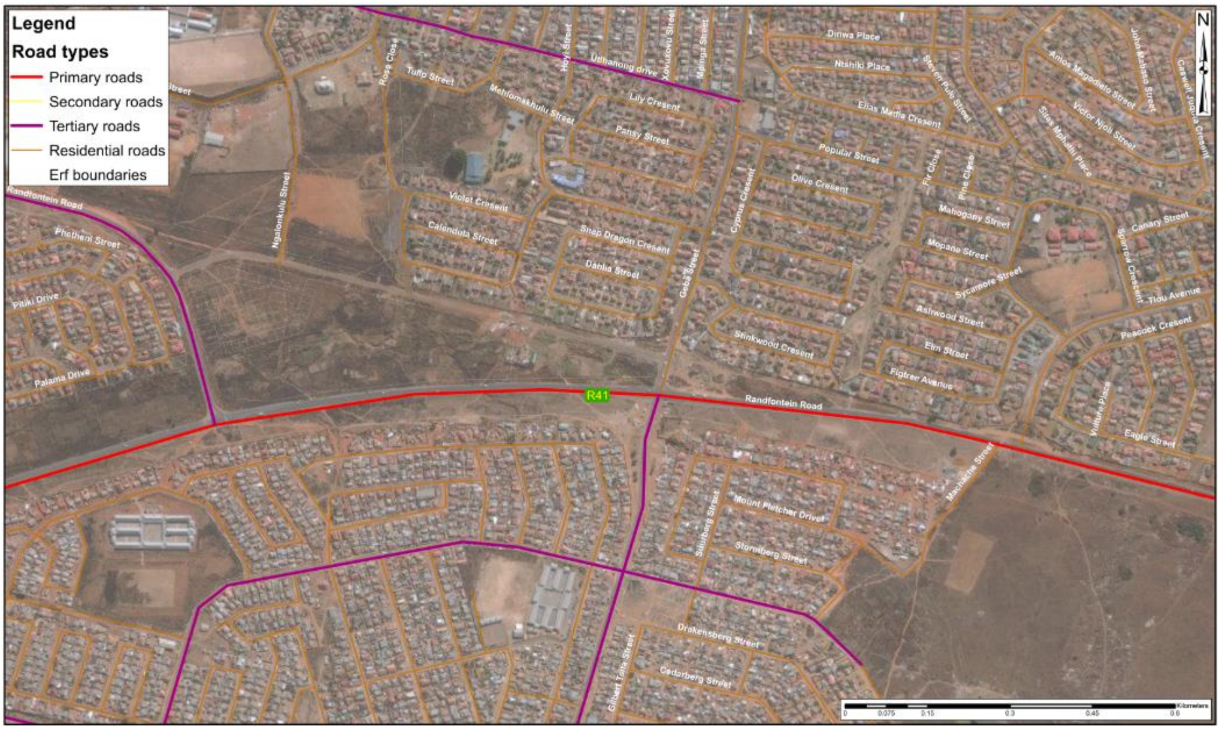

Figure 3.2.2.2h: Kagiso (Mogale City)

Source: Map compiled by AECOM SA (Pty) Ltd, service layer credits: Esri, DigitalGlobe, GeoEye, icubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Kagiso (Figure 3.2.2.2h) is largely developed on dolomite and represent a range of formal and informal dwelling construction, with backyard dwelling construction. The settlement was selected as sample area due to the large area that it covers, with emerging backyard dwelling construction.

Vosloorus (Figure 3.2.2.2i) was selected as a research sample site in EMM since it has a history of development on dolomite. For over two decades, formal as well as informal settlements formed part of this urban landscape. Similar in characteristics as Kagiso, but in the same Municipality as where Bapsfontein is located, EMM has identified a number of dwelling and construction options suitable for development on dolomitic ground. One of the particular wins in regards to dwelling densification on dolomite is in Extension 28, where multi storey dwellings are proposed.

Figure 3.2.2.2i: Vosloorus Extension 3 (in EMM)

Source: Map compiled by AECOM SA (Pty) Ltd, service layer credits: Esri, DigitalGlobe, GeoEye, icubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Hard copies of the field observation forms were taken on site visits. A site map for each selected settlement was used during the site assessment, depicting aerial photography or satellite imagery (whichever was available at the smallest scale at the time of the field visit being done). Site visits included activities such as:

- logging GPS coordinates of each site to confirm its location;
- doing visual observation;
- completion of the field assessment form; and
- discussion with the knowledgeable person or specialist when present. These discussions focussed specifically on settlement characteristics, dolomite risk concerns and potential for assessment and reduction of settlement vulnerability.

In this study, settlement density considers the spaces between dwellings, regardless of occupancy and formal or informal road or pathway existence, or the presence of servitudes. *Dwelling* refers to the unit of residence (excluding outbuildings, lapas (roofed recreation areas), sanitation amenities and/or cooking facilities). Where backyard dwellings exist, such buildings were treated as individual dwelling units, where it could be distinguished. I recognise that it may not always be possible to distinguish the difference between outbuildings used as residential units *versus* those used for storage purposes or as garages without detailed individual stand investigations. Where such features were identified using spatial data, the real-world situations were verified by means of multiple random street-view spot-checks in the selected areas, to provide an overview of the general characteristics of the built structures in the specific settlement. The density classification for settlement types for purposes of this study was established by considering the average distances between units in metres, across a roughly square 250m² area in the settlements, in areas where it was possible to identify relatively uniform spatial layouts.

After completion of the field visits, the information collected from the sample sites was compared and common characteristics in relation to settlement vulnerability on dolomitic ground identified. The dwelling density, building material use and layout types was also considered. The analysis and characterisation enabled the categorisation of low-income settlement types for the research analysis phase into ten distinct types. The ten settlement types defined in this manner and the list of recorded characteristics that lead to the identification of key parameters are applied in AHP assessment of Phase 3. In addition to the fieldwork that is directly related to the research and analyses, I immersed myself in the challenges related to living on dolomite. I engaged as both a tenant and an owner, with residential dwellings located in a relatively low-income area in Centurion, Gauteng. Details of the engagement are presented in Appendix J.

CATEGORISING LOW-INCOME SETTLEMENTS

4.1 Introduction

4.1.1 Background

Chapter four explores the existing theoretical classification of settlement types in South Africa in relation to low-income settlements on dolomitic ground in Gauteng. The existence of and challenges related to limited nuances in the classification of low-income settlements on dolomite is highlighted, whereafter dwelling characteristics encountered during the course of the research is presented. Based on sample site visits, the variations in low-income settlement types in regards to density, construction materials and the existence of backyard dwellings are described. During sample site visits, a number of challenges also were identified that are directly related to the construction of wet services on dolomitic ground: these challenges are presented and described.

Section 4.3 considers the grouping of low-income settlements on dolomite in and around Gauteng based on the literature review and sample site visits. The section describes the characteristics of these settlements in regards to dwelling materials, dwelling size, open spaces in-between dwellings and provision of wet services. The process culminates in six main settlement types, of which four are sub-divided, totalling ten settlement types for the purpose of this research. The types are visually presented, showing hypothetical arrangements of the characteristics associated with each type. The sample settlement types are then considered in terms of the diagrams and type characteristics, considering the applicability of the settlement types to real-world examples, including consideration of overlap between types. Finally, the parameters that influence physical settlement vulnerability on dolomite are explored and elaborated on based on its selection for inclusion in the research questionnaire and AHP analysis.

4.1.2 Long term development trajectories of state-subsidised low cost housing projects

Subsidised low cost housing development (which South African policy calls “social housing”) often see large numbers of dwelling units constructed in a relatively short period of time. Each settlement (conventionally in South Africa referred to as ‘Reconstruction and Development Programme (RDP) settlements’, stemming from the 1994 election manifesto of the African National Congress (ANC) and a name short-lived in the Office of the Presidency between 1994 and 1996) is individually planned and submitted for approval based on, among others, geotechnical and legal feasibility. There is no standardised type applied throughout South Africa, and developers each have their own design or a limited number of designs for low-cost dwellings. However, due to the vast spatial expanse of most low-cost housing developments, the housing tends to be standardised in the sense that developers often use one house design for an entire settlement. The result is settlement layouts that, although conforming to building regulations and development application requirements, look the same with regard to dwelling form and layout.

Due to the spatial expanse that these development formats require and the need for acceptability of ground surface engineering conditions, many areas that could potentially be utilised for low-income housing are not selected for this purpose (Huchzermeyer, personal communication, 2015). Instead, alternative more ‘suitable’ land is selected where the same surface-based constraints do not apply. Due to urban development pressure and a lack of available affordable land in large expanses inside or close to urban centres, many of the available areas are removed from urban development nodes. The result is an unsustainable method of implementation of low-income housing, producing sprawling urban suburbs where communities are physically removed from employment and other opportunities that can improve their lives.

Historically a few low-income developments were placed on dolomite, for example parts of Lenasia and sections of Winnie Mandela Park. There is also increasing consideration of RDP settlement development on dolomite where land is available and suitable based on dolomite hazard zoning, for example in Khutsong, near Carletonville. Even in such formally developed low-income settlements and where geotechnical building standards have been complied to, informality often arises as residents construct backyard dwelling units, often out of impermanent materials, after the original formal development (Stoch, personal communication, 2012). This densification is taking place on potentially dangerous ground without formal development planning and approval processes being applied. The process intensifies a key dimension of the interrelationship between poverty and inequality due to locational disadvantage. The situation creates settlements that are often far removed from economic opportunities

In the case of informal settlements, a further compromise emerge in the health and safety element, where poor communities often inhabit dwellings built on ground that may be unsuitable for increased density – for example in floodplains, on dolomite, or where highly erodible soils or wetlands exist. These communities are burdened by locational disadvantage, low household incomes (StatsSA, 2011) that are exacerbated by the settlement locations, and exposure to hazards resulting from their living on potentially dangerous ground (Stoch, personal communication, 2012). In these conditions, even where the ground that dwellings are built on is not unsafe, households face constant uncertainty if not direct threat of eviction or relocation (Huchzermeyer, 2011a). Where such settlements are located on dolomite a further burden is added where, due to the unsuitability of the ground, basic wet infrastructure services delivery is highly contested. Then, threats of eviction or relocation are then often exaggerated through the ground condition debate.

Post-apartheid urban development has seen the development of subsidised housing primarily through the project-linked subsidy programme (referred to as 'RDP-housing' and later 'BNG housing'(Housing Development Agency (HDA), 2004). To a large extent these subsidy programmes adopted the model that 'apartheid era development' sites and services-projects piloted in the early 1990s (Hervé, 2009). The spatial patterns that were set historically sometimes continue to be followed (CSIR, 2012). This perpetuation exacerbates challenges that low-income residents face in regards to social segregation and disaster-related hazards (Stoch, personal communication, 2012).

The circumstances that these communities face continue to relate to restricted access to sustainable living opportunities, socio-economic constraints and elevated disaster risk. Urban infilling with backyard dwellings often leads to the regression of formally developed areas into what may resemble informal settlements with inadequate service provision for the population density that it serves (Turok, 2015), thereby opposing the originally desired formalisation which public housing development programmes aim to achieve.

4.1.3 Attempts to classify settlement types

There are different ways in which to define settlements, based on their location, form and function. A human settlement is in its simplest form an organised grouping of human habitation (Boyd, n.a.). In the context of my research, settlement type refers to categories at suburb-level or smaller sized areas of uniform dwelling types, characterised by combinations of materials and clustered in average densities. Methods to classify discrete and distinct categories of settlement types abound, with examples such as the Knowledge Factory (KF, n.d.) focusing their categorisation predominantly on financial value of individual units of dwelling structures. The CSIR refined their classification of settlement typologies over the past decade, using primarily spatially quantifiable methods (CSIR, n.d.(a); CSIR, 2007; CSIR, 2009), with one of their recent publications providing a "quantitative and rational framework" for the provision of social facilities in various "levels" of settlements (CSIR, 2012: 4). The standards for development on dolomite (DPW, 2010; SABS, 2009, 2010 and 2012) does not follow these settlement type classifications since it focuses on smaller scale building clusters for suitability on dolomite land, as opposed to settlement types which may include more than one building type in a given geographical space. Although the dolomite classification provides clarity regarding the types of developments allowed on certain dolomite hazard zones, the categorisation does not consider the interaction of social facilities, public buildings and dwellings in a wider urban or suburban setting. Therefore, when entire settlements have to be developed or upgraded on dolomite, the inclusion of a combination of for example shops, residential area, parks and schools have to be carefully planned not only in regards to town planning layouts but also with consideration for the hazard zoning. The result is a fairly complex process that may compromise the provision of dwellings, amenities and facilities in some way or another.

In South Africa, when government departments or institutions classify settlements, the data sets that are used are (often exclusively) made up of spatial data. Data-driven settlement type identification methods using satellite imagery and remote sensing, with associated software that consider unique characteristics of land use and land cover patches, are not always replicable when compared to real-world scenarios (Busgeeth *et al*., 2008). The challenge regarding land use, zoning and land cover identification, and visual representation thereof, remain lively. As an example, the processes involved in the implementation of the new Spatial Planning and Land Use Management Act (SPLUMA) (Republic of South Africa, 2013b)_is the cause of many discussions, workshops and debates (DRDLR, 2016), with as yet no firm consensus regarding land cover definitions as yet. Procedurally and GIS generated patterns may reflect real-world settlement patterns, such as those presented by Glass *et al*. (2006), Mdakane, van den Bergh and Moodley (2014), and that which SPLUMA aims to implement. However, the reality of configurations based on elements such as density and clustering present constraints when applied to especially informal settlement types, such as those present in the far south-western corner of Protea South (visible in Figure 4.3.2c).

Vertical aerial views of settlement layouts do not usually consider variables such as construction materials (where informal settlements have predominantly informal structures but brick and mortar is also present), height of structures, and location or layout of wet services infrastructure. The boundaries that can be identified from an aerial perspective in informal settlements in particular is not ideally suited to settlement type recognition for determination of suitability on dolomite if not combined with site visits to confirm the mentioned characteristics. The building material and weight (usually related to height), foundation type and subsequent ability to withstand ground motion in the form of dolines or sinkholes, as well as wet services materials and condition is of significant importance when determining suitability on dolomite. The classification is even more difficult to do when settlement spatial patterns differ across small geographical areas, for example where settlements are part-formal, part-informal and a combination thereof due to backyard dwelling infill. During fieldwork, I often observed a combination of what can be considered as settlement types within a single suburb or small dwelling cluster.

Although difficult, it is possible for settlement types to change over time and for these changes to be tracked to some extent using aerial photography (Ahmad, 2013). Such changes in settlement types are especially prevalent in South Africa where, for example, dwellings could change from wooden to metal or brick and mortar, thereby transforming temporary dwellings over time into more permanent structures. In some cases informal settlements may be subject to what is referred to, as mentioned earlier, incremental or roll-over upgrading (Kornienko, 2013), thereby formalising both the basic municipal services as well as the dwellings. Entire settlements may also be relocated during formalisation, thereby changing the land use and land cover pattern of the larger area. In other instances, informal settlement upgrading may take place through provision of basic services only, without housing interventions by municipalities or their service providers. Where such upgrading takes place, residents may be prompted by their perceived security of tenure to change their dwelling from informally built out of largely non-durable materials (such as wood or metal sheets) into one made of brick and mortar.

Such changes as described above – especially unapproved formalisation of informal dwellings take place on small scale on a daily basis and there is no quick way of translating these changes into information that can be used for spatial planning processes. The South African urban planning process usually covers a period of three to five years through the design and implementation of programmes such as Spatial Development Frameworks (SDF) and Integrated Development Plans (IDPs) (Ahmad, 2013). These plans consider spatial delineation of residential areas but cannot consider small-scale changes within individual settlements. Thus, a disjuncture could occur between what transpires in reality as opposed to what has been planned for a given area (*ibid.*). When low-income settlements are viewed from this formalised planning perspective, what may thus have been informally constructed dwellings made out of cardboard and metal sheets in one year, could very well be brick and mortar the next.

The identification of settlement types for purposes of my research takes cognisance of the spatial dissolution of boundaries between settlement classes. While recognising that no two settlements are exactly alike and graphic depictions of layouts fall short of reality, my research ground-truthed settlement types that can be applied during a multi criteria analysis process of low-income settlements on dolomite in Gauteng. My research does not consider these types the only potential selections possible, nor the likelihood of a combination of types to be present in a given situation. Thus, this research provides a general classification of settlement type based on dwelling materials, open spaces between dwellings and wet services configurations as parameters to influence physical disaster vulnerability on dolomitic ground, and not quantification of geotechnical and structural components related to dolomite hazard zoning.

4.1.4 Classification challenges for low-income settlements on dolomite

In addition to the effects that geographic location has on human well-being in terms of economy and infrastructure, as stated in South Africa's National Development Plan (NCP, 2012), the location of settlements has a significant impact on people's environmental and subsequently their physical well-being. When societies live on potentially dangerous ground, it directly affects their physical safety. Environmental hazards also indirectly affect their ability to overcome other related challenges that they may face in life, for example loss of income due to personal injury, or loss of possessions due to disaster. When disaster strikes, much-needed funds are channelled towards recovering from the situation, thereby challenging economic stability and mobility within family and community units. The dual contest of physical safety and social immobility, which compromised communities battle with, leads to reduced quality of life. My research of settlement types within the ambit of low-income settlements on dolomite seeks to add depth to understanding the complexity that surrounds human habitation on dangerous ground.

The Knowledge Faculty (KF) (KF, n.d.) is a private company in South Africa developing among others spatial products to assist investors in selection of properties. They designed “Cluster Plus” - a commercial product classifying settlement based on the financial/economic characteristics of dwellings. The classification relates well to dwelling form and function and reflects physical settlement characteristics effectively. The product also considers low-income settlement differences in much detail. However, since it is a commercial venture, KF does not publish the method of analysis and differentiation, thus making it ineffective to apply to my research. Additional difficulties related to the identification of especially different types of informal dwellings, stem from features such as:

a) an inability to distinguish dwelling types using aerial photographs and satellite imagery, since roof areas for different types of dwellings may look similar, while the wet services, sanitation, foundations and walls may be constructed in entirely different ways and with different materials for individual units; and

b) where dwellings are located close together or against each other, it is not possible to distinguish the individual units or boundary walls.

Only field verification can confirm differences between settlement characteristics (Ahmad, 2013). This makes commercial investigation and classification time-consuming and costly, especially where large expanses of settlements are anatomised. As noted earlier, the danger that dolomite poses to development can be overcome in selected cases via the use of geotechnical interventions and by employing particular, often costly construction materials and methods. South African regulations and guidelines for building on dolomite are clear about the procedures that have to be followed (SABS, 2012) and even in cases where site investigation and available documentation may not be comprehensive (for example where formal development took place before the 1970s), a conservative approach is followed when constructing buildings on dolomitic ground (Kleynhans, personal communication, 2012; Grobler, personal communication, 2014; McLuckie, personal communication, 2015).

These guidelines and practices are often unknown and poorly understood by the populace who lives on dolomite. The result is that households may purchase properties, develop informal unapproved dwellings, or rent units, not aware that the ground may be unstable. In such cases, they may further unknowingly engage in behaviour that puts them at significant risk. Even well-educated citizens living on dolomitic ground in formally developed middle- and high-income residential areas often have little understanding of the disaster risk they are exposed to and that their wet services- and water-handling conduct may increase the risk for subsidence or sinkholes to occur. Even when residents are aware that they live on dolomite, they usually do not know what they can do to reduce the risk (Cowie, 2012), while the dolomite management programmes are operational only in large commercial developments (CoT, n.d.). In low-income settlements there is even less awareness of the dangers for housing development and wet services delivery and maintenance on dolomite. With dolomite in some areas in Gauteng hidden under the surface soils with little or no evidence visible above ground, convincing communities of the risks they face is a challenging task.

4.2 Low-income settlements on dolomite

4.2.1 Dwelling characteristics

As noted in Section 4.1, low-income settlements often lack boundaries between formality and informality of structures. Characteristics of these settlements that formed part of my research ranged from complete informality, without considering formally approved planning processes, architectural design or construction methods, to subsidised or bank-guaranteed (mortgaged) housing, and then with or without backyard dwellings.

The GCRO conducted a Quality of Life (QoL) Survey across the Gauteng City Region (GCR) (an area that includes the Gauteng Province and a number of immediately surrounding municipalities) in 2011 that identified, among other variables, materials used in the construction of dwellings. The sample of 16 729 respondents indicated a considerable percentage of respondents (on average between 5 and 35% across municipalities) living in dwellings made of non-durable building material (Figure 4.2.1a). Such materials include wood, corrugated iron sheets and even cardboard and plastic sheeting. There was no differentiation between dwellings built from recycled or recovered brick versus ‘new’ bricks. The Figure shows the percentage of types of materials used to construct dwellings on the vertical axis, with colours on the top of the legend represented by colours on the top of the stack graphs, in the municipalities considered part of the GCR. Corrugated iron makes up a large percentage of the dwelling materials – both for roofing and walls (almost 40% in Westonaria), with wood, and mud and cement mixtures also playing a notable role. I noted during sample site visits that the topmost material type in the graph, namely ‘bricks with no plaster or internal covering’ is present to a large extent in low-income and informal settlements where unapproved formalisation and backyard dwelling construction is prevalent.

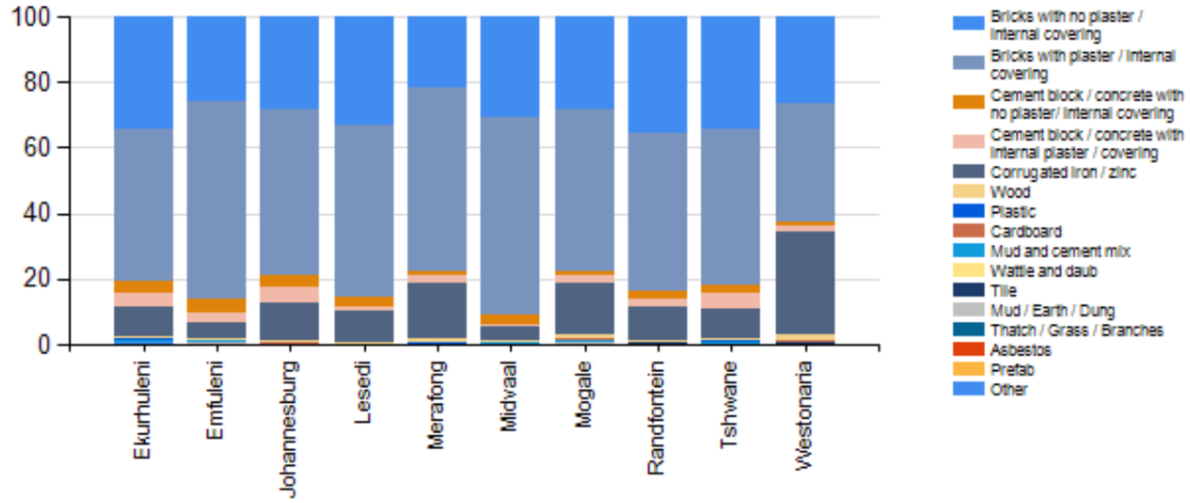

Figure 4.2.1a: Materials used for dwelling construction in the Gauteng City Region

Source: GCRO (2011c).

Based on the Knowledge Factory's classification, the most basic scenario of low-income settlements and informally built dwellings is that they house the poorest of the poor communities (K.F., n.d.). These settlements are constructed usually without permission to do so, on open ground – such land usually being owned by the state or municipality and zoned for a purpose other than residential. A next tier of dwelling type may be constructed using informal and recycled building materials and construction methods, on ground allocated to the occupants by means of an informal lease or rental arrangement with the landowner. In this case, private landowners may make parcels of land available for informal settlement development for commercial gain. It is also common for informal dwellings to be managed by a "*shack lord*", who, without having a legal right to the land, rents out sub-standard or temporarily constructed dwelling units. In all these above-mentioned situations, whether via formal or informal commercial arrangement, the dwellings do not conform to building standards or guidelines and are constructed without approval or input from authorities or specialists, as is the case with formal residential township development and approved building alterations. Figures 4.2.1b and c show examples of informal dwellings, constructed from a variety of materials.

Figure 4.2.1b: Informally constructed dwellings made of wood and metal sheeting (alongside N14)

Source: GCRO (2012b).

Figure 4.2.1c: The use of different materials in the construction of informal dwellings (Makause, in Germiston and Harry Gwala, in Watville respectively, both informal settlements in Ekurhuleni)

Source: Author's photographs (2013).

Basic services delivery to informally developed settlements may occur only after long processes of negotiation, often associated with violent protests or pursued through the courts, as in the cases of Mnisi and Nokotyana respectively (Mnisi v CoJ, 2014; Nokotyana v EMM, 2009). Through these actions, communities attempted to gain access to for example piped potable water, waste removal and sanitation. When installed, the services are often provided in the form of communal standpipes and temporary non-waterborne sanitation, either as chemical toilets, or sealed pits which require suction or emptying less often. The latter imply ongoing maintenance cost to municipalities. In these settlements, central high-masts provide public lighting. Where sanitation solutions are not sufficient in terms of numbers, or are rejected as in the case of chemical toilets in some areas in Ekurhuleni and the City of Cape Town, residents resort to self-dug unsealed pits. Such pits are often also used for grey water disposal or drainage. Such situations hold significant risk if it intersects with dolomite. Figures 4.2.1d and e shows examples of wet infrastructure, or lack thereof, in informal settings.

Figure 4.2.1e: Sanitation infrastructure commonly found in informal settlements (Harry Gwala, Watville)

Source: Author's photographs (2013).

In contrast to the materials used for informal dwelling construction, formal housing development employs approved building materials and techniques and the dwelling design conform to building regulations (Figure 4.2.1g).

Figure 4.2.1g: Typical freestanding low-income subsidy-funded housing (Goudrand/Kagiso, Mogale City)

Source: GCRO (2012b).

Beneficiaries of subsidy-funded housing may remain in informal settlements while awaiting access to formal lodging. Alternatively, during this *pro tem* time, a stand or erf may be allocated to them in which case informality often emerges. Where stands are allocated and informal dwellings constructed, the informal dwellings in some cases remain after construction of the formal subsidised top structure. After construction of subsidy-funded housing, additional dwelling units may be constructed, thereby increasing the originally planned dwelling and occupation density of the area.

An example of such a situation is visible in Figure 4.2.1h, where subsidy-funded housing (an example is the light green house in the figure), four brick-and-mortar backyard units (under construction behind the light green house), and dwellings built from metal and wood sheeting (in the corner closest to the viewer) is visible, all constructed on a stand which was originally intended for one dwelling unit. Figure 4.2.1i shows an example of a mixture of construction materials and -methods on formally delineated stands.

Figure 4.2.1h: Formally constructed housing with informal backyard units (Winnie Mandela Park, Tembisa)

Source: GCRO (2012b).

Figure 4.2.1i: A mix of formal and informal dwellings on formally serviced sites (North of Tembisa, Olifantsfontein)

Source: GCRO (2012b).

The level of informality associated with the construction methods and materials, and the associated type or lack of wet infrastructure poses a potential threat when these forms of development intersect with dolomitic ground. Wet infrastructure service delivery to these units is either in the form of stand-piped water (i.e. a water tap every 100 to 200m), usually with no grey water drainage provided, and a combination of communal and individual sanitation. Where stand pipes and taps leak or where sanitation infrastructure is leaking or is inappropriate to development on dolomite, the dissolution of subsurface geologic strata may occur.

Where houses are individually owned and where basic wet service delivery takes place at stand or dwelling unit level, development on dolomite generally follows the necessary geotechnical investigation sequences, building guidelines and SABS requirements (SABS, 2012). Therefore, when dealing with the physical vulnerability of such settlements on dolomite, it is not the construction methods or materials, but rather the maintenance and after-care of the infrastructure that matters most. Such situations, where activities related to post-development risk detection, monitoring and reduction is lacking, leaks in wet-infrastructure left undetected and not repaired, pose a significant subsidence and sinkhole risk on dolomitic ground.

The uppermost tier in the low-income range of settlements that I consider in my research is bank-guaranteed, privately funded and commercially constructed housing. This usually takes the form of fairly small (approximately 100 m²) dwelling units on separate stands, with shared foundations (Figure 4.2.1j), walk-up apartments (Figure 4.2.1k), blocks of flats, or otherwise associated or connected units in a sectional title or building association format. The latter types are often in the form of gated complexes or estates, meaning that some collective decision making on maintenance expenditure takes place. Such collective management approaches could have a positive impact on wet infrastructure maintenance regimes on dolomite if the members of the body corporates or associations involved are aware of and committed to structure and infrastructure risk reduction.

Figure 4.2.1j: Duplex sectional title units on dolomite (Lyttelton Manor Extension 3, Centurion)

Source: Author's photograph (2015).

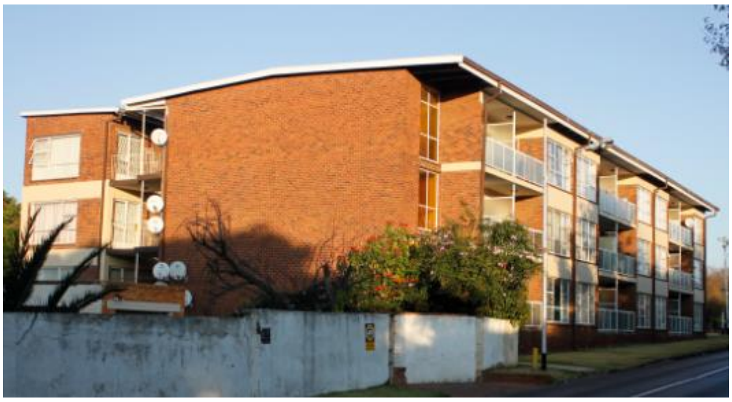

Figure 4.2.1k: Triple-storey walk-up apartments (Roodepoort, Johannesburg)

Source: GCRO (2012b).

In the above-mentioned dwelling and settlement types, rules regarding occupancy, changes to building facades, and construction of structures on common property are strict, thereby ensuring a high level of formality associated with such developments. Since awareness regarding the risks of development on dolomite originated in the 1970s, dolomite development guidelines were enforced, geotechnical and building requirements related to dolomitic land rigorously guide the development. As is the case with part- or fully funded low-income housing, maintenance and the monitoring of leaks become an important factor when considering physical vulnerability of such settlements on dolomite.

The dwelling characteristics of low-income settlements described above present the results of the pre-feasibility phase of my research. Although the settlements on dolomite in Gauteng display the observed range of characteristics, the settlement types are not mutually exclusive and different dwelling material and construction types are often found in a mixed fashion in close proximity to one another. Therefore, decision making in the national, provincial or municipal sphere regarding the development or upgrading of low-income settlements on dolomite is riddled with difficulties when attempts are made to apply dolomite-specific building regulations and guidelines intended for formally approved settlement forms to the low-income domain.

4.2.2 Sample site investigations

As alluded to earlier, the form and function of government-funded housing in South Africa has remained much the same over the past two decades. The standard layout consists of individual stands, each with a freestanding house of a current minimum size of $42m^2$ (before this minimum was introduced in 2000 dwellings were often smaller). The row-upon row of small freestanding houses leaves little space for deviation from the predefined form. Planners and engineers take note of geographical features such as floodlines, slopes, valleys and watercourses, but since the layout design does not consider potentially dangerous types of ground for development, such tracts of land are left undeveloped (Huchzermeyer, 2011a). This means that on the one hand these areas become susceptible to informal development, and on the other hand that alternative layout patterns and densities are not usually explored. Due to the standardised nature of the housing subsidy (coupled with the need for relatively low cost of land which is usually on the periphery of urban areas), well located land that might be more expensive to develop remains untouched. The same principle has until recently been applied to informal settlement upgrading, basically making *in-situ* upgrading 'unfeasible' (Huchzermeyer, personal communication, 2015).

As opposed to single stands with small freestanding houses, walk-up apartments and row housing have been considered and implemented in a minority of locations. This settlement form was commonly constructed on dolomite in the 1970s and 1980s, as is evident in Lyttelton Manor

Extension 3 (Figure 4.2.1i). However, in the context of so-called RDP or BNG projects it is considered an "alternative" form and remains implemented in limited selected locations such as Vosloorus Extension 28 (Figure 4.3.2j). In addition to examples presented in Figures 4.2.1f to j, Figures 4.2.2a and b as well as Figure 4.2.2d show supplementary illustrations of dwelling structures encountered on or close to dolomitic ground during the course of this study.

Figure 4.2.2a: Attached dwelling units on shared foundations on dolomite (Goudrand East, Mogale City)

Source: GCRO (2012b).

Figure 4.2.2b: Hostel-type dwellings (towards the East of Winnie Mandela Park, Tembisa)

Source: GCRO (2012b).

To date a significant amount of formal and informal development has taken place on dolomite in Gauteng. However, relocations of entire communities remain a contested domain. An example of recent relocation of a community took place during 2013, in the town of Khutsong, near Carletonville, in the Merafong Local Municipality, which forms part of the West Rand District Municipality (Figure 4.2.6a). Here, residents were moved from a formal apartheid-era township that was located on dolomite ground to a newly developed government-subsidised housing project approximately two kilometres towards the South-east (Figure 2.2.2c). Due to the expanse of dolomite across this entire region, the new site was also on dolomite (Figure 2.2.2d). The dolomite hazard assessment for the development in question considered the potential for development of small sized sinkholes to be probable (Stoch, personal communication, 2012), and therefore implementation of dolomite-specific infrastructure interventions such as appropriate Polyvinyl Chloride (PVC) (synthetic thermoplastic) water and sanitation pipes supported a decision allowing construction of low-cost housing in the area. The new dwellings were constructed using an accepted technique to stabilise dwellings on dolomite – that of constructing reinforced raft foundations (Figure 4.2.2e). However, the sizes of this particular development's raft foundations are approximately 8mx6m, which is considerably smaller than the dwellings that are usually built in higher-income urban areas on dolomite using the same technique.

This begs the question as to whether the risk of sinkhole development would in reality be mitigated, considering the relatively small raft foundations and uncertain maintenance regime of wet services. In addition, there was no sign of gutters or stormwater runoff being installed, other than a single stormwater canal towards the South West of the development. Rainfall run-off thus entering the ground directly alongside the building foundations – a feature that is considered inappropriate for development on dolomite in other areas in Gauteng (CoT, n.d.) – could pose a sinkhole or doline risk. During subsequent site visits in early 2014, several small sinkholes have already been identified throughout the development and up to seven of the newly constructed houses had to be demolished (Stoch, personal communication, 2014), confirming suspicions that the technical interventions may not have been entirely successful.

Figure 4.2.2d: Low-density freestanding housing units on dolomitic ground (Khutsong, near Carletonville)

Source: Author's photograph (2013).

4.2.4 A brief overview of low-income settlement density in the context of this study

The conventional ways of analysing density are either Du/ha (residential density) or occupational density which includes population density (conventionally individuals per room. However, in terms of geotechnical writing it may also refer to individuals/ha) and spatial arrangement of density. The vertical spatial arrangement of dwelling units in the form of multi-storey arrangements enables higher population densities (UN-Habitat, 2012).

In South Africa, the arrangement of dwelling unit density, potential population density and occupational density, and then the spatial arrangement of the unit density, are reflected on by planning authorities when considering development projects. However, a large portion of low-income settlements where informality and backyard dwellings proliferate are unauthorised and not captured in an accurate manner. The settlement typology that is achieved in these latter instances exists via delineation of stands either in an informal manner, or via formal planning processes, as Figures 4.2.4a to 4.2.4e show.

In addition to the determinants and dimensions of settlement densities, the level of basic service delivery adds to the liveability of the settlements. Inadequate or lower levels of basic service delivery may result in a misrepresentation of the applicability of the traditional assumptions regarding actual density. For example: even if a settlement or suburb has a high spatial density, thus a high ratio of Du/ha and/or a large number of individuals/ha, in combination with high levels of service delivery, access to public amenities and recreational space, residents may readily accept living in the area and their living conditions may be considered tolerable. However, even where spatial densities and Du/ha ratios may be low, thus allowing more "breathing space", but where the situation is characterised by poor access to services, amenities and recreational space, the living conditions are not necessarily desirable.

The latter situation is often the case in informal and low-income settlements in South Africa. When considering wet infrastructure-related risk on dolomitic ground in association with these characteristics mentioned above, for the purposes of this study I refer to "density pressure", using the terminology of “density” as a proxy. The density relates in this instance thus to the level of wet service delivery in association with the density pressure within the low-income settlement under consideration.

The density of low-income settlements in the context of my study is focussed on what may be considered low to medium density dwelling unit distribution, averaging approximately 60 to 100 Du/ha gross density (gross density including roads and open spaces). Using the latest available Stats SA census enumerator area averages (2011), this translates roughly to between 180 to 500 individuals/ha. In comparison, high residential densities exist in low-income areas in cities such as Nairobi, where an estimated 862 persons per ha lives, based on the 1999 Population and Housing Census, while the real density revealed by Huchzermeyer (2011b) an average of up to 5 242 and even an estimated 5 371 persons per ha.

As noted in the methodology (chapter three), the density of settlement types based on dwelling layout composition and wet services infrastructure distribution (if applicable) was determined using remote sensing and aerial photography, making use of measuring tools in GIS software, as well as through field verification. Figures 4.2.4a, b, c, d and e present selected visual representations of the densities applicable to low-income settlements on dolomite in context of my research. These density characteristics of these examples formed the basis for the settlement type categorisation for low-income settlements on dolomite that is considered in Section 4.3.

Figure 4.2.4a: Medium-density informal settlement with a right-angle layout (dwelling units approximately 10m² in size; approximately 100 dwelling units per ha (Du/ha) gross density)

Source: CoJ (2009a).

Figure 4.2.4b: Low-density informal settlement with an irregular layout (dwelling units on average 10m² in size. However, the absence of clearly visible walls between some of the units using aerial photography present challenges; approximately 80 Du/ha gross density)

Source: CoJ (2009a).

Figure 4.2.4c: Low-density housing (dwelling units approximately 40m² in size. However, larger units are visible where owners extended the dwelling, approximately 50 Du/ha gross density, expected to increase in future due to establishment of backyard dwellings)

Source: CoJ (2009a).

Figure 4.2.4d: Originally low density housing, however densifying with backyard units (formal units on average 120m² and backyard dwellings between 10 and 15m² in size, originally approximately 90 Du/ha gross density, increasing to approximately 90 Du/ha gross density)

Source: CoJ (2009a).

Figure 4.2.4e: Low density somewhat higher income formal settlement, where original dwellings are larger and there is not much space for backyard infill (units on average 120m² in size, approximately 60 Du/ha gross density)

Source: CoJ (2009a).

4.3 Settlement types on dolomite

4.3.1 Defining low-income dolomite settlement types

Settlement types for purposes of this research consider primarily density as discussed above, dwelling type as it relates to building materials, and wet services infrastructure type and configuration. Initially, standard density delineations applicable to development of residential stands on dolomite (CGS, n.d.(a)) were considered for application in my research. However, informal settlements and areas where backyard units proliferate do not portray the characteristics considered in construction guidelines. The difficulty in identifying individual dwelling units in many of these instances, in addition to the existence of newly inserted dwellings and the ongoing trend towards further densification, in future possibly multi-story development reduces the possibility to apply the concept of "dwellings per hectare" as is reflected in the dolomite regulations, to the investigated configurations of informality. The dwelling density considerations and information gathered from field visits related to building materials and wet services, as described in Section 4.2.4, enabled the development of settlement type classification on dolomite (Table 4.3.1). The settlement types are grouped into six classes, (A to F), with descriptions of each class according to characteristics that were most prevalent during field observations. Figures 4.3.1.a to j graphically depict the characteristics of each type.

Table 4.3.1: Settlement types identified and described for purposes of this research

Type	Name	Description of dwellings commonly found in this type
A	Shacks	Small dwellings constructed from wood, cardboard, metal sheets or plastic. Floors are usually covered with soil, dung, wood or cardboard (sometimes later replaced with concrete) (Figures 4.2.4a and b)).
B	Informal (not approved by municipality, not compliant with building regulations)	Dwellings of roughly the same size as Type A, but with dwellings constructed of cement bricks, and usually second-hand brick-and-mortar randomly spaced throughout the settlement.
C	Low-cost formal housing	RDP-type dwellings, part- and privately mortgaged/bank-guaranteed (in South Africa also referred to as 'bonded') residences, where individual stands/erfs can be clearly recognised, and formally constructed out of cement, brick and mortar. Dwelling sizes generally remain small.
D	Low-cost formal housing with backyard units	Similar dwelling size as Type C but with informally constructed dwellings on the formal stands in addition to formal low-income housing. This differs from Type B which also has dwellings in the settlement constructed out of brick and mortar, in that Type D has a formal and more regular layout, based on formal planning design and usually infrastructure and basic services having been provided.
E	Row or attached units on common raft foundations	These types provide opportunity for the same or slightly higher population densities than Types A to D, but with increased stability on dolomite (depending on the specific hazard level of the dolomite in a given location). Historically, before dolomite building regulations and standards were rigorously applied, these dwelling types shared foundations that were normal to all dwellings whether they were on dolomite or not – the concept of raft foundations was only introduced after the 1970s. The average height of these units range between two and four storeys.
F	Apartments and high-rise flats (more than four storeys without an elevator; or whichever building regulations permit in a given municipality)	Medium to high density social housing, usually unsuitable for construction on dolomite due to the significant increase in structural weight and construction costs. Recently, a high rise apartment block (with bachelor units selling for prices from just under R 500 000 each) was approved and is under construction in Gerhard street in Centurion, Gauteng (during 2015), on dolomite. However this is not the norm and was thus only included in the early research classification stage since it forms part of low-income housing provision and urban densification strategies worldwide especially on non-dolomitic ground.

To distinguish between “more” or “less” dense forms of the same type, the numbers “1” and “2” are associated with Types *A*, *B*, *C* and *E*, with dwellings in density form 1 loosely spaced compared to those in form 2. For purposes of this study, *A1* and *B1* refer to low density distribution, while *A2* and *B2* refer to medium density (Figures 4.3.1.a to d). Owing to high-rise residential flats not commonly being developed on dolomitic ground, the high density depicted by structures that fall into category F depicted in Table 4.3.1 is not included in detail in the context of my study.

Due to the influence that wet services integrity and maintenance has with regard to dolomite risk, the configurations of such infrastructure were included in the delineation of settlement types. In cases of dwellings made of non-durable building materials (Types *A* and *B*), it is possible that wet services such as standpipe-supplied potable water and any given form of sanitation services may or may not be present. In some cases, where no potable water is supplied, the residents rely on borehole or river water, or water brought in by vehicles or other means. Therefore, although the presence of wet services is included in the graphic representations, the study recognises that it may be absent. The resultant analysis considers the hypothetical existence of such services, even if it may not currently exist in a given settlement. While individual dwelling sizes may differ from the given descriptions, the average size of dwelling units in the area is considered. The distribution of dwellings may also be more irregular than depicted in the representations.

In Figures 4.3.1a to d and g, dwellings depicted in grey with black outline represent those constructed of informal materials such as wood, metal sheets and cardboard. Unit depicted in yellow blocks with black outline represent dwellings constructed out of cement bricks, new or re-used brick and mortar or similar materials (considered “more durable” to some extent), regardless of whether it conforms to design or building specifications, building application processes and building regulation requirements. The reason for this undefined specification that treats all brick and mortar buildings as one feature is that the description focuses on spatial density and not on whether the density was achieved via formal or informal processes. Features in brown and outlined in black depict examples of positioning of sanitation units (toilets) in or near dwellings while blue lines and blue cylindrical features present examples of the presence of potable water services (in the form of pipes and taps).

The main difference between Types *A* (Figures 4.3.1a and b) and *B* (Figures 4.3.1c and d) is that settlements of Type *B* display a significantly higher proportion of dwellings (estimated 40% or more) constructed from cement, brick and mortar, even though they remain informal in nature.

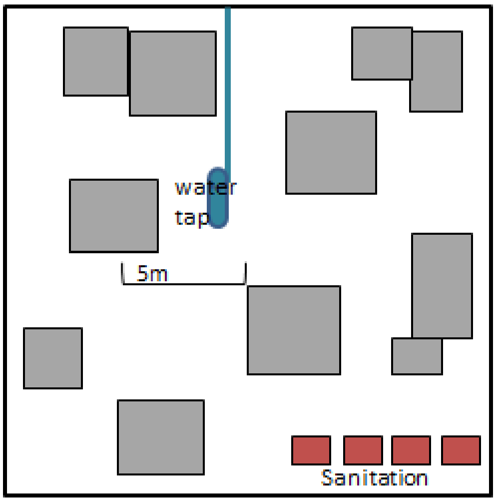

Figure 4.3.1a: Type A1: Very low to low density, shacks

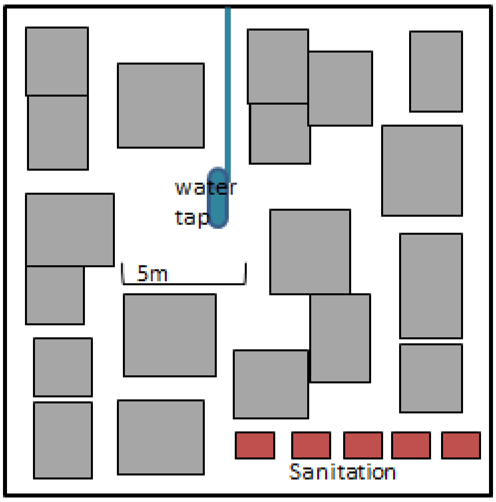

Figure 4.3.1b: Type A2: Low to medium density, shacks

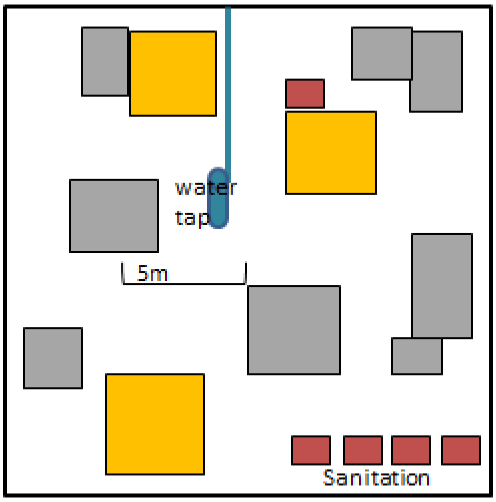

Figure 4.3.1c: Type B1: Very low to low density, informal dwellings

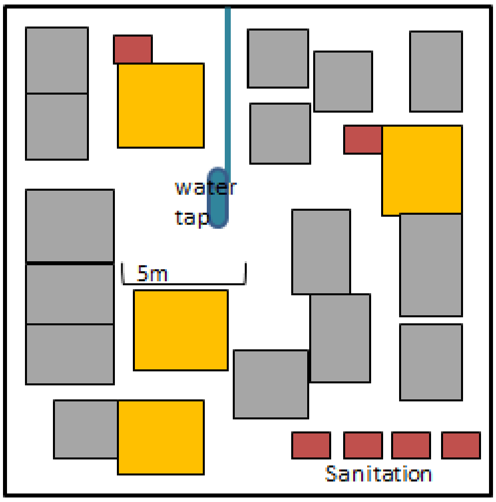

Figure 4.3.1d: Type B2: Low to medium density, informal dwellings

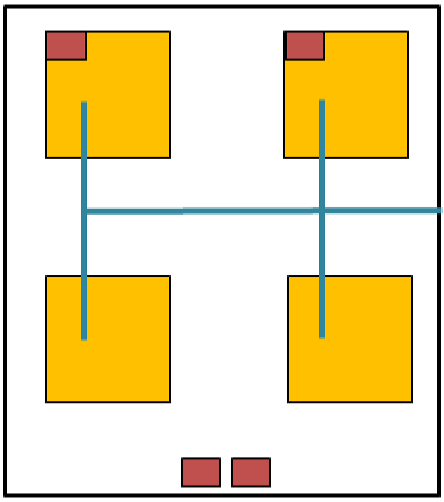

Figure 4.3.1e: Type C1: Very low to low density, formal housing (including fully or part subsidised housing)

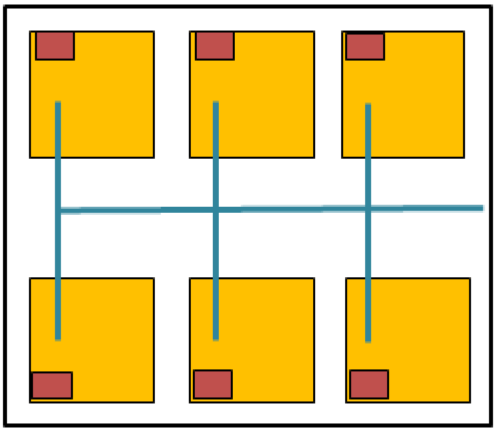

Figure 4.3.1f: Type C2: Low to medium density, formal housing (including fully or part subsidised housing)

Although Types *C1* and *C2* both conform to the “low density” classification devised by the CSIR (2009), two distinct densities were defined for this study after field visits were done, reflecting the situation that was found in sample settlements, with Type *C1* being less densely spaced than *C2* (Figures 4.3.1.e and f). Settlement Type *D* is initially comprised of formal housing, which includes fully subsidised or part subsidised bonded or privately mortgaged housing. This Type may originally have been classified as Type *C* after initial construction, but due to the emergence of backyard dwellings and shacks in-fill between the free-standing brick and mortar dwellings is now considered Type *D*. Sanitation could be formal or informal in nature. Figures 4.3.1g and 4.3.4e)

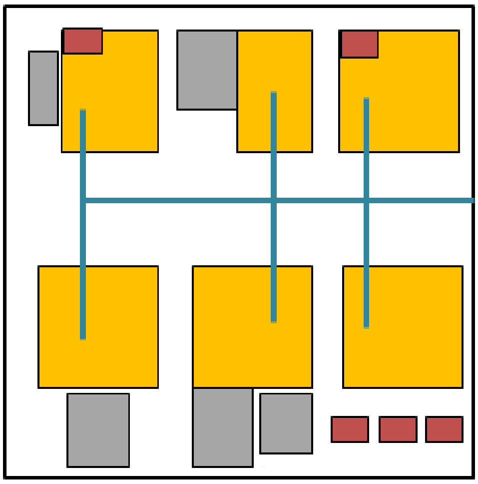

Figure 4.3.1g: Type D: Low to medium density, formal housing with backyard units

Settlement Types *E1* and *E2* reflect formally constructed dwellings on shared or raft foundations considered suitable when building on dolomite. The reason for including shared non-raft foundations is due to a large number of this type of dwellings that were built during the 1970s and shortly thereafter that did not have raft foundations implemented, but where wider foundations (at the time usually not including additional reinforcements) were considered safer options on dolomitic ground at the time. Although Figures 4.3.1h and i depict rectangular layouts, dwelling units with this foundation type may be staggered or diagonally arranged. The stands, when designed for construction on dolomite, conform to the stand size and Du/ha determination as per dolomite hazard investigation requirements. Type *E1* reflects predominantly single-storey dwelling units on shared foundations, while Type *E2* reflects multiple storey units (up to three storeys high, or depending on what is deemed acceptable for the specific dolomite hazard level as per SABS (2012).

As noted earlier, settlement Type *F* is not generally suitable on dolomitic ground, but represented since it may be contemplated in unique cases where high dwelling density on dolomite is indeed possible. However, since this form is largely avoided by planners and developers alike, this Type is excluded from the data collection and result analysis of my research.

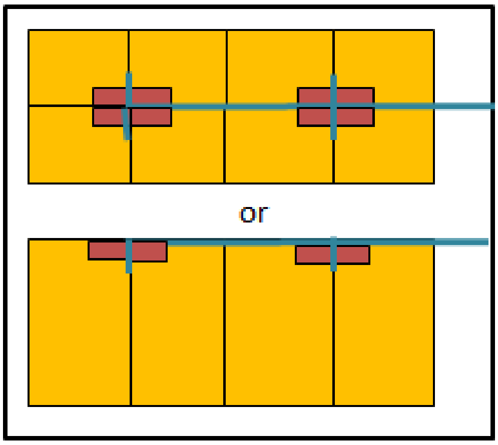

Figure 4.3.1h: Type E1: Low to medium density, with shared or raft foundations

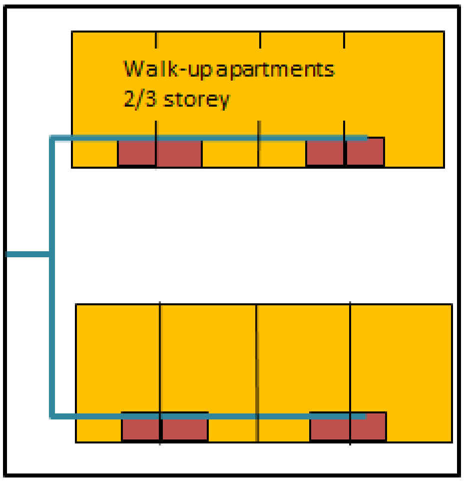

Figure 4.3.1i: Type E2: Medium density, with shared or raft foundations

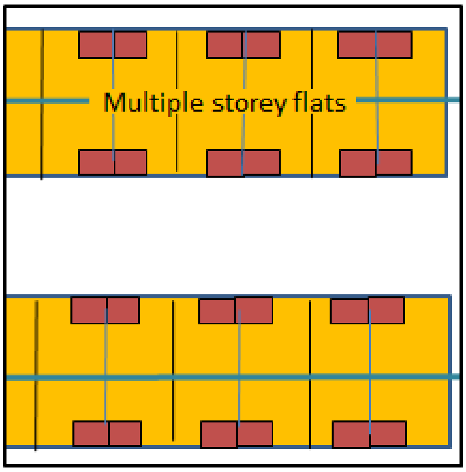

Figure 4.3.1j: Type F: Medium to high density, multiple storey and high-rise flats

4.3.2 Comparing diagrams and sample settlements

The defined settlement types are unlikely to appear in reality exactly as per the graphical representations above. Even the descriptions do not cover all possible permutations of actual settlement characteristics. For example, plot and dwelling sizes may vary while the position of wet infrastructure and layout may differ. However, the general combination of features visible from an aerial and in-field perspective assists in categorising each real-world settlement type. Figure 4.3.2a to Figure 4.3.2j show the sample settlements engaged in this study in relation to the settlement types (white patches in some Figures are due to satellite or aerial image distortions).

Figure 4.3.2a: Winnie Mandela Park resembles settlement Type *D.* Towards the South-East of the view settlement Type *B2* is visible (towards the east of the road indicated in yellow)

Source: Map compiled by AECOM SA (Pty) Ltd, service layer credits: Esri, DigitalGlobe, GeoEye, icubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

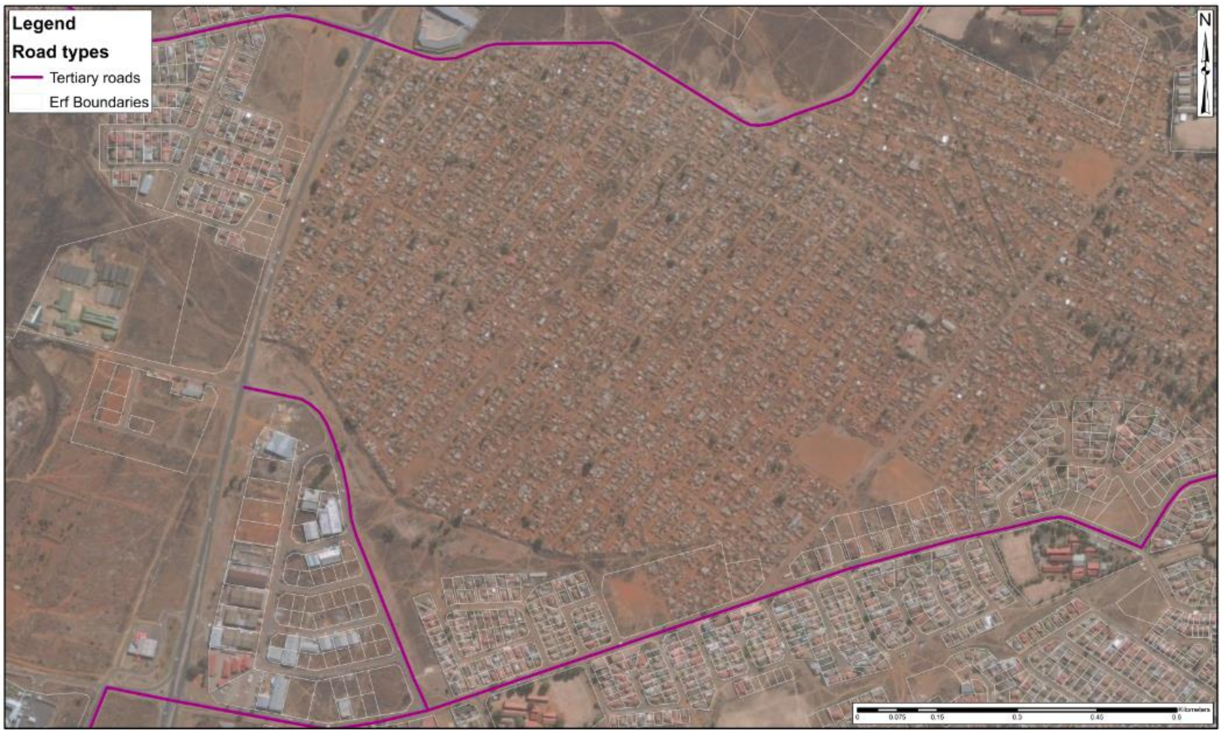

Figure 4.3.2b: Thembelihle resembles settlement Type *B1*

Source: Map compiled by AECOM SA (Pty) Ltd, service layer credits: Esri, DigitalGlobe, GeoEye, icubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Figure 4.3.2c: Protea South resembles a combination of settlement Types *A1* and *A2*

Source: Map compiled by AECOM SA (Pty) Ltd, service layer credits: Esri, DigitalGlobe, GeoEye, icubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Figure 4.3.2d: Goudrand East resembles settlement Type *E1* (in Mogale city)

Source: Map compiled by AECOM SA (Pty) Ltd, service layer credits: Esri, DigitalGlobe, GeoEye, icubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Figure 4.3.2e: Kagiso/Goudrand West, resembles settlement Types *A2* and *D* (where *D* was formerly Type *C*, but now in-filled with informal backyard dwellings)

Source: Map compiled by AECOM SA (Pty) Ltd, service layer credits: Esri, DigitalGlobe, GeoEye, icubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

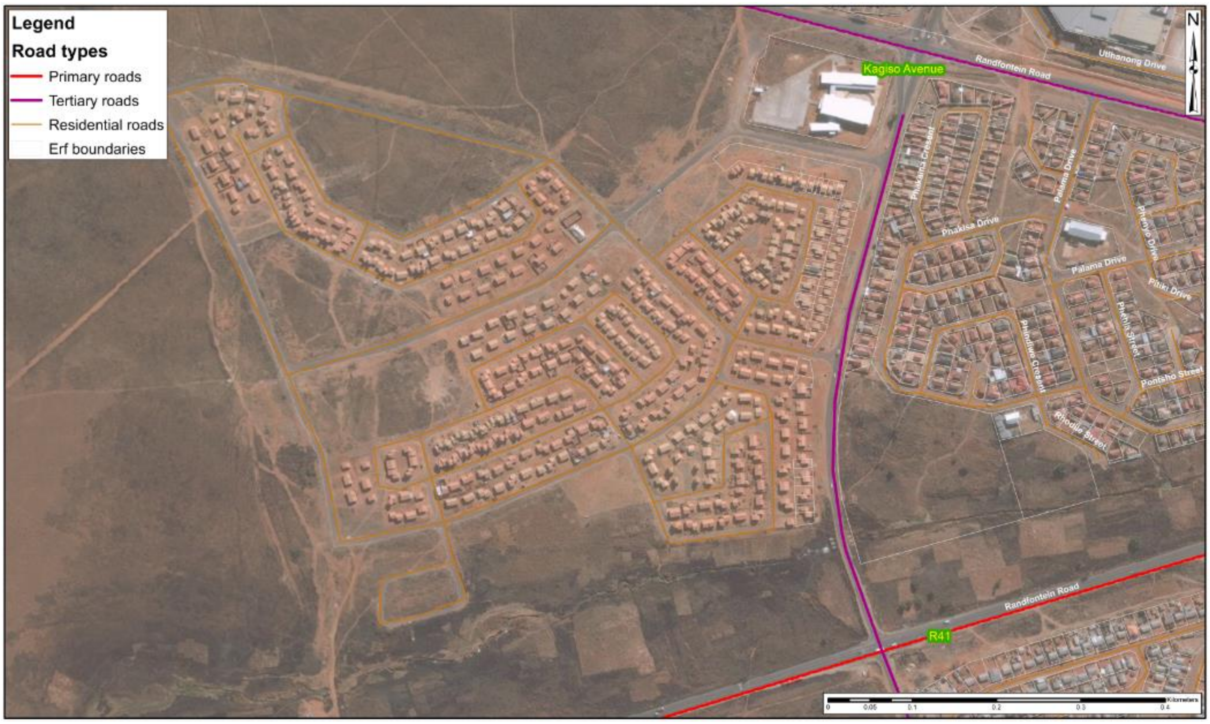

Figure 4.3.2f: Kagiso resemble settlement Type *E,* with a limited amount of Type *C* units included

(in Mogale City)

Source: Map compiled by AECOM SA (Pty) Ltd, service layer credits: Esri, DigitalGlobe, GeoEye, icubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Figure 4.3.2g: Khutsong (historical township location) resembles settlement Types *A* (towards the North-West), and *D*

Source: Map compiled by AECOM SA (Pty) Ltd, service layer credits: Esri, DigitalGlobe, GeoEye, icubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Figure 4.3.2h: New developed area in Khutsong resemble Type *C1*; however, it may experience in-fill with informal dwellings, thus changing it into Type *D*

Source: Map compiled by AECOM SA (Pty) Ltd, service layer credits: Esri, DigitalGlobe, GeoEye, icubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

Figure 4.3.2i: Vosloorus Extension 3 resembles settlement Type *C2*

Source: Map compiled by AECOM SA (Pty) Ltd, service layer credits: Esri, DigitalGlobe, GeoEye, icubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

CHAPTER 6: WHERE COMMUNITIES MEET DANGER: CONCLUDING THE RESEARCH AND CONSIDERING FUTURE APPROACHES

6.1 Introduction

This chapter considers the research process and challenges, and the outcomes of the research in context of the literature review and the research method, in relation to the wider implication that the research outcome has in relation to the physical vulnerability of low-income settlements. This outcome can be applied not only on dolomite but also on other types of potentially dangerous ground. This concluding chapter contemplates the limitations of the currently implemented solutions in terms of challenges of low-income settlements located on potentially dangerous ground. The chapter also highlights the need for additional parameters to be considered and avenues of research to be pursued, to not only improve the decision making process itself, but also to enhance the sustainability of development or upgrading of low-income communities who find themselves in danger of exposure to disaster risk or potential relocation due to the level of hazard exposure they face.

As discussed by authors such as du Plessis and Landman (2002), Osman and Herthogs (2010) and Enninful (2013) and supported in South African context by policies, including the National Housing Programme (NDH, 2004), the National Housing Code (DoHS, 2009) and NUSP (DoHS, 2011), a shift is emerging in the emphasis of urban development and low-income housing provision towards enabling more cost-effective sustainable living environments to emerge. This shift is placing new demands on not only financial and budgeting requirements, but also on planning and technical professions involved with the design and implementation of these human settlements. As a result, the professionals in particular are being confronted with the need to consider potential unfamiliar and unconventional approaches where physical and social sciences meet. It is expected that these professionals will increasingly turn to guideline-type documents as opposed to purely standards and regulatory boundaries in order to obtain the information they require to perform their work effectively (CSIR, 2000: 5). This introduces new and multi-faceted solutions to mainstream and historically proven avenues applied to development challenges.

Within this multi-faceted and challenging environment, my research considered the physical vulnerability of low-income settlements on dolomite. In the context of Gauteng, South Africa, the available literature and consideration of settlement types, as well as guidelines related to development on dolomite, offers potential for supplementary approaches to the current decision making processes related to settlement upgrading, development or relocation. When considering the conundrum of locating or allowing low-income settlements to exist or be upgraded on dolomite, there is no easy solution – a finding that is supported by the significantly varying perceptions reflected by the respondents that was part of the AHP assessment method as presented and discussed in Chapter five. However, within this variation of perception there are areas of commonality which could open avenues for disaster risk reduction intervention that both enable and place responsibility on officials and municipalities, as well as owners and communities of properties or dwellings that are located on dolomite.

As discussed in this thesis, the geotechnical standards and characteristics of infrastructure related to residential housing development on dolomite, as well as housing provision and housing policies does not commonly take into consideration human behaviour and community interaction to promote disaster risk reduction, especially after development is completed or handed over to new residents or owners. In addition, the technical training of engineers and scientists with regard to the dangers of developing and living on dolomite focus predominantly on prevention and pre-development interventions from a civil and geotechnical perspective, as opposed to monitoring and post-development risk reduction that incorporates elements of social interaction and human behaviour (McLuckie, 2015). Finally, current standards and regulations regarding development on dolomite cater predominantly for middle to high income types, with low-income settlement types especially in the informal sector rarely being considered for development or upgrading (Kleynhans, personal communication 2012). In the case of informal settlements, upgrading in particular is actively discouraged (*ibid.*). The challenge with this status quo is that the speed of development and densification pressure that is characteristic of urban areas such as the Gauteng City Region is placing significant strain on the continued implementation of these conventional approaches.

My research indicates a need to increasingly consider additional parameters related to manageability from an official perspective and capacity of communities when deciding on the design, development, upgrading and/or relocation of low-income settlements on dolomite. These parameters associated with official and municipal elements of management and especially post-development and post-upgrading monitoring of low-income housing located on dolomite, has emerged as a key focus area that needs to be incorporated into the current spatial and housing decision making and action plan processes in municipalities. However, my research also indicated that this incorporation of additional process elements and behavioural elements into the development-on-dolomite debate needs to be done in a framework that maintains conformity with geotechnical variables. Thus, I call for a more multi-disciplinary approach that opens up the possibility of considering management and reduction of disaster risk, by formally including municipal monitoring intervention and ownership responsibility, as well as community awareness.

By considering these additional elements of intervention that my research has highlighted, it may be possible to reduce the future disaster risks that relate to maintenance and monitoring of wet service infrastructure on dolomite as opposed to focusing primarily intervention during the design and construction phases of development. However, official management capacity and behavioural or social engagement constraints may present challenges to the practical incorporation therefore in the already sluggish development and upgrading process for low-income settlements. The same could be said for settlements located on dangerous ground in other instances, such as where flooding and landslides are prevalent (Prenger-Berninghoff and Greiving, 2015). Thus, the suggested interventions may be more effective if implemented via guidelines rather than attempting to incorporate them as standards and regulatory requirements. In this form, the guidelines would still be able to provide a measure of intervention and responsibility-taking while enabling the interventions to be customised to the specifics of the location, municipal structure and community where it is applied.

6.2 Responding to the research questions and objectives

6.2.1 Achieving the research objectives

The key question of my research was how low-income settlement types and risk related variables could be considered when using physical vulnerability assessment in addition to existing dolomite hazard classification processes. In this regard, my research identified significant differences between low-income settlement types, which in many instances especially where informality is high, are treated as the same type of settlement. Secondly, a range of parameters were identified and applied as criteria in the AHP process, thus showing not only how the AHP method can be applied with regard to physical vulnerability assessment, but also which of the criteria could be added to enhance the existing management of disaster risk on dolomite.

As stated in Chapter one (Section 1.5.3), my research aimed to provide a basis for significantly improved understanding of the long-term sustainability implications of low-income settlement development or upgrading on dolomitic ground. In this regard, my research showed how the consideration of official manageability (including risk monitoring), as well as owners and communities raking responsibility for living with certain levels of risk, can enhance the potential for and improve sustainable urban living on dangerous ground. My research thus supports the reduction of human settlement vulnerability, with associated increased settlement sustainability. In addition, it highlights the importance of the need to consider the long-term repercussions of locking an urban region into a more sustainable built environment trajectory.

The study was guided by the following objectives, which it worked towards achieving as best possible. These were to:

- compile spatial data of the selected marginalised land types (i.e. dolomite), that supported the thesis discussion and enabled mapping of the study area and identification of specific locations that were included as sample sites in the research field visits;
- investigate the characteristics of low-income settlements related to its design and density in correlation to dolomitic ground – something that was threaded throughout the thesis, and presented in Chapter four, Section 4.3, whereafter it was used as one of the research parameters of the AHM method (Section 4.4.2);
- investigate methods of assessing physical vulnerability of settlements and presenting related research outputs. After various approaches were considered and attempted, the MCA process namely the Analytical Hierarchy Process (AHP) was selected and successfully applied to collect data and obtain the research results;
- establish the relative importance of criteria of vulnerability, manageability and capacity related to low-income settlement types on dolomite. The results that were obtained through the application of the AHP method indicate the level of perceived importance of various criteria that relates to the physical vulnerability of low-income settlements on dolomite, as presented in Chapter five; and
- consider conditions that influence low-income settlement vulnerability on dolomitic ground as related to human behaviour, and determine the relevance thereof in decision making related to settlement development and/or upgrade.

These five research objectives were addressed and discussed in Chapters four and five, where the spatial data collected, field visits engaged in, low-income settlement types considered and classified, the physical vulnerability parameters related to the study identified and selected, and finally analysed using the AHP method. The introduction of this, my final thesis chapter, discussed how the analysis unfolded.

6.2.2 The importance of geographical location and changes in the natural environment when applying the research outcomes

With regard to the achievement of my research objectives (Section 6.2.1), it remains pertinent to consider that the geographical location and associated hazards in urban environments influence the behaviour of individuals and communities that inhabit these areas. Furthermore, the geographical location and associated hazards drive the economics and infrastructure that in turn affect the long-term viability and sustainability of the settlement or area. Furthermore, this geographical environment governs the ecological processes that affect the availability of resources that are needed to keep a city alive.

Mileti (1999) defined sustainability in relation to natural disasters in part as the ability of a community to recover by utilising its own resources, which encompass the elements of economics, infrastructure and ecological processes. Elements that change the level of sustainability of a community include but are not limited to events such as storm occurrences, floods, earthquakes, air pollution, surface and ground water resource contamination, changes in biodiversity and a variety of other hazards (Rose, 2011), including subsidence and sinkholes. In the case of climate change, the hazards are exacerbated through the in the manner in which for example precipitation occurs, thereby influencing run-off, water ponding and the general characteristics of the geographical environment over time. Thus, the location of a low-income settlement in association with changes that takes place in its natural surroundings, not only present direct dangers such as changes in flooding probabilities, severities and extents, but may indirectly increase geotechnical risks such as those posed by dolomite through changes in dissolution of soil and changes in ground water levels.

6.2.3 Challenges encountered during the research

The method that I initially intended to follow during the research proposal stage and at the onset of the research was met with difficulties long the way. Some of the challenges encountered included:

- an inability to gain access to specific geotechnical reports that reside in restricted libraries or are protected by client-confidentiality clauses; and
- non-availability of some historical reports, due to it being archived in non-digital format and it not being accessible except via insupportable financial expense.

These document related challenges were overcome by engaging in verbal discussions with specialists who had knowledge of the particular details contained in some of the reports, and although based on their recollection of its contents, provided adequate information.

A more substantial challenge that arose during my research was that not all specialists who have knowledge of and access to detailed documents and information on development and upgrading of low-income settlements on dolomite were willing to engage in the research. As discussed in Section 3.2.3, some specialists showed apprehension towards being identified or quoted, and preferred to remain anonymous. This, as well as the relatively small pool of dolomite geotechnical experts in South Africa who know one another and may have been able to identify each other's opinions with regard to especially upgrading of informal settlements on dolomite, compounded the sensitivity. This made the quoting of information or perceptions difficult, thus challenging the potential application, strength and level of importance that may be attributed to my research.

Especially when it came to commenting on the details of the results of some of the studies they were engaged in, and where they may have differing opinions regarding the outcome than accepted in mainstream geotechnical environments, the challenge became a significant hurdle towards successful completion of my research. Since the details of the reports were not critical to my research the inability to access to these documents did not present a fatal flaw in the considering of the physical vulnerability of low-income settlements on dolomite. However, the challenge regarding conducting interviews necessitated the change in approach, which allowed anonymous interaction and inputs into the research.

Due to the above-mentioned challenge that limited the direct engagement or reference to specialist inputs into the research, I had to divert my initial research proposal, which was to develop a vulnerability *curve* (as per the original thesis proposal), towards the implementation of the MCA AHP method. The AHP method allowed consideration of parameters that may be contested and not usually integrated into one process when decision making regarding development or upgrading on dolomite is undertaken. The results that emerged from the successful application of this research and analysis method expanded the boundaries of conventional geotechnical applications of knowledge in regards to development on potentially dangerous ground and the incorporation of management and capacity criteria that are not usually considered when decision making regarding low-income settlement location or upgrading on dolomitic ground takes place.

Even though my research provided insight into the criteria that could enhance the decision making process when dealing with low-income settlements on dolomite, the challenge of professional sensitivities remains. I can say with confidence that the methods I selected as a result of the challenge helped overcome what emerged to be a real and justified sensitivity.

6.2.4 Applicability of the AHP method

In the international context, my research supports the potential to apply the widely accepted AHP method to the field of disaster risk and physical vulnerability assessment. The approach substantiates the successful application of the use of this method to integrate the multiple criteria that are commonly present in disaster risk assessment and risk reduction research.

In the context of the existing South African housing and urban development policy environment, the application of the AHP research method confirms the need for change to be incorporated in the manner in which settlement research is approached and the way in which practical development and upgrading of low-income settlements is effected. By applying this research method, the difficulties that arise when considering the expected significant increase in Gauteng's population count as a growing urban region, could be approached in a systematic manner that does not implicate role players who may not necessarily agree with conventional or mainstream procedures. When the question comes to mind as to what is most desired, such as whether more advanced building requirements should precede or dominate as opposed to relocation and associated community disruption, the AHP method could be used to eliminate even internal conflicts that specialists may be struggling with when determining suitable development avenues.

6.3 Low-income communities living with risk

6.3.1 Continued prevalence of life on dangerous ground

The plight of low-income communities who live on hazardous ground worldwide remains difficult to address even where financial capacity, human resources and knowledge abound. The technical and policy related difficulties in solving their situation tend to turn their impoverished and deprived situation into an ever increasing and enduring barrier from accessing prosperity and quality of life. Where low-income communities settle close to or inside cities, they often find themselves knowingly or unknowingly located on dangerous ground. In instances where official financial resources to assist in addressing their plight are restricted, and with space in the city at a premium, the result is forced consideration of development and upgrading of settlements on the marginalised and potentially hazardous ground that would be avoided during the formal course of development in its ideal form.

These marginalised spaces that occur in-between established and planned settlements are exposed to not only dolomite hazards, but also floods, soil contamination (in the Gauteng City Region specifically related to mine residue areas (Gualandi, 2016)), and ground movement (Lesupi, personal communication, 2016). Where they are aware of the risks, communities may consider the risk versus the benefit of living in such potentially dangerous areas, with the potentially real and immediate benefits often perceived to outweigh the sometimes uncertain or unpredictable risks.

The concern in this regard, in particular from a town planning and regulatory perspective, is the location of not only low-income, but in particular informal settlements. Even though geotechnical considerations are well founded and placed to address the challenges associated with potentially dangerous surface and subsurface environments in a formal development context, the persistence and increase of settlements in the informal livelihood sector remain. The situation goes further than dolomitic ground alone, and is present in large cities countrywide (CoCT, 2005) and worldwide (Dutta and Tingsanchali, 2003; Sagala, 2006), where settlement takes place on slopes, in wetlands and on floodplains (Figure 6.3.1) and other similar unstable or unsuitable locations.

In the formal urban environment it is procedurally manageable, although not always uncomplicated, to apply development and planning guidelines and standards (Ahmad, 2013). However, informal and low-income areas are more difficult to direct, control or manage, and the development and upgrading process is often governed by a completely different set of unwritten rules, legal contestations and role players that may not always understand or engage in the decision making process. In addition, the current legislative, policy and regulatory environments are fraught with technicalities that are difficult for non-specialists, especially community members, to understand, least of all to act upon. The result is a significant rift between low-income communities whose basic needs are to be met, compared with legal and practical elements that govern formal planning and disaster risk reduction.

6.3.2 Wider implications of the research results

Chapter five presented and discussed the specific details related to the results of the application of the AHP method. On a broader level, apart from the direct findings evident from the outcomes of the AHP method assessment, another significant discovery emerged. The literature review and legitimised knowledge related to the matter of low-income settlement development and upgrading on dolomite seem to differ dramatically from the perception that some qualified individuals hold regarding the potential for integration of non-conventional wisdom and undertakings into the established geotechnical approaches to development and upgrading as well as wet infrastructure service delivery on dolomite. This finding is important in particular in the context of low-income settlement typologies that were identified and considered during this research. There seem to be little differentiation in current literature, research and application in the policy and development context, as well as during litigation, between different low-income settlement types, especially when it comes to informal settlements.

My research highlighted a concern that all informal settlements in particular are treated as similar entities, without consideration of both physical differences and the different socio-behavioural elements related to communities living in them. Conventional wisdom thus remains un-nuanced when it comes to the consideration of the physical vulnerability and differences in physical vulnerability levels that are associated with disaster risk, between low-income settlements. In the same vein, the manner in which authorities, specialists, owners and residents engage with regard to the manageability and capacity for disaster risk reduction remain in many such cases overlooked. This finding is furthermore important in the context of the identification of settlement typologies for town planning and commercial purposes, thus identifying a need to increase consideration of more variation and differentiation to be included when such settlement types are identified and classified.

In addition to the above, my research alluded to professional sensitivities that exist around the application of conventional wisdom and related standards and regulations, and the ability or interest of the scientific and technical community to challenge some of these conventional approaches or include additional non-technical parameters in the development and upgrading decision making process. Thus, in addition to the direct findings related to the research method, my research alludes to the potential importance of peer pressure in promoting future alternative approaches to be included into the development-on-dolomite debate. In this regard I conclude that conventional wisdom needs to be challenged and that a way must be found for the guidelines in regards to development on dolomite to be refined even further than the latest SANS (2012) standards do. Alternatively, municipalities or housing development authorities need to have the courage to base their decisions and developmental approaches on the findings of my research, so as to start demonstrating their willingness to test and adopt the relevance of new approaches.

Standards and guidelines for development on dolomite have come a long way since the early 1970s when this subject first emerged as a focus of geological and geotechnical research in the South African context. Recent and fairly new considerations such as the design of subsidy-funded walk-up apartments (EMM, 2012) and the integration of management plans and monitoring requirements for developments on dolomite (CoT, n.d.; SANS, 2012) shows a willingness from both authorities and technical sciences to consider alternatives and additions to the previous options for development on dolomite. The addition of parameters such as those that emerged from the results of the AHP method would not only strengthen the current community awareness processes that are under way in some municipal areas, but allow for it to be included in the formal processes related to decision making when development or upgrading on dolomite is being considered in regards to low-income settlements.

In the attainment of quality of place for human settlements (as defined among others by the CSIR, 2000), uniqueness of not only the ground that is being constructed on and the type of dwellings and layouts that are considered, but also the human factors of awareness, responsibility-taking and ownership of risk should be embraced. These latter characteristics of settlements are not physical in nature and more difficult to gauge, engage with and affect changes to when needed. The development and provision of guidelines, standardisation requirements and regulations alone are no longer adequate to deal with the challenges associated with human settlement development (*ibid.*). In addition, settlement design should also be more responsive to the different natural landscapes in which it is situated (*ibid.*). By applying additional parameters in decision making considerations, as illustrated in Chapter five, the characteristics of such criteria can be harnessed towards improved decision making as well as amelioration of the sustainability of urban living spaces. However, when official or municipal manageability, community beliefs, behaviours, awareness and capacity are added to the disaster risk reduction processes that are envisaged for human settlement development (UNISDR, 2015), processes become more complicated. Although the principle of manageability and capacity are therefore envisioned to emanate through housing development programmes and policies, its practical implementation is challenged when applied to especially low-income settlements on dolomite, as shown in my study.

The following areas of interaction were in particular highlighted as important to consider in the debate on development and upgrading of low-income settlements on dolomite, even if it may add complexity and require more time and other resources to resolve:

- exploration of more detailed differentiation between different low-income settlement types especially in the informal housing sector;
- focussing on the practical implementation of sound and regular monitoring practices for wet services infrastructure development on dolomite;
- inclusion of formal engagement with owners and residents of dwellings in low-income settlements; and
- introducing a measure of customisation of development and upgrading outcomes that suits both naturally occurring environmental hazards, as well as promote community understanding with regard to living with risk and being directly involved in disaster risk reduction in their living area.

6.3.3 Sustainability of urban development in context of low-income settlements

One of the key issues in achieving urban sustainability is to work harmoniously with the natural landscape, rather than causing breakdowns in natural systems (CSIR, 2000). Dolomite landforms are part of a natural system of geological processes and soil formation that perpetuates its transformation over hundreds and even thousands of years. Thus, in opposition to operating with these landforms as an enemy to the urban form and function, an approach of working *with* dolomite characteristics could enable more sustainable settlements. By introducing officials and communities to a better understanding of and caring for dolomitic land, in the same manner as is commonly recommended for example wetlands, an approach of responsibility, care and custodianship of the dolomitic environment could be promoted. Such an approach could introduce the concept of living sustainably alongside the hazards the environment pose, as opposed to viewing the potentially dangerous land as a negative entity.

Such a change in approach requires stakeholder participation by not only the technical and scientific fraternity, but also includes the informed and pro-active engagement of officials, landowners and residents of affected properties or areas to be involved. Whereas wet services infrastructure such as stormwater culverts are traditionally viewed as interventions that are used to fight a “common enemy” (*ibid.*) such as floods and erodible soils, the water-based *enemy* or threat could instead be viewed as a potential supporter of an improved understanding of the natural environment and its geological processes. This could enable officials and communities alike to understand the nature of the hazard and the impact that it may have on them or their constituents better. In turn, they may then become empowered to also better understand their own vulnerabilities and be able to counter the hazards and vulnerabilities where possible with appropriate managing and capacity-building interventions. Ultimately, the intention is thus to reduce disaster risk and increase official and community resilience to hazards that will only put increased pressing in future as urban areas densifies.

In the process described above, the potentially dangerous ground thus becomes an integral part of society and community life, and their living within this environment in a sustainable manner could shape their day-to-day behaviour to focus on risk reduction. On dolomitic land, this process would engage the entire community to be involved in improved care for wet services infrastructure, and engaging in ongoing and frequent monitoring of potential areas of water leakage and ponding. In this context, prevention of doline and sinkhole formation through observation, engagement, reporting to officials and maintenance of potential elements of concern would promote positive interaction with their living environment. This approach, however, require official engagement and actioning to ensure that the community has faith in the upkeep of both parts of the engagement – theirs and the governing structures involved.

6.3.4 Costs versus benefits when including additional considerations in decision making

The implication of the consideration of the inclusion of additional criteria or parameters when making decisions regarding development and upgrading on dolomite is to contemplate whether the potential increase in time and resource cost (human, financial and related) can indeed be afforded or implemented. A notion central to my research is to promote a move away from a predominantly responsive approach towards disaster risk mitigation and prevention programmes, where risk is avoided as far as possible through pre-emptive design, construction, maintenance and societal behavioural intervention. As such, the consideration of the initial time and cost that may thus be initially spent on the inclusion of supplementary interventions would counter the longer term, ongoing and rising cost of settlement relocation, and rehabilitation of ground that are subjected to hazard occurrences.

As explained earlier, despite the existence of well-intentioned and scientifically founded guidelines for geotechnical assessments and the implementation of standards for development of certain settlement typologies and densities on dolomite these guidelines and standards remain largely unresponsive to development contexts of informal development and informal settlement upgrading, irrespective of the actual level of hazard, vulnerability and ultimately disaster risk that is involved. Despite the efforts of engineers, geologists and planners alike to overcome the difficulties associated with low-income settlement development and upgrading, the regulatory and policy environment remains uneasily navigated, and communities living on dolomite remain in intense conflict with some of these role players and governing processes.

During consideration of the physical vulnerability characteristics that are present when attempting to live more safely on dolomite, my research has shown that there is a need to understand the varying disciplines and perspectives that relate to a differing set of costs and benefits. This goes beyond technical interventions and directly engages governing processes and community behaviour. It is recognised that the inclusion of each new approach has the potential to create additional conflict elsewhere in the complex set of parameters, in turn translating into additional challenges when searching for a solution. Still, for a long term and more sustainable solution to be found, the choice for development or upgrading of low-income settlements on dolomite needs to be considered from the perspective of all the disciplines involved, including those not directly related to engineering and technical solutions. Such an approach, although probably more costly in terms of time and resources, has the potential for a positive impact on not only the debate, but also the practicalities related to urban sustainability, especially in densifying urban areas where hazards and vulnerabilities will persist.

6.3.5 Responsible parties in disaster risk reduction

Current housing development, upgrade and service delivery policy does not place much emphasis on the influence or behaviour of municipal entities landowners and communities in risk acceptance and risk management. Although the National Disaster Management Act (RSA, 2002) and the National Disaster Management Framework (RSA, 2005) and the like; nor does it consider the level of interaction and awareness and implementation of special measures to reduce hazardous situations on dolomite, at governmental/administrative and community level. The results of this research shows that the level of monitoring, engagement, and implementation of these processes to address risks and behaviour of individuals and communities need to get a lot more attention in order to reduce the risk that settlements are exposed to, when located on dolomite.

When discussing disaster risk attribution and reduction, the question arises as to who would take responsibility for resident’s health and safety and loss of property in case a disaster occurs. Based on the United Nations HFA and Sendai Frameworks (UNISDR, 2005; UNISDR, 2015) and Human Rights legal framework (GSDRC, n.d.; WaterLex, 2011), governments are accountable for implementing DRR measures – the plethora of dolomite-related regulations, standards and guidelines in South Africa demonstrates that. However, the regulatory framework should ideally also reflect a balanced view of levels of accountability afforded individuals or communities, as opposed to placing the liability on Government alone. To my knowledge, and through the exploration of my research, no evidence exists that the level of disaster risk that low-income residents may be willing to accept and possible subsequent acceptance of their own accountability in terms of the risks they are willing to live with, plays a role in development and upgrading decision making processes on dolomite in Gauteng.

Geologists often have to rely on experiential judgement to determine unknown or uncertain elements encountered during the investigation (Heath, personal communication, 2011). In addition, uncertainty increases with an increase in the potential interpretations by individual geologists based on their unique understandings of “invisible” geological strata and zones across a site, or in relation to the regional geological sequence. Furthermore, uncertainties exist in relation to the exact nature of the underground situation, as based on selected borehole records, which may be influenced by sampling errors. Potential sampling errors could emerge due to the particular (regulated) density of boreholes and the sample spacing, which even though well designed and well-intended, may cause important flaws or strengths in the subsurface characteristics to be overlooked.

van Westen, van Asch and Soeters (2006) agreed that Varnes (1984) presented one of the most useful definitions of risk, namely the expected number of fatalities, injuries, property damage and economic activity disruption, due to a particular hazard occurrence within a defined geographic area and within a specific time period. Usually, the level of hazard is considered in terms of the expected losses for all different types of the elements that are at risk. Internationally, there is a plethora of methods and formulae that have been developed and used to quantify or qualify physical and geographical risk. Most of them are based on the same principles of the intersection between vulnerability and the presence or probability of hazard. For example: van Westen *et al.* based their formula of landslide risk on Varnes (1984), Fell (1994), Leroi (1996) and Lee and Jones (2004); and this study uses techniques that were first used in the 1970s (Saaty, 1970) to determine indicator weightings.

Kirsten *et al*. (2009) and Coetzee *et al.* (2010) applied the consideration of personal safety to living on dolomite. Although these studies play an important role in unpacking the risk-on-dolomite debate in Gauteng, they do not consider settlement type in detail, nor behavioural-linked indicators at government and community level. Through the combination of a variety of indicators, the AHP method used in my research may open the way for future alternative considerations when making decisions regarding developing or upgrading low-income settlements on dolomitic ground.

6.3.6 Development and upgrading of low-income settlements on dolomite: a call to consider individual settlement characteristics

Traditionally, wet infrastructure construction on dolomite is treated as being significantly different from "normal" wet infrastructure in geotechnical circles. However, in some cases these differences are not alluded to in housing literature. For example, The Red Book (CSIR, 2000), in particular Chapters 6 to 12 that deals with engineering related issues of human settlements, makes no specific mention nor does it consider the different geotechnical interventions that are applicable on dolomitic ground. This gives the impression to the uninformed reader that all wet infrastructure could be handled in the same way, which is not the case. Thus, the potential for sustainable living in dolomite affected urban areas are undermined by inadequate information sharing with officials who may be new to the area where different disaster hazards may be prevalent than what they are used to or have been exposed to in the past.

As this research has highlighted, and something that was especially prevalent during engagements with local community representatives during the course of the research (GCRO, 2012a), the current housing policy and developmental guidelines, in particular those relating to development on dolomite remains, are difficult for the average person to understand. Thus, the solid scientific foundation of geotechnical investigations and recommendations for reducing the level of risk that is present when living on dolomite, is weakened and not integrated into society in a manner that would ensure comprehensive understanding of the level of risk that is present nor the reasons for and methods of reducing the risk.

In addition to this technical pursuit, it is necessary to address the assumption that low-income settlements take similar shapes and forms across geographical spaces in South Africa. Thus, instead of being treated as similar entities with the same characteristics, low-income settlements should be viewed as delineating potentially significantly different settlement types, as was identified and discussed in my research. In turn, this recognition will affect budget allocations, housing design, construction interventions, as well as community engagement and public participatory processes when development, upgrading or relocation of settlements is considered. In this form, low-income decision making can promote the pursuit of urban sustainability, even if it means that the time frame for implementation and resources allocated to the process may have to be reconsidered. Such sustainability then directs lower future maintenance and rebuild options, due to construction as well as behavioural intervention that take place in the pre-development stage.

When low-income settlement development and upgrade is considered in the context of DRR, there are more issues to take cognisance of than those addressed via housing policy, disaster risk management, geotechnical analysis and urban development spheres alone. My research highlights the need for consideration of additional low-income settlements types, along with alternative management and capacity (including behavioural) interventions to be implemented when considering the development and upgrading of low-cost housing on land that present dolomite hazard levels, especially where these hazards are considered low to medium in intensity. As a result, urban sustainability could be promoted.

My research has highlighted that no significant differences are perceived to exist in the distribution of risk across different low-income settlement types. As expected, the range of possibilities for decreasing risk of low-income settlements on dolomite remain dependent largely on the infrastructure decisions that are made when developing or upgrading the settlements, combined with the ability of authorities and communities to manage the risk and behave in such a way as to reduce the risk. This low level of perceived importance of the difference between informal and formal types of low-income settlements, coupled with the importance of infrastructure solutions indicate that there are indeed possibilities for informal settlements to gain access to wet services, should adequate resources and commitment towards sustainable risk reduction be applied by all parties involved. Thus, the implementation of options would be based on the unique characteristics of a site, the type of low-income settlement, the community that lives on it and their behaviour, and the government and official management interventions. Importantly, my research highlights that possibilities may exist in for development of low-income areas or upgrading of even informal settlements on dolomite, at the same time as governance processes and behaviour at household and community level would have to be applied to reduce the level of disaster risk.

6.4 Relevance of my research results

6.4.1 Engaging alternative and additional perspectives

When deconstructing the situation of low-income settlements on dolomite a relatively limited number of role players have been involved to date. These groups (including but not limited to geotechnical engineers, geologists, planners, housing development agents and communities) display a range of sometimes vastly different approaches and understandings regarding the appropriateness of development and upgrading options for low-income settlements on dolomite. This wide range of responses that was evident from the perspectives obtained from the research method, as discussed in Chapter five, translates into a multitude of potential options of how the weighting of parameters in the debate is applied and how changes in a real-world situation may change the level of disaster risk.

My research provides a framework within which to perform similar evaluations for individual settlements on dolomite and allows alternative viewpoints to be included and evaluated in terms of the impact that it may have on the level of risk. My research also brings to light that informal settlements in particular may benefit from such an approach to upgrading decision making, since there does not seem to be a significant difference in levels of disaster risks when compared to formal settlement or dwelling types. Some of the key variables in affecting the level of risk, namely intervention in regards to monitoring and maintenance, points to the need to consider the level of responsibility for these elements that communities could accept in order to achieve access to basic wet services.

My research also shows that it is possible to evaluate different viewpoints and technical elements of the debate, using for example the MCA AHP method. The building blocks of the evaluation method are not at all new – in fact, some elements thereof have existed for over 40 years (Saaty, 1970). However, the manner in which these variables are applied in my research provides new possibilities for disaster risk reduction and decision making in regard to consideration of disaster risk reduction, not only in the context of dolomite but also with regards to other hazards. The opportunity therefore exists to apply the same method in other environments where different indicators for physical vulnerability may be applicable, for example in severe storm- and flood-prone area or areas with unstable or erodible soils. In turn, such wider application gives a certain level of global relevance to the research and opens up possibilities to explore disaster risk in a more multi-faceted manner.

The thesis shows that it is indeed possible to examine the application of physical vulnerability evaluation in situations where different role players have vastly different perceptions of levels of risk. An important result emerging from this study is that there is possibility to provide guidance in the level of risk that communities living on hazardous ground face, using more angles than purely that of technical intervention. This means that possibilities exist for government agents and communities alike to reduce the levels of disaster risk they are exposed to. From a government agency perspective, the risk they are exposed to relate to future increased maintenance if infrastructure is either deliberately damaged or not adequately monitored and maintained, or in a more subtle form through, for example, service delivery protests and litigation. Government agency risks in particular can be addressed by introducing elements of manageability as elaborated on in Chapter five of this thesis. On the side of owners and communities, the potential for disaster risk reduction lies in the ability of government to enable these role players to understand and live with the risks they face, and provide them with capacity for self-management, by including increasing awareness and instituting behavioural change, towards reducing hazard probabilities.

Whereas studies in the individual disciplines involved in development on dolomite risk assessment focus on specifics related to each particular discipline, my study linked the interactions and the relationships between the human/social and engineering/geotechnical factors that influence disaster risk. Through this approach, the study's findings call for a move towards a more integrated method of both socio-cultural and geotechnical intervention, focussing on the introduction of a more collaborative approach to the challenge of dolomite risk reduction where low-income communities are involved.

6.4.2 Low-income settlement type assessment

The low-income settlement types defined in this research shows that characterisation of settlement types as defined for purposes of this study would be virtually impossible to delineate spatially in a real-world situation, due to the multiple contortions of settlement forms in low-income settlements, especially where high levels of informality are present. This is due to a variety of reasons, including the fact that subsidised housing, basic services and infrastructure provision as well as household and community behaviour may differ across geographies. In the real world, considerations regarding settlement types and suitability on dolomite are complex, especially when the ranges of geotechnical classification of dolomite hazard levels versus behavioural interactions are deliberated.

On a housing policy and development implementation level, this complexity calls for a potentially alternative approach to addressing the unique intricacies that the situation brings with it when dealing with low-income settlements. Currently it applies when the situation deals with an almost ideal world where the geographical area and community that is intended to live in the settlement conform to a considered norm without significant geographical or socio-cultural challenges. However, due to the vastly different geographical hazards in particular, as discussed in this thesis, a blanket approach towards low-income settlement development and upgrading on dolomite is not possible – neither in respect to different settlements across the Gauteng City Region, nor within settlements or even small fragments of townships or suburbs. This approach is called for in the recent research of Kornienko (2013), which with regard to an informal settlement in Johannesburg proposed the consideration of differences within individual settlements to determine the manner in which service delivery and upgrading is approached. Kornienko (2013) calls for an approach in which different areas within a settlement should be treated in unique ways and that the possibility exists to handle different sub-placements within settlements differently with regard to services delivery.

6.4.3 Quest for understanding of policy and practice

In an effort to transition toward increasingly sustainable human settlements, housing development and urban management aims to unbundle the multi-dimensional disaster risk challenge in a constantly changing spatial context. This change management component is necessary to enable human settlements to undergo change in its geography and characteristics over time while considering the multiple trans-disciplinary variables that are involved. My research proposes that the risk of settlements on dolomite, especially for informal settlements, may be countered to some extent by engaging not only technical experts, but also with officials and communities at risk in the policy design process that underpins housing development and upgrading decision making processes. The results of my study may thus open the door for clarification of elements that mitigate the risk via manageability and capacity elements of the disaster risk reduction process. For example, better understanding and cognisance of residents with regard to the risks they face and the policy-based decision making processes that enable wet services infrastructure delivery may assist them to identify potential problems and alert official channels of engagement, so that action can be taken speedily.

Considering the large percentage of land in Gauteng and surrounds underlain by dolomite, a large percentage of the population living in the region still has little understanding regarding the risk it presents (GCRO, 2012a). In particular, the meaning of dolomite hazard classifications, characterisations and descriptions of hazard levels and associated guidelines, as well as housing policy details are not well known to communities and in some cases even their representatives when disputes regarding service delivery restrictions based on dolomite hazards are present (GCRO, 2012a; CoT, 2013b). For example, ward councillors, ward committee members, community leaders and even housing construction service providers who may not entirely understand the need for restrictions or specific regulations often have little knowledge of elements that are critical to dolomite risk management including:

- potential constraints related to non-upgrading or non-development;
- required geotechnical investigations and associated costs;
- dwelling specifications for different building classifications;
- allowed densities and reasons for such density allowances as well as the need to not exceed the allowed densities;
- requirements during construction; and
- maintenance and prevention/mitigation requirements *ad infinitum* after construction is completed (*ibid.*).

While these listed factors impact on the level of risk that any development on dolomitic ground poses, the technical background is considered by some of these role players to be too complicated and in some instances believed to be driven by a conspiracy to avoid service delivery or settlement formalisation (GCRO, 2012a). Thus, technical interventions and explanations alone are inadequate to enable a lasting solution to the challenge. Community-based interaction seems to be critical in order to create awareness, enhance understanding and disseminate information regarding the risks that they face and the opportunities to their disposal for reducing dolomite related disaster risk (Lesupi, personal communication, 2016).

6.5 Future avenues of research

A number of alternatives or additions to the AHP method that I applied are possible. Such alternatives and additions of parameters would influence the physical vulnerability outcomes and resultant possible interventions and associated interpretations of levels of disaster risk. In this manner, future research is proposed to consider not only additional or alternative parameters, but also consideration of the effect that these additional criteria would have on the risk and intervention outcomes.

Another next step would be to consider the levels of acceptability of risk at community level, meaning how much risk residents would be formally willing to live with in order to gain certain benefits in return. Whereas formal settlements are able to accept the risks of living on dolomite and not being covered by homeowners' insurance (CFG, 2014), low-income settlements and particular informal settlements do not currently have that option. I therefore propose a shift in the development-on-dolomite debate from the current situation in which technical questions dominate discussions, to one where the social elements of taking responsibility for actions, monitoring, and engagement in maintenance regimes of wet services infrastructure come to the fore. In particular, as has emerged from the research results, it is important for municipalities to ensure effective monitoring and after-development implementation maintenance programmes. In low-income settlements, the engagement and actions of individuals and households within these communities therefore become significantly important. I encourage that there should be closer engagement and interaction between communities and officials, in order to improve their mutual understanding of the process of housing development and upgrading as well as reduction of disaster risk within human settlements.

The results of this research, however also highlight the continued importance of geotechnical considerations, showing at the same time how critically important understanding of risk, engagement with risk and behaviour to reduce risk at municipal and community level is. The current guidelines and standards for dolomite hazard classification in South Africa provide a firm basis on which the geotechnical intervention required for development and upgrading of human settlements is based. The need for these regulated processes is confirmed by my research results, since without the application of the established procedures for dolomite hazard assessment, the risk cannot be defined. However, with the ever-increasing densification of the urban environment, it becomes almost impossible *not* to also consider ways to provide guidance where increased development and densification on dolomitic ground is eminent, especially in areas where the potential for subsidence and sinkhole occurrence is low.

6.6 Conclusion

Ultimately, the choices we make are based on the contemplation and aversion to or acceptance of one or other type or level of risk, to gain some type or level of benefit (de Palma, Ben-Akiva, Brownstone, Holt, Magnac, McFadden, Moffat, Picard, Train, Wakker and Walker, 2008). During the course of this research, when interviews with specialists and officials reflected on instances where low-income communities were made aware of and began to understand the concerns related to and causes for elevated dolomite hazard levels, a willingness seemed to emerge with them to consider various options regarding living with risk (for example Stoch, personal communication, 2012 and Lesupi, personal communication, 2016). In workshops and interviews where individuals hailing from low-income settlements were engaged (for example from the Protea South informal settlement), they were able to reflect on the risk they face when living on dolomite in relation to the risk of for example living far away from work and education opportunities (GCRO, 2013).

Currently, low-income communities remain immobilised through exclusion from decision making and are afforded no choice regarding the level or type of risk that they may or may not be willing to live with in order to access other rights or benefits. When not given the option to implement measures to monitor and manage even to a small extent their own safety and well-being, their human right of choice with regard to disaster risk reduction is eliminated. This removal of choice poses a fundamental ethical question regarding the true application of basic human rights.

In terms of the human rights framework, for basic rights to exist, for example, for individuals to exercise their right to a safe place to live and having access to adequate water and sanitation services, each low-income settlement development or upgrading on potentially dangerous ground will have to be evaluated according to its specific vulnerability parameters. The indicators or variables that determine the physical vulnerability, as well as owner and resident behaviour and governmental management specific to the settlement and its locality has to be considered when deciding on interventions – whether it be structural, geotechnical, or social in nature. The Bill of Rights also states in Chapter 2 article 24 that everyone has the right to an environment that is not harmful to their health or well-being and to have the environment protected for the benefit of present and future generations. This should be achieved through reasonable legislative and other measures that prevent pollution and ecological degradation, promote conservation and ensure ecologically sensitive development while using natural resources and promoting justifiable economic and social development.

The Constitution (Republic of South Africa, 1996) express rights of choice, for example political (i.e. choosing which political party to vote for), religious (i.e. freedom of belief and opinion), reproductive (i.e. regarding termination of pregnancy), trade, occupation, and so on. In regards to settlements, Chapter 3 of the Constitution states that every person shall have the right freely to choose his or her place of residence anywhere in the national territory. In the same chapter, environmental right is expressed as every person having the right to an environment that is not detrimental to his or her health or well-being. Considering these two particular rights, direct conflict emerges between the Right to choose a place of living versus Right to a safe environment when hazardous ground is encountered. This area of conflict is where access to information could play an important role in reducing the challenges, with participation in decision making processes as implied by the HFA (UNISDR, 2005) and Human Rights legal framework (WaterLex, 2011) becoming a critical requirement. Without formal avenues for information sharing and participative processes instated to enable communities to understand the risk and consider the risk-benefit balance when living on dangerous ground, they have little chance of playing a role in disaster risk reduction, regardless of whether the situation is characterised by new development, upgrading or relocation.

Whereas the results of this study point to an opportunity for intervention in the way in which low-income settlement development and upgrading on dolomite are approached, it also highlights the need for:

a) a much wider view to be taken of the situation of settlements in its specific urban landscape, in addition to the currently applied primarily geotechnical assessments only
b) a more critical assessment of socio-cultural behaviour that play a role in determining behaviour related to risk acceptance or avoidance, and
c) economic impacts that may be apparent at the household level and on a regional economic scale where municipal and provincial governments apply development interventions.

The route proposed by my research requires a firm commitment for additional tasks to be added to current workloads of officials and technical specialists, and a higher demand on already existing financial resource constraints. None of this is easily achieved in practice. The route also implies a greater engagement with communities where blanket-approaches cannot exist. Each community and situation will have to be evaluated according to its specific indicators and the behaviour and management within the locality has to be considered when deciding on interventions – whether it be structural/geotechnical, or social/cognitive in nature.

Ultimately, by combining the elements and indicators involved in the debate regarding development and upgrading of low-income settlements on dangerous ground such as dolomite, the integration of interactions between technical, official and community stakeholders could be utilised to identify opportunities that can promote DRR as opposed to re-actively attending to the potential disaster risk. The opportunities related to this integration process can be summarised to include:

- increased cooperation and collaboration between role players across disciplines to find solutions; and
- a search for opportunities for service delivery and settlement upgrade where previously there may have been no option.

Such participation as proposed above would enable decision makers to work alongside communities to address a lack of awareness and understanding of disaster risk related to geological related disaster concerns. In this manner, geotechnical regulations and financial practicalities that arise when implementing developmental planning processes on dangerous ground can be explained to communities well before options for addressing the disaster risk are presented.

When considering the complexities outlined in this thesis, I identified opportunities towards achieving increased urban sustainability, based on the interaction between settlement type and social understandings. In this context, I propose practical implementation of processes to create not only awareness in communities and with owners of properties on dolomite that will enable them to adapt their behaviour towards exercising risk aversion attitudes. Such interventions would have to be formalised as guidelines and standardised through documents and processes such as the SANS standards regarding dolomite (2012), and could include:

- dolomite management plans and programmes to be enforced not only for new development or upgrades to existing developments, but also for historical settlements and developments;
- introduction of dolomite management programmes and plan requirements before properties may be bought or sold (in addition to the current dolomite hazard level reporting and residential specifications that is defined for individual properties);
- determination of the acceptable frequency, level and specifics of monitoring to be done as part of these programmes;
- development of a regional cross-border relational database and information management system that standardises the recording of the mentioned programmes and monitoring processes, as well as keeping record of the maintenance and preventative interventions that are embarked on (in addition to the existing geotechnical investigation database held by the CGS);
- specific dolomite awareness and education programmes to be introduced at primary and secondary school level in the Gauteng City Region; and

- dolomite risk awareness introduction to all newly appointed employees in municipal and provincial governments in the affected areas to enable them to understand and effectively and accurately interpret the dolomite standards.

This approach does require a change in mind-set when considering how low cost housing financing, the types of dwellings that are designed and built, and the processes and elements involved when considering settlement upgrading, service delivery infrastructure development/maintenance and settlement re-location is approached. It also indicates the importance of engagement with government officials, NGOs, contractors and communities before, during and after the technical assessment process to understand the impact that different choices which they make, and behaviour that they perpetuate, will have on the ultimate vulnerability and resilience of the settlements they reside in or engage with.

Many low-income settlements are already located on dolomite, and their call for service delivery as a basic human right is intensifying daily (Govender *et al.*, 2011). In addition to the necessity to consider settlement types unequal in constituent behaviour, a need also exist for differentiation in the types of infrastructure and associated maintenance behaviour, since the behaviour will remain in place long after the initial geotechnical assessment is complete. When current standards, guidelines and regulations are applied to the characterisation of low-income settlements on dolomite, nuances in the manageability and capacity of governing bodies and the inhabitants of the settlements are often lost. The focus of investigations is thus often focused on geological sub-surface conditions, which overrides the potential for integration of realities of specific community-based interventions. With the ever-increasing densification of the urban environment, it becomes almost impossible *not* to consider increased development and densification on dolomitic ground, especially where the potential for subsidence and sinkhole occurrence is low.

The two empirical components of my research – that of considering differences in low-income settlement types, and the engagement with experts through the application of the AHP method, produced the core contribution of my research to the existing knowledge base. Through these two components, my research challenges the status quo regarding development and decision making for upgrading of low-income settlements on dolomite - not to disregard scientifically founded rules, guidelines and regulations, but rather to propose options to integrate human behaviour and the acceptance of various levels of risk. In such a more balanced process, much determination is required to improve the level of responsibility that government officials monitoring and managing, communities living on, and owners of property located on dolomite, take to improve disaster risk exposure and promote risk reduction. In conclusion, my research firmly supports the statement of Health (2011), that “*(w)e can't always avoid dangerous ground, but [the question is] how can we use it? … We have to use what land we've got.*"

REFERENCES

Adger, W.N. (2006). Vulnerability. *Global Environmental Change*. 16(3): 268 - 281. Elsevier.

Adger, W.N. and Winkels, A. (2007). The resource curse and sustainable development. In: Atkinson, G., Dietz, S. and Neumayer, E. (Eds.). *Handbook of sustainable development.* pp. 489. Cheltenham, UK; Northampton, MA; Edward Elgar.

Agyeman, J. (2007). Vulnerability, poverty and sustaining well-being. In: Atkinson, G., Dietz, S. and Neumayer, E. (Eds.).*Handbook of sustainable development.* pp. 489. Cheltenham, UK; Northampton, MA; Edward Elgar.

Ahmad, P. (2013). *Presentation on spatial elements of Johannesburg.* SACPLAN: Professional Planner. At the time: Directorate: City Transformation; Department of Development Planning; City of Johannesburg Metropolitan Municipality. Presented to Wits University: School of Architecture and Planning, 12 May 2013.

Alexandrova, A., Hamilton, E.L. and Kuznetsova, P. (2006). What can be learned from Introducing Settlement Typology into Urban Poverty Analysis: The Case of the Tomsk Region, Russia. *Urban Studies.* 43: 1177 - 1189. Sage Journals. Available at: http://usj.sagepub.com/content/43/7/1177.short Accessed on 13 October 2011.

Ali, S. M. (2012). An Analytical Hierarchical Process for Prioritising the Safety Management Elements for a Manufacturing Organisation in Bangladesh. *International Journal of the Analytic Hierarchy Process* (IJAHP). 4(2). Electronic journal. Available at: http://www.ijahp.org/index.php/IJAHP Accessed on 10 July 2013. Creative Decisions Foundation (CDF).

Allen, W.L. III (2012). Environmental Reviews and Case Studies: Advancing Green Infrastructure at All Scales: From Landscape to Site. *Environmental Practice*. 14(1): 17 – 25. National Association of Environmental Professionals. Cambridge Journals. Cambridge University Press. doi:10.1017/S1466046611000469

Alonso, W. (1964). *Location and Land Use: Towards a general theory of land rent.* Cambridge, MS: Harvard University Press. London.

Amaratunga, D., Baldry, D., Sarshar, M. and Newton, R. (2002). Quantitative and qualitative research in the built environment: application of “mixed” research approach. Work Study, *International Journal of Productivity and Performance Management*. 51(1): 17 – 31. Available at: http://www.emeraldinsight.com/doi/pdfplus/10.1108/00438020210415488 Accessed on 8 April 2015. MCB UP Ltd.

American Society of Civil Engineers (ASCE). (2010). *Report Card for America's Infrastructure 2009.* Available at: http://www.infrastructurereportcard.org/a/#p/home Accessed on 20 July 2014.

Anas, A., Arnott, R. and Small, K.A. (1998). Urban Spatial Structure. *Journal of Economic Literature.* 36(3): 1426 - 1464. American Economic Association.

Aronoff, S. (1989). Geographic Information Systems: A Management Perspective. *Geocarto International.* 4(4): 58. Ottowa: WDL, Taylor & Francis.

Austin, L. M. (1996). The Red Book: A tool for the municipal engineer. Paper presented at *IMIESA Seminar*. May 1996, East London.

Avutia, D. J. (2014). *Analytical and Numerical Study of Dolomite Sinkholes in Centurion, South Africa.* University of Cape Town, Faculty of Engineering and the Built Environment, Department of Civil Engineering. MSc Dissertation in Civil Engineering. Available at: http://open.uct.ac.za/handle/11427/9076?show=full and https://open.uct.ac.za/bitstream/handle/11427/9076/thesis_ebe_2014_avutia_d.pdf?sequence=1 Accessed on 24 August 2015. pp. 122.

Banzhaf, E. (2007). *Monitoring the development of urban gradients and inner urban*. Available at: http://www.researchgate.net/publication/242150680_Monitoring_the_development_of_urban_gradients_and_inner_urban Accessed on 12 January 2013.

Blaikie, P., Cannon, T., Davis, I. and Wisner, B. (1994). *At Risk: Natural hazards, people's vulnerability and disasters*. Second Edition. New York, Routledge. pp. 469.

Blanco, A. and Schanze, J. (2012). Conceptual and methodological frameworks for large scale and high resolution analysis of the physical flood vulnerability of buildings. In: Klijn, F and Schweckendiek, T. (Eds.). *Comprehensive Flood Risk Management: Research for Policy and Practice*. CRC Press. Taylor & Francis Group. pp. 460.

Belton, V. and Gear, T. (1983). On a shortcoming of Saaty's method of analytic hierarchies. *Omega*. 11: 228 - 230.

Belton, V. (1986). A comparison of the Analytic hierarchy process and a simple multi - attribute value function. *European Journal of Operational Research.* 26: 7 - 21. Elsevier.

Berke, P.R. and Campanella, T.J. (2006). Planning for Postdisaster Resiliency. *The Annals of the American Academy of Political and Social Science*. 604(1): 192 – 207. Sage Journals. Available at: http://ann.sagepub.com/content/604/1/192.short and Accessed on 3 December 2014.

Biesbroek, G. R., Swart, R. J. and Van der Knaap, W. G. M. (2009). The mitigation-adaptation dichotomy and the role of spatial planning. *Habitat International.* Climate Change and Human Settlements. 33(3): 230–237. Elsevier. Available at: http://dx.doi.org/10.1016/j.habitatint.2008.10.001 and http://www.sciencedirect.com/science/article/pii/S019739750800060X Accessed on 3 December 2014.

Bigio, A.G. (2003). Cities and climate change. in Kreimer, A., Arnold, M. and Carlin, A. (Eds). *Building Safer Cities: The Future of Disaster Risk.* World Bank. Washington DC. pp. 91 – 99.

Birkmann, J. (2006). *Measuring vulnerability to natural hazards: towards disaster resilient societies.* 400pp. Tokyo, New York, Paris. United Nations University (UNU) Press: The Academic Arm of the United Nations.

Birkmann, J. and Fernando, N. (2008). Measuring revealed and emergent vulnerabilities of coastal communities to tsunami in Sri Lanka. *Disasters*.32(1): 82 - 105. Wiley-Blackwell.

Blum, A. and Gruhler, K. (2010). *Typologien der gebauten Umwelt: Modellierung und Analyse der Siedlungsentwicklung mit dem Strukturtypenansatz.* Leibniz Institute of Regional and Ecological Development, Dresden, Germany. Shaker Verlag.

Bolin, R.C. and Stanford, L. (2005). *The Northridge earthquake: Vulnerability and disaster.* 276pp. London and New York, Routledge.

Bostrom, A., French, S.P. and Gottleib, S.J. (Eds.). (2008). *Risk assessment, modeling and decision support: strategic decisions.* pp. 322. Berlin, Springer Verlag.

Boyd, N. (n.d.). *Human settlements: Definition and Functions.* Available at: http://study.com/academy/lesson/human-settlements-definition-functions.html Accessed on 30 August 2015

Brackley, I.J.A., Rosewarne, P.N. and Grady, L.A. (1986). A prediction of surface subsidence caused by lowering the water table in dolomite. *International Association of Hydrological Sciences (IAHS) Publication Series: Red books*. 151: 127 - 136. Available at: http://iahs.info/redbooks/a151/iahs_151_0127.pdf Accessed on 2 December 2011.

Bradley, D.T., McFarland, M. and Clarke, M. (2014). *The Effectiveness of Disaster Risk Communication: A Systematic Review of Intervention Studies.* PLOS. Currents Disasters. Available at: http://currents.plos.org/disasters/article/the-effectiveness-of-disaster-risk-communication-a-systematic-review-of-intervention-studies/ Accessed on 4 December 2014.

Brite, K. (n.d.). *Definition of an Informal Settlement.* Available at: http://www.ehow.com/facts_6776791_definition-informal-settlement.html Accessed on 8 August 2011.

Brody, S.D., Zahran, S., Vedlitz, A. and Grover, H. (2008). Examining the Relationship Between Physical Vulnerability and Public Perceptions of Global Climate Change in the United States. *Environment and Behavior.* 40: 72 - 95, first published on August 2, 2007. Sage Journals. Available at: http://eab.sagepub.com/content/40/1/72.abstract Accessed on 20 August 2011.

Brook, G.A. and Allison, T.L. (1986). Fracture mapping and ground susceptibility modeling in covered karst terrain: the example of Dougherty County, Georgia. *Proceedings of Symposium on Land Subsidence.* 151: 595 - 606. IAHS, Venice, Italy.

Brown, J.M. (1985). *Dolomite investigation stand 919 Twala Section Katlehong.* Johannesburg, SRK Consulting.

Brown, J.M. and de Beer, J.H. (1989). *Dolomite stability investigation Etwatwa Extension 16 Township.* Johannesburg, SRK Consulting.

Bunce, M. (1982). *Rural settlement in an urban world.* pp 219. Guildford, London, Oxford, Worcester: Billing and Sons Limited. Available at: http://books.google.co.za/books?id=rTsOAAAAQAAJ&pg=PA23&lpg=PA23&dq=settlement+typologies&source=bl&ots=-sqe99UVm1&sig=WJKs6uUBl_6VagOjfpl6ax_y1rs&hl=en&ei=cd-aTvjUAq7RmAWJ_5n6AQ&sa=X&oi=book_result&ct=result&resnum=7&sqi=2&ved=0CEIQ6AEwBg#v=onepage&q=settlement%20typologies&f=false Accessed on 13 October 2011.

Busgeeth, K., Brits, A. and Whisken, J. (2008). *Potential application of Remote Sensing in monitoring informal settlements in Developing Countries where complimentary data does not exist.* Planning Africa Conference. 14-16 April 2008. Sandton Convention Centre, Johannesburg. Available at: http://researchspace.csir.co.za/dspace/bitstream/10204/3102/1/Busgeeth1_2008.pdf Accessed on 13 October 2011 and 4 December 2014.

Buttrick, D.B., van Rooy, J.L. and Ligthelm, R. (1993). Environmental geological aspects of the dolomites of South Africa. *Journal of African earth sciences.* 16(1-2): 53 - 61. Pergamon Press Ltd.

Buttrick, D.B. and van Schalkwyk, A. (1998). Hazard and risk assessment for sinkhole formation on dolomite land in South Africa. *Environmental Geology*. 36(1-2): 170 - 178. Springer.

Buttrick, D.B., van Schalkwyk, A., Kleywegt, R.J. and Watermeyer, R.B. (2001). Proposed method for dolomite hazard and risk assessment in South Africa. *Journal of the South African Institution of Civil Engineering.* 43(2): 27 - 36. South African Institution of Civil Engineering (SAICE).

Buttrick, D.B., Trollip, N.Y.G., Watermeyer, R.B., Pieterse, N.D. and Gerber, A.A. (2011). A performance based approach to dolomite risk management. *Environmental Earth Sciences.* 64: 1127 - 1138. Springer-Verlag.

Centre for Neighbourhood Technology (CNT) (2010). *The value of Green Infrastructure: A Guide to Recognising Its Economic, Environmental and Social Benefits*. Available at: http://www.americanrivers.org/wp-content/uploads/2013/09/Value-of-Green-Infrastructure.pdf Accessed on 19 July 2014. CNT, Chicago; American Rivers, Washington DC. pp. 80.

Chapman, D. (2013). Sinkhole rehab complete: The multi-million rand rehabilitation of the massive sinkhole on Ben Schoeman Freeway has been completed. *Centurion Rekord*. Pretoria

Charlton, S. (2013). *State ambitions and people's practices: An exploration of RDP housing in Johannesburg.* Unpublished PhD thesis, University of Sheffield, UK.

Chen, K. (n.d.). *Note on conceptual framework of integrative risk assessment.* Risk Frontiers – Natural Hazards Research Centre; Division of Environmental and Life Sciences; Macquarie University, Australia. 2pp. Available at: http://docs.google.com/viewer?a=v&q=cache:tMwsot-oOSoJ:www.riskfrontiers.com/staff/kchen/Note_integrative_risk_assessment.pdf+physical+vulnerability+curve&hl=en&gl=za&pid=bl&srcid=ADGEESh2snLtuvguj5N2JEbioXjgxjKulB4LIbEOyTimx9sTK_Ft35W7wMgUr077F9IIMG_aMX0f3ju3Cgi_nEGyNHWgKYkN09-bAAvDgEK-xkgZ-IeeRkK71xsHS1OUaVvP5lJyQEmM&sig=AHIEtbQPKauj5DjQqNHmkBSM8dvGXI45fg Accessed on 11 October 2011.

Chenwi, L. (2012). Legislative and Judicial Responses to Informal Settlements in South Africa: A Silver Bullet? *Stellenbosh Law Review.* 2012(3): 540 – 563.

Chinitz, B. (1960). *Freight and the Metropolis: The Impact of America's Transport Revolutions on the New York Region.* pp. 226. Cambridge, MA: Harvard University Press.

Christaller, 1933. *Central Places in Southern Germany*. C.W. Baskin. Translated: London: Prentice-Hall.

City of Budaörs. (n.d.). *Budaörs, The Innovative City* ('Innovacity'). Website of the Municipality of the City of Budaörs, Szabadság. Available at: http://www.budaors.hu/en/?module=news&fname=natural-values Accessed on 1 December 2011.

City of Cape Town (CoCT). (n.d.). *What is the 5 Year Plan (IDP)?* City of Cape Town. Available at: www.capetown.gov.za Accessed on 18 July 2015. Cape Town, City of Cape Town Metropolitan Municipality.

City of Cape Town (CoCT). (2005). *Sustainability Report.* Cape Town, City of Cape Town Metropolitan Municipality.

City of Johannesburg (CoJ). (2000). *Report on the Interactive Planning Workshop for Johannesburg*. Project Spotlight: Alexandra township, Johannesburg, South Africa. Greater Johannesburg Metropolitan Council. 27 – 30 September 2000. Available at: http://portal.unesco.org/ci/en/ev.php-URL_ID=5260&URL_DO=DO_TOPIC&URL_SECTION=201.html and http://web.mit.edu/urbanupgrading/upgrading/case-examples/overview-africa/alexandra-township.html Accessed on 4 December 2014. United National Educational, Scientific and Cultural Organisation.

City of Johannesburg (CoJ). (2009b). *Climate change adaptation plan.* Johannesburg, City of Johannesburg.

City of Tshwane Metropolitan Municipality (CoT). (n.d.). *Brief outline of site specific dolomite risk management program (DRMP).* Transport Department: Transport and Infrastructure Planning Division, Pretoria.

Coetzee, C., van Niekerk, D. and Annandale, E. (2010). *Towards a Disaster Risk Assessment Methodology for Communities Underlain by Dolomite.* African Centre for Disaster Studies (ACDS). North-West University (NWU). Potchefstroom. Unpublished paper presented at Disaster Management Institute of South Africa (DMISA) conference, September 2010, Jeffreys Bay.

Council for Geoscience (CGS). (n.d.(a)). *Sinkholes and Subsidences.* Available at: http://www.geoscience.org.za/index.php?option=com_content&view=article&id=994%3Asinkholes-and-subsidences&catid=116 Accessed on 3 October 2011. Pretoria, Council for Geoscience.

Council for Geoscience (CGS). (n.d.(b)). *Dolomite Report Index.* pp 163. Available at: http://www.geoscience.org.za/ Accessed on 4 October 2011. Pretoria, Council for Geoscience.

Council for Geoscience (CGS). (2007). *Consultants Guide: Approach to sites on Dolomite Land*. November 2007. Pretoria, Council for Geoscience.

Council for Geoscience (CGS). (2015). *Dolomite distribution across South Africa.* CGS GIS Spatial Data, supplied by Magda Roos, Data Management: Shared Services. Pretoria.

Council for Scientific and Industrial Research (CSIR). (n.d.(a)). *Human Settlements. Construction. Buildings.* (Brochure). Pretoria, CSIR.

Council for Scientific and Industrial Research (CSIR). (n.d.(b)). *Guidelines for Human Settlement Planning and Design: Planning method and participation.* Available at: www.csir.co.za Accessed on 10 September 2016.

Council for Scientific and Industrial Research (CSIR). (2000). *Guidelines for Human Settlement Planning and Design (The Red Book).* Reprint 2005. Pretoria, CSIR.

Council for Scientific and Industrial Research (CSIR). (2007). *Sustainability Analysis of Human Settlements in South Africa.* Available at: http://ndp.treasury.gov.za/Courses%20Library/2007,%2029%20Oct-2%20Nov%20-%20TTRI%20Overview%20Course,%20Midrand/Day%202%20-%2030%20Oct%202007/Reading%20SAHS%20Ch3%20CSIR.pdf Accessed on 14 October 2011.

Council for Scientific and Industrial Research (CSIR). (2009). *Human Settlement Atlas.* Pretoria, CSIR.

Council for Scientific and Industrial Research (CSIR). (2012). *CSIR guidelines for the provision of facilities in South African Settlements.* First Edition. Pretoria, CSIR.

Cronon, W. (1992). *Nature's Metropolis: Chicago and the Great West.* NY: W.W. Norton & Company.

Cross, C. (2008a). *Toward effective spatial planning at municipal level: The Tip Settlement Typology and Survey Results.* Report to Department of Science and Technology (DST). Available at: http://www.hsrc.ac.za/Document-3209.phtml Accessed on 14 October 2011. pp 105. Pretoria, Centre for Poverty, Employment and Growth, of the Human Sciences Research Council (HSRC).

Cross, C. (2008b). *Demonstrator Toolkit for Integrated Planning (Annexure 3): Profiling Housing Demand: Settlement Typology and Survey results.* Prepared for the Department of Science and Technology: Technology for Social Impact. CSIR: Pretoria.

Dalalah, D., Al-Oqla, F. and Hayajneh, M. (2010). Application of the Analytic Hierarchy Process (AHP) in Multi-Criteria Analysis of the Selection of Cranes. *Jordan Journal of Mechanical and Industrial Engineering* (JJMIE)*.* 4(5): 567 - 578.

Davidson, N.M. and Malloy, R.P. (2009). *Affordable Housing and Public-Private Partnerships: effective or Damaging to Low-Income Housing Management?* Research paper. Farnham, Surrey, England; Burlington, Vt; Ashgate. Available at: http://www.customwritten.com/Writing/affordable-housing-public-private-partnerships.html Accessed on 19 October 2011.

Dawson, H. and McLaren, D. (2014). *Monitoring the right of access to adequate housing in South Africa*: An analysis of the policy effort, resource allocation and expenditure and enjoyment of the right to housing. Studies in Poverty and Inequality Institute (SPII). Monitoring the Progressive Realisation of Socio-Economic Rights Project: Working Paper 8. FORD Foundation. pp 108.

de Beer, J.H. (1987). *Addendum Report on Dolomite Stability investigation Lenasia Nirvana Drive.* Johannesburg, SRK Consulting.

de Palma, A., Ben-Akiva, B., Brownstone, D., Holt, C., Magnac, T., McFadden, D., Moffat, P., Picard, N., Train, K., Wakker, P. and Walker, J. (2008). Risk, uncertainty and discrete choice models. *Marketing Letters* 19(3-4): 269 – 285. Springer. Available at: http://www.economics.uci.edu/~dbrownst/MarketLet08.pdf and http://link.springer.com/article/10.1007%2Fs11002-008-9047-0 Accessed on 4 December 2014.

Dekens, J. (2007). Local knowledge for disaster preparedness: A literature review. ICIMOD. Series: *Living with risk – sharing knowledge on disaster preparedness in the Himalayan region*. Available at: http://www.mtnforum.org/sites/default/files/publication/files/1518.pdf Accessed on 4 December 2014.

Demurger, S., Sachs, J.D., Woo, W.T., Bao, S.M. and Chang, G. (2002). The relative contributions of location and preferential policies in China's regional development: being in the right place and having the right incentives. *China Economic Review.* 13 (4): 444 – 465. Elsevier.

Department of Human Settlements (DoHS). (2009). *The National Housing Code*. Available at: www.dhs.gov.za/content/national-housing-code-2009. Accessed on 17 March 2015.

Department of Human Settlements (DoHS). (2011). *National Upgrading Support Programme* (NUSP). Available at: http://www.upgradingsupport.org Accessed on 11 October 2011.

Department of Labour. (1993). *Government Notice: Occupational Health and Safety Act, 1993 (Act No 95 of 1998)*. Government Printer, Pretoria.

Department of Public Works (DPW). (2010). *Appropriate development of infrastructure on Dolomite: Manual for consultants*. pp 375. Johannesburg, Republic of South Africa: Department of Public Works.

Department of Rural Development and Land Reform (DRDLR). (2016). *National Land Use Classification Workshop.* Proceedings of the workshop held on 7 September 2016, Kempton Park.

Department of Water Affairs (DWA). (2009). *Dolomite Guideline: a short guide to available documents on procedures for developing dolomitic land.* 23pp. Pretoria, Department of Public Works, Department of Water Affairs , Council for Geoscience, Water Geosciences Consulting, and University of Pretoria.

Department of Water Affairs and Forestry (DWAF). (1998a). *Minimum Requirements for the Handling, Classification and Disposal of Hazardous Waste.* Waste Management Series: Second Edition. pp 172. Cape Town, CTP Book Printers.

Department of Water Affairs and Forestry (DWAF). (1998b). *Minimum Requirements for Waste Disposal by Landfill.* Waste Management Series: 2nd Edition. Cape Town, CTP Book Printers.

Douglas, J. (2007). Physical vulnerability modelling in natural hazard risk assessment. *Natural Hazards and Earth System Sciences.* 7: 283 - 288. Copernicus Publications.

Drake, P.R. (1998). Using the Analytic Hierarchy Process in Engineering Education. *International Journal of Engineering* (IJE)*.* 14(3): 191 - 196.

DRDLR (n.d.). *Legal Framework for Planning.* Available at: www.ruraldevelopment.gov.za Accessed on 10 September 2016

du Plessis, C. and Landman, K. (2002). *Sustainability analysis of human settlements in South Africa*. Prepared for the Department of Housing. Pretoria, CSIR.

du Plessis, L. (2014). Sinkhole repaired and road opened. 20 June 2014. *Centurion Rekord.*

Dutta, D. and Tingsanchali, T. (2003). *Development of Loss Functions for Urban Flood Risk Analysis in Bangkok. New Technologies for Urban Safety of Mega Cities in Asia,* Tokyo*.* Quoted in Sagala, S. A. H. (2006). Analysis of Flood Physical Vulnerability in Residential Areas. Case Study: Naga City, the Philippines. Unpublished M.Sc. Thesis. International Institute for Geo-information Science and Earth

Observation, Twente University, Netherlands. Available at: http:www.itc.nl/library/papers_2006/msc/upla/sagala.pdf Accessed on 20 August 2011.

Dyer, J.S. (1990a). Remarks on the analytic hierarchy process. *Management Science*. 36: 249 - 258. Informs: A Journal of the Institute for Operations Research and the Management Sciences. Maryland (USA).

Dyer, J.S. (1990b). A clarification of "Remarks on the Analytic Hierarchy Process". *Management Science*. 36: 274-275. Informs: A Journal of the Institute for Operations Research and the Management Sciences. Maryland (USA).

Easton, S. (2014). *Make It Rational.* Analytical Hierarchy Analysis Software. United Kingdom. ExpertChoice™.

Eernink, N. (2012). Building the science-policy gap in Poland: Bydgoszcz Waterproof. In: Klijn, F and Schweckendiek, T. (Eds.). *Comprehensive Flood Risk Management: Research for Policy and Practice*. CRC Press. Taylor & Francis Group. pp. 460.

Enninful, J.P. (2013). *Rainwater Harvesting: A Sustainable Practice for low-income Housing in South Africa.* Unpublished research report submitted in partial fulfilment of the requirements of the degree of Master of the Built Environment in Housing. University of the Witwatersrand, Johannesburg. pp. 131.

Environomics. (2012). *Midstream Ridge. Township establishment of Midrand Estates New Extensions on the remaining portions of the farm Olifantsfontein 410JR*. Gaut 002/11-12/E0268. Environmental Impact Assessment Process: Final Scoping Report. June 2012. For Bondev Midrand (Pty) Ltd. pp. 38.

Erickson, P.A. (2006). *Emergency Response Planning for Corporate and Municipal Managers.* 2nd Edition. Butterworth-Heimann Homeland Security Series. pp 416. Oxford, Elsevier Butterworth-Heimann.

Ernstson, H. (2012, in review). The social production of ecosystem services: Environmental justice and ecological complexity in urbanized landscapes. *Landscape and Urban Planning.* Special issue on 'Ecosystem Services in Cities'. Elsevier.

Education and Training Unit for Democracy and Development (ETU) (n.d.) *Integrated Development Planning for Local Government*. Available at: www.etu.org.za/toolbox/docs/localgov/webidp/html Accessed on 16 March 2015.

Fainstein, S.S. (1999). *New Directions in Planning Theory*. Available at: http://www.oamk.fi/luova/hankkeita/entracop/copack/docs/introduction/theories/literature/Feinstein.pdf Accessed on 16 July 2014. CoPack: Toolkit for training collaborative planning: http://copack.oamk.fi/ Education and Training, European Commission (EC).

Fales, R. and Moses, L.N. (1972). Land Use Theory and the Spatial Structure of the Nineteenth Century City. Papers and Proceedings: *Regional Science Association*; 28: 49 – 80.

Faling, W., Tempelhoff, J.W.N. and Van Niekerk, D. (2012). Rhetoric or action: Are South African municipalities planning for climate change? *Development Southern Africa.* Taylor & Francis Online. 29(2): 241 – 257. Available at: http://www.tandfonline.com/doi/abs/10.1080/0376835X.2012.675695#.VH7qP9oaJD8 Accessed on 3 December 2014.

Fell, R. (1994). Landslide risk assessment and acceptable risk. *Canadian Geotechnical Journal.* 31(2): 261 - 272. National Research Council (NRC) Research Press.

Festa, V., Fiore, A., Miccoli, M.N., Parise, M. and Spalluto, L. (2015). Tectonic versus Karst Relationships in the Salento Peninsula (Apulia, Southern Italy): Implications for a Comprehensive Land-Use Planning. In: Lollino, G., Manconi, A., Culchaw, M., Bobrowsky, P. and Luino, F. (Eds). *Engineering Geology for Society and Territory: Urban Geology, Sustainable Planning and Landscape Exploitation.* Volume 5. Springer. Heidelberg New York Dordrecht London. pp. 493 – 498.

Fleury, S. (2009). *Land use policy and Practice on Karst Terrains: Living on Limestone.* USA, Springer.

Florida Geological Survey (FGS). (n.d.). *Sinkholes in Florida.* Available at: http://www.dep.state.fl.us/geology/ Accessed on 7 December 2011.

Foerster, P.A. (2006). *Algebra and Trigonometry: Functions and Applications*, Teacher's Edition. Upper Saddle River, NJ. Prentice Hall. pp. 573.

Forman, E.H. and Gass, S.I. (1999). The Analytic Hierarchy Process – An Exposition. *Operations Research*. pp. 86.

Galve, J.P., Bonachea, J., Remondo, F., Gutiérrez, F., Guerrero, J., Lucha, P., Cendrero, A., Gutiérrez, M. and Sánchez, J.A. (2008). Development and validation of sinkhole susceptibility models in mantled karst settings. A case study from the Ebro valley evaporate karst (NE Spain). *Engineering Geology.* 99: 185 - 197. Elsevier.

Galve, J.P., Gutiérrez, F., Remondo, J., Bonachea, J., Lucha, P., and Cendrero, A. (2009). Evaluating and comparing methods of sinkhole susceptibility mapping in the Ebro Valley evaporate karst (NE Spain). *Geomorphology.* 111: 160 - 172. Elsevier.

Garreau, J. (1992). *Edge City: Life on the New Frontier.* NY: Doubleday.

Geocaching. (2014). *Blyvooruitzicht Sinkholes: An explanation why sinkholes appeared in the Blyvooruitzicht and Carletonville areas, North-west province, South Africa during the 1960's*. Available at: http://www.geocaching.com/geocache/GC4W7DA_blyvooruitzicht-sinkholes Accessed on 23 June 2014.

Gauteng City Region Observatory (GCRO). (2011c). *Proceedings of Dolomite Workshop, 11 November 2011*. Available at: www.gcro.ac.za Accessed on various dates between March 2012 and June 2013.

Gauteng City Region Observatory (GCRO). (2013). *September 2013 Map of the Month: Backyard structures in Gauteng*. Available at: http://www.gcro.ac.za/maps-gis/map-of-the-month?page=1 Accessed on 6 June 2014.

Gautrain. (2010). *Overview of the Dolomitic Geology underlying Centurion*. 5 March 2010. Available at: http://www.gautrain.co.za/construction/2010/03/overview-dolomitic-geology-centurion/ Accessed on 23 June 2014.

Getis, A. (1983). Second-Order Analysis of Point Patterns: The Case of Chicago as a Multi-Center Urban Region. *The Professional Geographer.* 35(1): 73 – 80. Association of American Geographers. Taylor & Francis.

Gibson, N.C. (2008). Upright and free: Fanon in South Africa, from Biko to the shackdweller's movement ('Abahlali baseMjonodolo'). *Social Identities: Journal for the Study of Race, Nation and Culture.* 14(6): 683 - 715. Routledge.

Glavovic, B.C. and Smith, G. P. (Eds). (2014). *Adapting to Climate Change: Lessons from Natural Hazards Planning*. Springer. pp. 461.

Glade, T., Anderson, M.G. and Crozier, M.J. (Eds.). (2005). *Landslide hazard and risk.* pp 809. Chichester, West Sussex, England; Hoboken, NJ; J Wiley.

Glaab, C.N. and Brown, T. (1967). *A History of Urban America.* London: Macmillan Press.

Glaister, S. and Pinho, R. (2003). Development of a simplified deformation-based method for seismic vulnerability assessment. *International Journal of Earthquake Engineering*. 7(S1): 107 - 140. Taylor & Francis, London.

Glass, K., Morkel, C. and Bangay, S.D. (2006). Duplicating Road Patterns in South African Informal Settlements using procedural techniques. *Afrigraph.* The African Computer Graphics Association. January 2006: 161 – 169. Cape Town. Available at: http://www.cs.ru.ac.za/research/Groups/vrsig/pastprojects/047proceduralmodelling/paper09.pdf Accessed on 15 July 2013 and 4 December 2014.

Glickman, T.S. and Gough, M. (Eds.) (1995). *Readings in Risk.* Fifth printing, 2004. pp. 262. Washington DC, Resources for the Future.

Global Crisis Solutions (GCS). (n.d.). *Understanding Vulnerability: Ensuring Appropriate and Effective Responses.* Promoting Rights through practice and policy. pp 11. Available at: http://www.globalcrisissolutions.org/libraries/understanding_vulnerability.pdf Accessed on 20 August 2011. GCS: Training Unit - Support to Program Quality Project.

Gogu, R.C. and Dassargues, A. (2000). Sensitivity analysis for the EPIK method of vulnerability assessment in a small karstic aquifer, southern Belgium. *Hydrogeology journal.* 8: 337 - 345. Springer

Gorgens, T. and van Donk, M. (2011). *From basic needs towards socio-spatial transformation: coming to grips with the 'Rights to the City' for the urban poor in South Africa*. The Isandla Institute. Accessed at: http://isandla.org.za/publications/152/ on 14 January 2014.

Govender, T., Barnes, J.M. and Pieper, C.H. (2011). Housing conditions, sanitation status and associated health risks in selected subsidized low-cost housing settlements in Cape Town, South Africa. *Habitat International*. 35(2): 335 – 342. Elsevier.

Governance Social Development Humanitarian Conflict (GSDRC). (n.d.). *Human rights legal framework*. Applied Knowledge Sciences. Available at: http://www.gsdrc.org/go/topic-guides/human-rights/human-rights-legal-framework Accessed on 4 December 2014.

Greve, N. (2014). Presidency defends e-tolls, names upgraded alternative routes. *Engineering News.* Available at: http://m.engineeringnews.co.za/article/presidency-defends-e-tolls-names-upgraded-alternative-routes-2014-01-17 Accessed on 23 June 2014.

Grimble, R. and Chan, M.K. (1995). Stakeholder analysis for natural resource management in developing countries. *Natural Resources Forum*. 19: 113 - 124.

Haas, R. and Meixner, O. (n.d.). *An Illustrated Guide to the Analytic Hierarchy Process.* Institute of Marketing & Innovation: University of Natural Resources and Applied Life Sciences, Vienna. http://www.boku.ac.za/mi/ Accessed on 10 July 2013.

Halpern, R. (1995). *Rebuilding the Inner City: A history of neighbourhood initiatives to address poverty in the United States*. Columbia University Press. New York, West Sussex. pp 264.

Hajkowicz, S.A., McDonald, G.T. and Smith, P.N. (2000). An evaluation of multiple objective decision support weighting techniques in natural resource management. *Journal of Environmental Planning and Management* . 43(4): 505 - 518.

Harker, P.T. and Vargas, L.G. (1987). The theory of ratio scale estimation: Saaty's Analytic Hierarchy Process. *Management Science*. 33: 1383 - 1403. Informs: A Journal of the Institute for Operations Research and the Management Sciences. Maryland (USA).

Harrison, P., Todes, A. and Watson, V. (2008). *Planning and Transformation: Learning from the Post-Apartheid Experience*. London, Routledge.

Harvey, D. (2008). The Right to the City. *New Left Review*. 53: 23 - 40. Verso Books. London.

Harvey, D. (2012). *Rebel Cities: From the Right to the City to the Urban Revolution.* Verso books. London.

Harker, P.T. and Vargas, L.G. (1990). Reply to "Remarks on the Analytic Hierarchy Process" by J.S. Dyer. *Management Science*. 36: 269 - 273. Informs: A Journal of the Institute for Operations Research and the Management Sciences. Maryland (USA).

Hartley, N. and Wood, C. (2006). Public participation in environmental impact assessment – implementing the Aarhus Convention. *Environmental Impact Assessment Review*. 26(4): 319 - 340. Elsevier.

Hawke, D.V. (1975). *Cavern development in the Malmani Dolomite, Transvaal.* Unpublished M.Sc. Thesis, University of the Witwatersrand, Johannesburg. pp. 81.

Headington Institute (n.d.). *Resilience.* Available at www.headington-institute.org Accessed on 10 September 2016

Heath, G., Oosthuizen, T. and Grobler, J. (2007). *Consultants Guide: Approach to sites on dolomite land.* 34pp. Pretoria, Council for Geoscience: Dolomite Section.

Heath, G. (2011). Sinkholes threat to houses in Gauteng. *News24, Times LIVE*, 5 October 2011. Available at: http://www.news24.com/SouthAfrica/News/Gauteng-Between-a-rock-and-a-hard-place-20111005 Accessed on 13 January 2013.

Herold, M., Liu, X. and Clarke, K. (2003). Spatial Metrics and Image Texture for Mapping Urban Land Use. *Photogrammetric Engineering and Remote Sensing.* Vol 69(9): 991 – 1001. American Society for Photogrammetry and Remote Sensing.

Herold, H., Roehm, P., Hecht, R. and Meinel G. (2011). Automatically georeferenced maps as a source for high resolution urban growth analyses. *Proceedings of the 25th ICA International Cartographic Conference*, July 3 – 8, 2011. Paris, France.

Herold, H., Meinel, G., Hecht, R. and Csaplovics, E. (2012). A Goebia approach to map interpretation – Multitemporal building footprint retrieval for high resolution monitoring of spatial urban dynamics. *Proceedings of the 4th Geobia*, May 7 – 9, 2012. pp. 252 - 256. Rio de Janeiro. Brazil.

Hervé, F. (2009). *Integrating Poor Populations in South African Cities: A Challenge for Government Authorities.* Notes and Documents: Number 47, October 2009. Agence Française de Développement (AFD): Research Department. pp. 167.

Hlubi, P. (2011). Car Swallowed by Sink Hole. *Signs of the times*. Available at: http://www.sott.net/article/238897-South-Africa-Johannesburg-Car-Swallowed-By-Sink-Hole Accessed on 23 June 2014

Hope, B.K. (2001). A Case Study Comparing Static and Spatially Explicit Ecological Exposure Analysis Methods. *Risk Analysis: An International Journal.* 21(6): 1001 - 1010. Wiley-Blackwell.

Houghton, J. T. (Ed.). (2001). ‘Appendix I – Glossary’. *Climate change 2001: the scientific basis: contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (IPCC). Cambridge, Cambridge University Press. Available at: http://www.ipcc.ch/ipccreports/tar/wg1/518.htm Accessed on 20 August 2011.

Huchzermeyer, M. (2008). *Settlement Informality: The importance of understanding change, formality and land and the informal economy.* Available at: http://wiredspace.wits.ac.za/handle/10539/11780?show=full Accessed on 12 May 2013 and 4 December 2014. WIReDSpace: Wits Institutional Repository environment on DSpace. Invited keynote paper. Groupement de Recherche Internationale (GDRI). Workshop on Informality. University of the Witwatersrand, Johannesburg.

Huchzermeyer, M. (2009). The struggle for *in situ* upgrading in informal settlements: a reflection on cases in Gauteng. *Development Southern Africa.* 26(1). pp. 59 – 73. Routledge, Taylor & Francis Group.

Huchzermeyer, M. (2011a). *Cities with ‘Slums’: From Informal Settlement Eradication to a Right to the City in Africa.* UCTPress. pp. 296.

Huchzermeyer, M. (2011b). *Tenement Cities: From 19th Century Berlin to 21st Century Nairobi*. Africa World Press. pp. 275.

Huchzermeyer, M., Karam, A. and Maina, M. (2014). Informal Settlements. In Harrison, P., Todes, A., Gotz, G. and Wray, C. (*Eds*). *Changing Space, Changing City: Johannesburg after Apartheid.* Johannesburg, Wits University Press. pp. 590.

Huggenberger, P. and Epting, J. (2011). *Urban Geology: Process-Oriented Concepts for Adaptive and Integrated Resource Management.* Springer. Heidelberg Dordrecht London, New York. pp. 203.

Hui, Y. (2011). Spatial Characters for Equality. *Sustainable Urban Design Journal*. Volume 1. Available at: http://www.stadsbyggnad.lth.se/fileadmin/stadsbyggnad/images/_1_Sudes_Book/_1_B5_webversion1.pdf Accessed on 17 July 2014. Sustainable Urban Design Programme (SUDes); Lund University School of Architecture; Ax:son Johnson Institute for Sustainable Urban design. Sweden: Lund. pp. 40.

Hyatt, J.A., Wilson, R. Givens, J.S. and Jacobs, P.N. (2001). Topographic, geologic and hydrologic controls on dimensions of locations of sinkholes in thick covered karst, Lowndes County, Georgia. In Beck, B.F., Herring, J.G. (Eds.). *Geotechnical and environmental conference on sinkholes and the engineering and environmental impacts of karst.* Louisville, Kentucky, USA. pp. 37 - 44.

InspectApedia (IAP). (2011). *Guide to Visual & Other clues Indicating the Risk of Sinkholes.* Available at: http://www.inspectapedia.com/vision/sinkholes.htm Accessed on 5 December 2011.

International Covenant on Economic, Social and Cultural Rights (ICESCR). (1976). *The International Covenant on Economic, Social and Cultural Rights*. United Nations. www.ohchr.org/EN?ProfessionalInterest/Pages/CESCR.aspx Accessed on 15 March 2015.

International Federation of Red Cross and Red Crescent Societies (IFRC). (2011). Public awareness and public education for disaster risk reduction: a guide. IFRC, Geneva. pp. 201.

Involve (2005). *The True Cost of Public Participation – Full Report.* Available at: http://www.involve.org.uk/wp-content/uploads/2011/03/True-Costs-Full-Report2.pdf Accessed on 10 July 2014. pp. 204.

Jack, J. (2011). *Environmental problems in Karst lands.* Environmental Science: Regional Updates. Available at: http://www.prenhall.com/esm/app/nebel/html/updates/update13.html Accessed on 4 December 2011.

Jenks, M. and Burgess, R. (Eds.) (2000). *Compact Cities: Sustainable Urban Forms for Developing Countries.* SOPN Press. London and New York. pp. 360.

Jha, A.K. and Barenstein, J.D., Phelps, P.M., Pittet, D. and Sena, S. (2010) *Safer Homes, Stronger Communities: A Handbook for Reconstructing after Natural Disasters.* Global Facility for Disaster Reduction and Recovery (GFDRR). pp 374. World Bank Publications. Available at: http://books.google.co.za/books?id=AylYZrXQDJwC&pg=PA347&lpg=PA347&dq=develop+physical+vulnerability+curve&source=bl&ots=_owiwR0Kdz&sig=iy9LDw4BBiG82h-hnLZZS28_kN4&hl=en&ei=hWLcToCBMrHMmAXr0qXECw&sa=X&oi=book_result&ct=result&resnum=3&ved=0CDsQ6AEwAg#v=onepage&q=develop%20physical%20vulnerability%20curve&f=false Accessed on 1 December 2011.

Jiang, M., Lei, M. and Dai, J. (2005). National-scale risk assessment of sinkhole hazard in China. In: Beck, B.F. (Ed.). *Sinkholes and the Engineering and Environmental Impacts of Karst.* Tenth Multidisciplinary Conference. San Antonio, Texas, USA. pp. 649 - 656.

Jiang, B. and Yao, X. (Eds). (2010). Geospatial Analysis and Modelling Urban Structure and Dynamics. *The GeoJournal Library.* 99. pp. 465. Springer.

Kasperczyk, N. and Knickel, K. (2005). *The Analytic Hierarchy Process (AHP)*. Published online. Available at: http://www.johnsaunders.com/papers/ahpexpo.pdf Accessed on 10 July 2013.

Kaufmann, O. and Quinif, Y. (2002). Geohazard map of cover-collapse sinkholes in the Tournasis area, southern Belgium. *Engineering Geology.* 65: 117 - 124. Elsevier.

Kaytech. (2006). *Road Rehabilitation Sinkhole Repair N14/P158-1, Centurion, Gauteng.* Available at: http://kaytech.co.za/upload/casestudies/N14%20Sinkhole.pdf Accessed on 26 February 2014. Kaytech Engineered Fabrics.

Kent, R. (2005). Maladaptive behaviour and disaster risk management. *Environment and Poverty Times #3*. Special Edition for the World Conference on Disaster Reduction, Kobe, Japan, January 2005. Available at: http://www.grida.no/publications/et/ep3/page/2596.aspx Accessed on 4 December 2014. GRID-Arendal: A Centre Collaborating with UNEP

Kirsten, H.A.D., Heath, G.J., Venter, I.S., Trollip, N.Y.G. and Oosthuizen, A.C. (2009). The issue of personal safety on dolomite: a probability-based evaluation with respect to single-storey residential houses. *Journal of the South African Institution of Civil Engineering*. 51(1): 26 - 36. SAICE.

Knowledge Factory (KF). (n.d.). *Cluster Plus: Helping you to better understand and locate your target customers and markets through geo-demographic segmentation.* Knowledge Factory, Johannesburg.

Kornienko, K. (2013). *Engaging informal settlements as landscapes of place: reconceptualising urban communities in the struggle for in situ upgrading.* Unpublished PhD thesis. Wits University, Johannesburg.

Kvale, S. (1992). Ten Standard Responses to Qualitative Research Interviews. pp 31. *Journal of Phenomenological Psychology*. U.S. Department of Education: Office of Educational Research and Improvement. Educational Resources Information Center (EDRS). Available at: http://files.eric.ed.gov/fulltext/ED348376.pdf Accessed on 8 April 2015.

Lefebvre, H., Kofman, E. and Lebas, E. (1996). *Writings on Cities*. (Translated from original work: Le Droit á la ville (1968)). pp 250. Social Science. Wiley.

Lei, M., Jiang, X. and Li Y. (2001). New advances of karst collapse research in China. In: Beck, B.F. and Herring, J.G. (Eds.). *Geotechnical and Environmental Applications of Karst Geology and Hydrology. Eighth multidisciplinary conference on sinkholes and the engineering and environmental impacts of karst.* Louisville, Kentucky, USA. pp. 145 - 151. Balkema, Lisse.

LeRoy, S.F. and Sonstelie, J. (1983). Paradise Lost and Regained: Transportation Innovation, Income and Residential Location. *Journal of Urban Economics.* 13(1): 67 – 89. Elsevier.

Lodge, T. (2003). The RDP: Delivery and Performance. In: Philip, D (Ed.). *Politics in South Africa: From Mandela to Mbeki*. Cape Town & Oxford.

Lollino, G., Manconi, A., Culchaw, M., Bobrowsky, P. and Luino, F. (Eds). (2015). *Engineering Geology for Society and Territory: Urban Geology, Sustainable Planning and Landscape Exploitation.* Volume 5. Springer. Heidelberg New York Dordrecht London. pp .

Lupala, J.M. (2002) *Urban types in rapidly urbanising cities. Analysis of Formal and Informal settlements in Dar es Salaam, Tanzania.* Doctoral thesis. Kungl Tekniska Högskolan: Royal Institute of Technology. Available at: http://www.diva-portal.org/smash/get/diva2:9224/FULLTEXT01.pdf Accessed on 4 December 2014.

Lynch, K. and Rodwin, L. (1958). A Theory of Urban Form. *Journal of the American Planning Association.* 24(4): 201 – 214. Taylor & Francis.

Macharis, C., Springael, J., de Brucker, K . and Verbeke, A. (2004). PROMETHEE and AHP: The design of operational synergies in multicriteria analysis. Strengthening PROMETHEE with ideas of AHP. *European Journal of Operational Research*. 153: 307 - 317. Elsevier.

Madden, S. (2010). *Choosing Green Over Gray: Philadelphia's Innovative Stormwater Infrastructure Plan*. Submitted in partial fulfilment of the requirements for the degree Master in City Planning, Department of Urban Studies and Planning. Massachusetts Institute of Technology. Massachusetts. pp. 49.

Mandela, N. (1994). *The Reconstruction and Development Programme Preface*. Available at www.nelsonmandela.org and www.polity.org.za/polity/govdocs/rdp/rdp.html. Accessed on 24 July 2015.

Martins, P. (2013a). More sinkholes appear*. Centurion Rekord*. 13 September 2013. Pretoria, Rekord.

Martins, P. (2013b) New sinkholes in Centurion. *The Citizen*. 7 September 2013. Available at: http://citizen.co.za/38981/new-sinkholes-in-centurion/ Last accessed September 2013.

Martin, S. (2014). Quantifying service delivery demand in South African cities. *Position IT.* June 2014: 29 – 33. EE Publishers.

Mauser, W. and Prasch, M. (Eds) (2016). *Regional Assessment of Global Change Impacts.* Springer. Available at: www.springer.com Accessed on 10 September 2016.

Maxwell, J.A. (2005). Qualitative research design: an Interactive Approach. Second Edition. pp 174. *Applied Social Research Methods Series.* Volume 41. Sage Publications, California, London, New Delhi. Available at: http://www.sagepub.com/upm-data/5056_Maxwell_Chapter_3.pdf Accessed on 20 September 2011.

McDonald, J. (1987). The Identification of Urban Employment Subcenters. *Journal of Urban Economics.* 21(2): 242 – 258. Elsevier.

McGuire, R.K. (2004). *Seismic hazard and risk analysis.* A monograph. Oakland, California; Earthquake Engineering Research Institute (EERI).

Mchunu, M. (2012). Huge Lenasia sinkhole has residents up in arms. *SABS News*. Available at: http://www.sabc.co.za/news/a/e0e75a804d07e52b9951998655ed9c76/Huge-Lenasia-sinkhole-has-residents-up-in-arms-20121010 Accessed on 23 June 2014.

McGranahan, G., Balk, D and Anderson, B. (2007). The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment & Urbanization*. International Institute for Environment and Development (IIED). 19(1): 17 – 37. Sage Publications.

Mdakane, L. and van den Bergh, F. (2012). *Extended Local Binary Pattern Features for Improving Settlement Type Classification of Quickbird Images*. Available at: https://www.google.co.za/?gfe_rd=cr&ei=_3KBVLOSM4ap8wfPn4G4Dw&gws_rd=ssl#q=grey+infrastructure+formal+settlement+types Accessed on 4 December 2014. PRASA.

Mdakane, L., van den Bergh, F. and Moodley, D. (2014). Improving settlement type classification of aerial images. ResearchSpace. Available at: http://researchspace.csir.co.za/dspace/handle/10204/7942 and http://www.aarse2014.co.za/assets/4.l_mdakane_subm_id_25.pdf Accessed on 1 September 2015. *Tenth International Conference of the African Association of Remote Sensing of the Environment* (AARSE), University of Johannesburg, 27 – 31 October 2014. South Africa.

Meijer, K. (2015). Damaged intersection turns into a sinkhole. *Centurion Rekord*. 27 March 2015. www.rekordcenturion.co.za. pp. 3.

Meinel, G. (2010). Advanced Procedure for the Monitoring of Settlement and Open Space Development on basis of Topographical Geodata sets in the IOER-MONITOR. In: *ISPRS Workshop on Geospatial Data Infrastructure: from data acquisition and updating to smarter services*, Guilin, China, October 20-21, 2011. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences; Vol XXXVIII, Part 4/W25, S. pp. 104 - 109.

Meinel, G. (2012). Advanced Procedure for German Wide High Resolution Monitoring of Settlement Development on Basis of Topographical Geodata Sets. *12th International Multidisciplinary Scientific GeoConference.* SGEM 2012, 17-23 June, 2012, Albena, Bulgaria. Conference Proceedings, Volume 2. Sofia: STEF92 Technology, S. pp. 939 - 948.

Merriman, P.A. and Browitt, C.W.A. (Eds.). (1993). *Natural disasters: protecting vulnerable communities.* Proceedings of the conference held in London, 13 - 15 October 1993. Telford, T. London.

Mills, E.S. (1967). An Aggregative Model of Resource Allocation in a Metropolitan Area. *American Economic Review.* 57: 197 – 210. JSTOR. American Economic Association (AEA).

Mitchell, J.K. (1999). Chapter 2: Natural disasters in the context of mega-cities. In Mitchell, J.K. (Ed). *Crucibles of hazard: mega-cities and disasters in transition.* P. 15 – 55. Tokyo and New York, United Nations University Press. pp.551.

Mitchell, D.W. (2004). More on spreads and non-arithmetic means. *The Mathematical Gazette.* 88: 142 - 144. The Mathematical Association. UK.

Mmemezi, H. (2011). Quoted in: Sinkholes threat to houses in Gauteng. *News24, Times LIVE*, 5 October 2011. Available at: http://www.news24.com/SouthAfrica/News/Gauteng-Between-a-rock-and-a-hard-place-20111005 Accessed on 13 January 2013.

Mnguni, T. (2014). Dolomite mine a concern. *Centurion Rekord*. 13 February 2014. Available at: http://rekordcenturion.co.za/13853/dolomite-mine-a-concern/ Accessed on 22 June 2014.

Mnisi, M. and Others v City of Johannesburg (Mnisi v CoJ). (2009). *[08/17819].* Johannesburg, South Gauteng High Court, 4 August 2009. Johannesburg. Southern African Legal Information Institute.

Mnisi, M. and Others v City of Johannesburg (Mnisi v CoJ). (2014). *[2008/1789].* Johannesburg, High Court of South Africa, 31 March 2014. Johannesburg.

Mosalam, K.M., Ayala, G., White, R.N. and Roth, C. (1997). Seismic fragility of LRC frames with and without masonry infill walls. *International Journal of Earthquake Engineering* (JEE). 1(4): 693 - 719. Open Select Journals.

Mosoetsa, S. (2010). *Housing and Service Delivery in Gauteng.* The Office of the Presidency Project. Society, Work and Development Institute (SWOP). Johannesburg, University of the Witwatersrand.

Moses, L. and Williamson, H.F. Jr. (1967). The Location of Economic Activity in Cities. *American Economic Review*. 57(2): 211 – 222. JSTOR. American Economic Association (AEA).

Morgan, M.G. (1995a). Choosing and Managing Technology-Induced Risk. In: Glickman, T.S. and Gough, M. (Eds.). *Readings in Risk.* 17-28. Fifth printing, 2004. pp. 262. Washington DC, Resources for the Future.

Morgan, M.G. (1995b). Probing the Question of Technology-Induced Risk. In: Glickman, T.S. and Gough, M. (Eds.). *Readings in Risk.* pp. 5 - 15. Fifth printing, 2004. pp 262. Washington DC, Resources for the Future.

Murphy, C.K. (1993). Limits of the Analytical Hierarchy Process from its consistency index. *European Journal of Operational Research*. 65: 138 - 139. Elsevier.

Muth, R.F. (1969). *Cities and Housing: The spatial pattern of urban residential land use.* Chicago, IL: The University of Chicago Press. pp. 355.

National Home Builders Registration Council (NHBRC). (n.d.(a)). *Implications of the Housing Consumers Protection Measures Act, 1998 (Act No 95 of 1998).* Available at: http://www.the-facilitators.com/index.php/about-the-nhbrc.html#Implication Accessed on 8 August 2011.

National Home Builders Registration Council (NHBRC). (n.d.(b)). *Why enrol – National Home Builders Registration Council.* Available at: http://www.nhbrc.org.za Accessed on 28 July 2015.

National Department of Housing (NDH). (1994). *White Paper: A New Housing Policy and Strategy for South Africa.* Available at: www.dhs.gov.za/sites/default/files/legislation/Policies_Housing_White_Paper.pdf Accessed on 12 March 2015.

National Department of Housing (NDH). (2002). *Geotechnical site investigations for housing developments:* Project Linked Greenfield Subsidy Project Developments. Generic Specification GFSH-2. Johannesburg, Republic of South Africa.

National Department of Housing (NDH). (2004). *National Housing Programme: Upgrading of Informal Settlements: Part 3: Chapter 13.* Available at: http://abahlali.org/files/Ch13finalversion19Oct2004InfSettleUpgrProgr.pdf Accessed on 7 October 2015. pp. 51.

National Snow and Ice Data Center (NSIDC). (n.d.). *Glossary on Climate Change.* Education Center - Arctic Climatology and Meteorology. Available at: http://nsidc.org/arcticmet/glossary/climate_change.html Accessed on 20 Aug 2011.

Nel, D.T. and Haarhoff, J. (2011). The failure probability of welded steel pipelines in dolomitic areas. *Journal of the South African Institution of Civil Engineering (SAICE).* 53(1): 9 - 21. SAICE.

Ndaba, B. (2013). 150 Schools at risk from sinkholes. *The Star*. 5 December 2011. Gauteng.

Ngie, A. (2012). *A GIS Approach for Flood Vulnerability and Adaptation Analysis in Diepsloot, Johannesburg*. Unpublished Master's Research thesis. University of Johannesburg. Johannesburg.

Nhlabathi, H. and Xaba, V. (2015). Risky Move in Housing. *Sowetan*. 10 March 2015. pp. 4.

Nokotyana, J.M. and Others v Ekurhuleni Metropolitan Municipality and Others (Nokotyana v EMM). (2009). *CCT 31/09 [2009] ZACC 33. Summary of judgement.* Constitutional Court of South Africa, 19 November 2009.

Norwegian Seismic Array (NORSAR) (n.d.). *Exploring the Earth: Seismic Vulnerability.* Available at: Available at: http://www.norsar.no/pc-27-68-Seismic-Vulnerability.aspx Accessed 2 December 2011.

National Upgrading Support Programme (NUSP). (n.d.). *The NUSP Resource Kit*. Available at: http://www.upgradingsupport.org/learn.html Accessed on 7 December 2012. South African Government: Department of Human Settlement.

O'Faircheallaigh, C. (2010). Public participation and environmental impact assessment: Purposes, implications and lessons for public policy making. *Environmental Impact Assessment Review*. 30(1): 19 - 27. Elsevier.

Onose, J-I. (1982). Prediction of damage ratio of reinforced concrete buildings due to earthquakes and comparison with actual damage ratio. *Proceedings of the 6th Japan Earthquake Engineering Symposium*: Japan Society of Civil Engineers. pp. 2081 – 2088. Tokyo.

Oosthuizen, A.C. (2013). *The hazard of sinkhole formation in the Centurion CBD and surrounding areas: Pretoria, Gauteng*. Unpublished thesis submitted in partial fulfilment of the requirements for the degree M.Sc. Engineering & Environmental Geology. University of Pretoria. Pretoria.

Orndorff, R.C., Weary, D.J. and Lagueux, K.M. (2000). Geographic information system analysis of geologic controls on the distribution of dolinas in the Ozarks of South-Central Missouri, USA. *Acta Carsologica* (AC)*.* 29(2): 161 - 175. Scientific Research Center of the Slovenian Academy of Science and Arts.

Orsini, G. (1999). A model for buildings' vulnerability assessment using the parameterless scale of seismic intensity (PSI). *Earthquake Spectra.* 15(3): 463 - 483. The Professional Journal of the Earthquake Engineering Research Institute (EERI).

Osman, A. and Herthogs, P. (2010). Medium-Density Mixed Housing: sustainable design and construction of South African social housing. *CSIR 3rd Biennial Conference 2010. Science Real and Relevant.* CSIR 3rd Biennial Conference 2010. Science Real and Relevant. Pretoria: CSIR. Available at: http://researchspace.csir.co.za/dspace/handle/10204/4308 Accessed on 6 December 2012.

Palmquist, R.C. (1977). Distribution and density of dolines in areas of mantled karst. In: Dilamarter, R.R. and Csallany, S.C. (Eds.). *Hydrologic Problems in Karst Regions.* Western Kentucky University, Bowling Green, Kentucky. pp. 117 - 129.

Pan American Health Organisation (PAHO). (1998). *Natural Disaster Mitigation in Drinking Water and Sewerage Systems: Guidelines for Vulnerability Analysis.* pp 80. Accessed at: http://helid.digicollection.org/en/d/Jwater/5.2.1.2.html Accessed on 20 August 2011.

Parnell, S., Simon, D. and Vogel, C. (2007). Global environmental change: conceptualising the growing challenge for cities in poor countries. *Area*. Wiley Online Library. 39(3): 357 - 369. Available at: http://onlinelibrary.wiley.com/doi/10.1111/j.1475-4762.2007.00760.x/abstract;jsessionid=7BA2433FD8E898020370034586D707FC.f04t03 Accessed on 3 December 2014.

Pascual, C., Garcia-Montero, L.G., Manzanera, J.A., Arroyo-Méndez, L.A., Beltrán, I. and Caballero, D. (n.d.). *Preliminary description of urban settlement typologies related to forest fire risk* (WARM project). Available at: http://www.fria.gr/WARM/chapters/warmCh25Pascual.pdf Accessed on 14 October 2011.

Patel, K. (2013). Shack dwellers take the fight to eThekwini – and the ANC takes note. *The Daily Maverick*. 16 September 2013. Available at: http://www.dailymaverick.co.za Accessed on 28 September 2013.

Pelling, M. and Wisner, B.(2009). Chapter 1: Urbanisation, Human Security and Disaster Risk in Africa. In Pelling, M. and Wisner, B. (Eds.). *Disaster Risk Reduction: Cases from Urban Africa.* Referenced from Foreword. Earthscan Publishers. UK and USA. p. 3-16. Available from www.books.google.za Accessed on 10 September 2016. pp.224.

Pheko, N. and occupiers of Bapsfontein Informal Settlement v Ekurhuleni Metropolitan Municipality (Pheko v EMM). (2011a). *Case CT 19/11 [2011]ZACC 34.* Available at: www.saflii.org Accessed on various occasions during August 2015. Constitutional Court of South Africa. Southern African Legal Information Institute.

Pheko, N. and occupiers of Bapsfontein Informal Settlement v Ekurhuleni Metropolitan Municipality (Pheko v EMM). (2011b). *Heads of Argument on behalf of the Amicus Curiae.* CCT Case No 19/11. Available at: www.saflii.org Accessed on various occasions during August 2015. Constitutional Court of South Africa. Southern African Legal Information Institute.

Pheko, N. and occupiers of Bapsfontein Informal Settlement v Ekurhuleni Metropolitan Municipality (Pheko v EMM). (2015). *Case CCT 19/11 [2015]ZACC 10.* Available at: http://www.saflii.org/za/cases/ZACC/2011/34.html#.VeMQi0m7OeU.gmail Accessed on various occasions during August 2015. Constitutional Court of South Africa. Southern African Legal Information Institute.

Pillay, U., Rule, S., Rubin, M. and Ntema, L. (2010). *A rapid verification study on the Informal settlements and backyard shacks' backlog and trends within the Eastern Cape.* Commissioned by the Eastern Cape Provincial Department of Housing. pp 138. Report of the Human Sciences Research Council (HSRC). Available at: http://www.hsrc.ac.za/module-KTree-doc_request-docid-1713.phtml Accessed on 14 October 2011.

Prenger-Berninghoff, K. and Greiving, S. (2015). The Use of Risk Information in Spatial Planning in Europe: Examples from Case Study Sites in Italy and Romania with a Focus on Flood and Landslide Hazards. In: Lollino, G., Manconi, A., Culchaw, M., Bobrowsky, P. and Luino, F. (Eds.). *Engineering Geology for Society and Territory: Urban Geology, Sustainable Planning and Landscape Exploitation.* Volume 5. Springer. Heidelberg, New York, Dordrecht, London. pp. 737 – 742.

Priestley, M.J.M. (1998). Displacement-based approaches to rational limit states design of new structures. *Proceedings of the 11th European Conference on Earthquake Engineering*. Rotterdam. AA Balkema.

Purcell, M. (2003). Excavating Lefebvre: The right to the city and its urban politics of the inhabitant. *GeoJournal.* 58: 99 - 108. Kluwer Academic Publishers. Netherlands.

QUEST. (2008). *Quest – Science for South Africa.* 4(2). Sabinet. Available at: http://www.questinetractive.co.za/back-issues/ Accessed on 6 December 2011.

Ramanathan, R. (2001). A note on the use of the analytic hierarchy process for environmental impact assessment. *Journal of Environmental Management* 63: 27 - 35. Academic Press.

Reger, J.P. (2010). *Foundation Engineering Problems and Hazards in Karst Terrains*. Maryland Geological Survey. Available at: http://www.mgs.md.gov/esic/fs/fs11.html Accessed on 6 December 2011.

Republic of South Africa. (RSA). (1996). *The Constitution of the Republic of South Africa* (The Constitution), Chapter 2: the Bill of Rights. Government Printer, Pretoria.

Republic of South Africa. (1997). *Government Notice: Housing Act, 1997 (Act No 107 of 1997)*. Government Printer, Pretoria.

Republic of South Africa. (1998). *Government Notice: Housing Consumers Protection Measures Act, 1998 (Act No 95 of 1998)*. Last updated 19 September 2008. Government Printer, Pretoria.

Republic of South Africa. (2000). *Government Notice: Local Government: Municipal Systems Act, 2000 (Act No 32 of 2000)*. Government Printer, Pretoria.

Republic of South Africa. (2002). *Government Notice: National Disaster Management Act, 2002 (Act No 57 of 2002).* Government Printer, Pretoria.

Republic of South Africa. (2005). *National Disaster Management Framework.* Government Notice 654 of 2005. Government Printer, Pretoria. Department of Provincial and Local Government (DPLG).

Republic of South Africa. (2008). *Government Notice: Housing Development Agency Act, 2008 (Act No 23 of 2008)*. Government Printer, Pretoria.

Republic of South Africa. (2011). *Government Notice: Geoscience Act, 1993 (Act No 100 of 1993).* Review of the Act. Last updated 7 September 2011. At the time that it was accessed in August 2012, the latest reviewed version was a confidential document, shared in confidence by Ms. S. Shabangu, Minister of Mineral Resources, Republic of South Africa. Pretoria.

Republic of South Africa. (2013a). *National Development Plan 2030*. Available at: www.gov.za Accessed on 12 March 2015. South African Government.

Republic of South Africa. (2013b). *Spatial Land Use Management Act, 2013 (Act No 16 of 2013)* (SPLUMA). Available at: www.gov.za Accessed on 12 September 2016.

Republic of South Africa. (2014). *Habitat III: National Report by the Republic of South Africa for the Third United Nations Conference on Housing and Sustainable Urban Development.* pp. 91. Government Printers. Pretoria.

Revi, A. (2011). Director of Indian Institute of Human Settlements (IIHS). Comments made during workshop on *Comparative dialogue on Sustainable Urban Transitions and Governance*, 30 March - 1 April 2011, at the Sustainability Institute, Stellenbosch.

Richardson, J.J. and Brown, T. (2005). Non-regulatory approaches to Development on Karst. Sinkholes and the Engineering and Environmental Impacts of Karst (GSP 144): *Proceedings of the Tenth Multidisciplinary Conference of the American Society of Civil Engineers (ASCE).* USA.

Ritchey, T. (2011). *General Morphological Analysis: A general method for non-quantified modelling.* Adapted from a paper 'Fritz Zwicky: Morphologie and Policy Analysis', presented at the 16th EURO Conference on Operational Analysis, Brussels, 1988. Available at: http://www.swemorph.com Accessed on 17 October 2011.

Roca, A., Goula, X., Susagna, T., Chávez, J., González, M. and Reinoso, E. (2006). A simplified method for vulnerability assessment of dwelling buildings and estimation of damage scenarios in Catalonia, Spain. *Bulletin of Earthquake Engineering*. 4: 141 - 158. Springer.

Rose, A. (2011). Resilience and sustainability in the face of disasters. *Environmental Innovation and Societal Transitions.* 1: 96 - 100. Elsevier.

Rossetto, T. and Elnashai, A. (2003). Derivation of vulnerability functions for European-type RC structures based on observational data. *Engineering Structures*. 25(2003): 1241-1263. Science direct. Available at: http://www.engr.psu.edu/amr_elnashai/docs/JournalArticles/69%20Rossetto.pdf. Accessed during August 2010 and again in August 2015.

Roux, R., Warwick, D.W. and Meintjies, H.A.C. (1998). *Dolomite stability and foundation investigation for the P T Xulu Secondary School, Vosloorus Extension 3.* Johannesburg, SRK Consulting.

Saaty, T.L. (1970). *Optimisation in Integers and Related External Problems*. McGraw-Hill Book Company. pp. 296.

Saaty, T.L. (1977). Scenarios and Priorities in transport planning: Application to Sudan. *Transportation Research.* 11(3): 343 - 350. Elsevier.

Saaty, T.L. (1980). *The Analytic Hierarchy Process: Planning, Priority Setting and Resource Allocation.* New York: McGraw-Hill.

Saaty, T.L. (1986). Axiomatic foundations of the analytic hierarchy process. *Management Science.* 32: 841 - 855. Informs: A Journal of the Institute for Operations Research and the Management Sciences. Maryland (USA).

Saaty, T.L. (1988). *What is the analytic hierarchy process?* Springer.

Saaty, T.L. (1990a). An exposition of the AHP in reply to the paper: remarks on the analytic hierarchy process. *Management Science.* 36: 259 - 268. Informs: A Journal of the Institute for Operations Research and the Management Sciences. Maryland (USA).

Saaty, T.L. (1990b). How to make a decision: The Analytic Hierarchy Process. *European Journal of Operational Research.* 48: 9 - 26. Elsevier.

Saaty, T.L. (1994). *Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process.* RWS Publications.

Saaty, T.L. (1995). Transport planning with multiple criteria: The analytic hierarchy process applications and progress review. *Journal of Advanced Transportation* 29(1): 81 - 126. Wiley.

Saaty, T.L. (2000). *Fundamentals of Decision Making and Priority Theory with The Analytic Hierarchy Process*. Pittsburg: RWS Publications.

Saaty, T.L. (2001). *Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World*. New Edition 2001, first published in April 1982. RWS Publications. pp. 323.

Saaty, T.L. (2005). Analytic Hierarchy Process. *Encyclopedia of Biostatistics.* John Wiley & Sons, Ltd.

Saaty, T.L. (2013). Theory and Applications of the Analytic Hierarchy Process: Decision Making with Benefits, Opportunities, Costs and Risks. RWS Publications. pp. 342.

Sabatino, M., Bambina, A. and Monteleone, S. (2015). Analysis of Hydrological and Landslide Hazards and Castellammare Del Golfo (Northern Sicily). In: Lollino, G., Manconi, A., Culchaw, M., Bobrowsky, P. and Luino, F. (Eds.). *Engineering Geology for Society and Territory: Urban Geology, Sustainable Planning and Landscape Exploitation.* Volume 5. Springer. Heidelberg, New York, Dordrecht, London. pp. 753 – 758.

Sagala, S. A. H. (2006). *Analysis of Flood Physical Vulnerability in Residential Areas. Case Study: Naga City, the Philippines.* Unpublished M.Sc. Thesis. International Institute for Geo-information Science and Earth Observation, Twente University, Netherlands. Available at: http:www.itc.nl/library/papers_2006/msc/upla/sagala.pdf Accessed on 20 August 2011.

Sartain, N., Mian, J., O'Riordan, N. and Storry, R. (2011). *Case Study on the Assessment of Sinkhole Risk for the Development of Infrastructure over Karstic Ground.* Conference Proceedings: 3rd International Symposium on Geotechnical Safety and Risk (ISGSR). June 2011: 635 - 642. ISGSR, München.

Satterthwaite, D., Huq, S., Pelling, M., Reid, H. and Romero Lankao, P. (2007). Adapting to Climate Change in Urban Areas: The possibilities and constraints in low- and middle-income nations. *Human Settlements Discussion Paper Series*. Theme: Climate Change and Cities – 1. IIED. pp. 124. Sage Publications.

Schöning, W.L. (1990). *Distribution of Sinkholes and Subsidences in the Dolomite Areas South of Pretoria.* Unpublished MSc dissertation. University of Pretoria, Pretoria.

Schweitzer, J. and Simpson, C. (1986). Cleavage development in dolomite of the Elbrook Formation, southwest Virginia. *Geological Society of America Bulletin.* 97: 778 - 786. GeoScienceWorld.

Selebalo, C. (2014). Keynote address. *AfricaGeo 2014*: *Developing Geomatics for Africa.* 1 - 3 July 2014. Cape Town. Available at: http://www.africageo.org/presentations#CS Accessed on 6 July 2014.

Shumow, L, Vandell, D.L. and Posner, J. (1999). Risk and Resilience in the Urban Neighbourhood: Predictors of Academic Performance Among Low-Income Elementary School Children. *Merrill-Parker Quarterly.* 45(2): 309 - 331. April 1999. Available at www.jstor.org Accessed on 10 September 2016.

Singh, R.B. (Ed) 2015. *Urban development challenges, Risks and Resilience in Asia Mega Cities.* Springer. Available at: www.springer.com Accessed on 10 September 2016.

Singhal, A. and Kiremidjian, A.S. (1997). *A method for earthquake motion-damage relationships with application to reinforced concrete frames*. National Center for Earthquake Engineering Research Report (NCEER). NCEER-97-0008. State University of New York, Buffalo.

Siöström, P. and Sternudd, C. (2011). Sustainable Urban Design – Making the World's Growing Cities Into Healthy, Attractive and Sustainable Places. *Sustainable Urban Design Journal*. Volume 1. Available at: http://www.stadsbyggnad.lth.se/fileadmin/stadsbyggnad/images/_1_Sudes_Book/_1_B5_webversion1.pdf Accessed on 17 July 2014. Sustainable Urban Design Programme (SUDes); Lund University School of Architecture; Ax:son Johnson Institute for Sustainable Urban design. Sweden: Lund. pp. 40.

Slaymaker, O. (1999). Natural hazards in British Columbia: An interdisciplinary and interinstitutional challenge. *International Journal of Earth Sciences.* 88: 317 - 324. Springer.

Smith, K. (2004). *Environmental hazards: assessing risk and reducing disaster.* pp 306. Routledge, London and New York.

South African Bureau of Standards (SABS). (2009). *South African National Standard (SANS) 1936: 2009: Development of Dolomite land.* SABS Standards Division, Pretoria.

South African Bureau of Standards (SABS). (2012). *Draft South African National Standard (SANS) 1936: 2012: Development of Dolomite land: Parts 1 to 4.* SABS Standards Division, Pretoria.

South African Government News Agency (SAGNA). (2014). Public transport exempted from e-tolls. 17 January 2014. Available at: http://www.sanews.gov.za/south-africa/public-transport-exempted-e-tolls Accessed on 23 June 2014.

South African Speleological Association (SASA). (1982). *Database of cave locations and surveys in Gauteng.* SASA, Johannesburg.

Spence, R.J.S., Coburn, A.W. and Pomonis, A. (1992). Correlation of ground motion with building damage: the definition of a new damage-based seismic intensity scale. *Proceedings of the 10th World Conference on Earthquake Engineering*. Rotterdam: AA Balkema. pp. 551 – 556.

Statistics South Africa (StatsSA). (2011). *Census 2011 South Africa*. Statistics South Africa.

Steiniger, S. (2006). *Classifying urban structures for mapping purposes using discriminant analysis*.

Storie, J.M. (2011). Representations of space: a case of karst, community and change in the urban landscape. *African Centre for Cities* (*ACC)/CUBES Cities Conference*, 7 - 9 September 2011. Cape Town.

Storie, J.M. (2012a). *Dolomite risk in the Gauteng City Region*. Presentation to the Gauteng Provincial Department of Local Government and Housing: Provincial Disaster Management Cross-boundary Forum, 28 March 2012. Johannesburg.

Storie, J.M. (2012b). *The choices we make determine the path we take: vulnerability of low income settlements in the GCR.* Presentation to the City of Johannesburg Disaster Management Advisory Forum, 22 June 2012. Johannesburg.

Strydom, J.M. (2003). *The use of Geographic Information System technology in determining the possible location for a Super Dump Hazardous waste site at the AECI Modderfontein facility based on Risk Assessment and Hazard Zoning.* Unpublished Master's Thesis. University of the Free State, Bloemfontein.

Sustainable Energy Africa (SEA). (n.d.). *Adapting South African cities and towns: A local government guide to climate change adaptation planning*. SEA. Cape Town. pp. 47.

Tacoli, C. (2011). Not only climate change: mobility, vulnerability and socio-economic transformations in environmentally fragile areas of Bolivia, Senegal and Tanzania. *Human Settlements Working Paper Series: Rural-Urban Interactions and Livelihood Strategies* – 28. International Institute for Environment and Development (IIED), London. pp. 39.

Tesch, R. (1990). *Qualitative Research: Analysis Types and Software Tools.* Routeledge Falmer, Taylor & Francis Inc. London & Philadelphia. Printed in Great Britain by LSL Press Ltd, Bedford. pp. 331.

Tissington, K. (2010). *A Review of Housing Policy and Development in South Africa since 1994.* Towards an SER Matrix: Monitoring the Progressive Realisation of Socio-Economic Rights in South Africa. Paper prepared for the Studies in Poverty and Inequality Institute (SPII). Socio-Economic Rights Institute of South Africa (SERI). pp. 91.

The Housing Development Agency (HDA). (2004). *Breaking New Ground: A Comprehensive Plan for the Development of Sustainable Human Settlements.* Available at: http://www.thehda.co.za/uploads/images/BREAKING_NEW_GROUND_DOC_copy-2_1.pdf Accessed on 20 June 2013. pp. 29.

The Housing Development Agency (HDA). (2013). South Africa: *Informal settlements status (2013).* Available at: http://www.thehda.co.za/uploads/files/HDA_South_Africa_Report_lr.pdf/ Accessed on 30 July 2015.

The Housing Development Agency (HDA). (2015). *Informal settlement upgrading: Incrementally upgrading tenure under customary administration.* Available at:

http://www.thehda.co.za/uploads/files/ISU_upgrading_tenure_publication_2015.pdf/ Accessed on 15 January 2016. The Housing Development Agency.

The Nature Conservancy (TNC). (2013). *The Case for Green Infrastructure: Joint Industry White Paper*. DOW, Swiss Re, Shell, Unilever, The Nature Conservancy. Available at: http://www.nature.org/about-us/the-case-for-green-infrastructure.pdf Accessed on 18 July 2014. pp. 9.

The Presidency. (2011). *National Development Plan: Vision for 2030.* Available at: http://www.npconline.co.za/medialib/downloads/home/NPC%202030%20-lo-res.pdf South African Government: National Planning Commission (NPC). Accessed on various occasions between January 2013 and March 2014.

Thomas, R.W. (1981). Point Pattern Analysis. In: *Quantitative Geography: A British View*. Wrigley, N. and Bennett, R.J. (Eds.). London: Routledge & Kegan Paul. pp. 164 – 76.

Todes, A., Harrison, P. and Weakley, D. (2015). *Resilient Densification: Four Studies from Johannesburg.* University of the Witwatersrand, Gauteng City Region Observatory. pp. 156.

Tolmachev, V., Maximova, O. and Mamonova, T. (2005). Some new approaches to assessment of collapse risks in covered karsts. In: Beck, B.F. (Ed.). *Sinkholes and the Engineering and Environmental Impacts of Karst.* Tenth Multidisciplinary Conference. San Antonio, Texas, USA.

Triantaphyllou, E. and Mann, S.H. (1995). Using the Analytic Hierarchy Process for Decision Making in Engineering Applicatins: Some Challenges. *International Journal of Industrial Engineering: Applications and Practice.* 2(1): 35 - 44.

Triantaphyllou, E. (2001). Two new cases of rank reversals when the AHP and some of its additive variants are used that do not occur with the multiplicative AHP. *Journal of Multi-Criteria Decision Analysis.* 10(1): 11 - 25. John Wiley & Sons.

Trollip, N.Y.G. (2006). *The geology of an area south of Pretoria with specific reference to dolomite stability.* Unpublished Master's thesis: University of Pretoria, Pretoria.

Turok, I. (2012). *Learn from Brics in dealing with migration to the cities*. Business Day Live, 6 December 2012. Available from: http://www.bdlive.co.za/opinion/2012/12/06/, Accessed on 13 December 2012.

Turok, I. (2015). Informal settlements: poverty traps or ladders to work? *Econ3x3*. Available at: http://www.econ3x3.org/sites/default/files/articles/ HSRC. Accessed on 20 February 2016.

United National Habitat (UN-Habitat). (2003). *The Challenge of Slums*. Global Report on Human Settlement 2003. United Nations Human Settlements Programme. pp 33. Earthscan Publications Ltd., London and Sterling, VA.

United National Habitat (UN-Habitat). (2012). *Urban Patterns for a Green Economy: Leveraging Density*. (Optimising Infrastructure). United Nations Human Settlements Programme. Earthscan Publications Ltd., pp 98. UN-Habitat, Nairobi, Kenya.

UNISDR. (n.d.) *Urban Risk Reduction and Resilience.* Available at: www.UNISDR.org Accessed on 10 September 2016

United Nations International Strategy for Disaster Reduction (UNISDR). (2004). *Terminology: Basic terms of disaster risk reduction:* UN/ISDR. Available at: http://www.unisdr.org/eng/library/lib-terminology-eng%20home.htm Accessed on 24 Nov 2010.

United Nations Office for Disaster Risk Reduction (UNISDR) (2005). *Hyogo Framework for Action 2005 – 2015: Building the Resilience of National and Communities to Disasters.* Extract from the final report of the World Conference on Disaster Reduction (A/CONF.206/6). United Nations International Strategy for Disaster Reduction. United Nations. pp. 28. Available at: http://www.unisdr.org/files/1037_hyogoframeworkforactionenglish.pdf Accessed on 4 December 2014. Also available at: http://www.unisdr.org/2005/wcdr/intergover/official-doc/L-docs/Hyogo-framework-for-action-english.pdf United Nations Office for Disaster Risk Reduction.

United Nations International Strategy for Disaster Reduction (UNISDR). (2014). *United Nations International Strategy for Disaster Reduction*: Resolution adopted by the General Assembly on 20 December 2013. (First published in 1998). United Nations Special Assembly. www.unisdr.org/files/resolutions/ARES68211E.pdf Accessed on 14 March 2015.

United Nations Office for Disaster Risk Reduction (UNISDR) (2015). *Sendai Framework for Disaster Risk Reduction 2015 – 2030.* www.unisdr.org Accessed on 14 June 2015. Pp 36. United Nations Office for Disaster Risk Reduction.

Uzielli, M., Nadim, F., Lacasse, S and Kaynia, A.M. (2008). A conceptual framework for quantitative estimation of physical vulnerability to landslides. *Engineering Geology.* 102: 251 - 256. Elsevier.

Vaidya, O. S. and Kumar, S. (2006). Analytic hierarchy process: An overview of applications. *European Journal of Operational Research*. 169: 1 - 29. Elsevier.

Vale, L.J. and Campanella, T.J. (Eds). (2005). *The Resilient City: How Modern Cities Recover from Disaster*. Oxford University Press. New York. pp. 363.

van Huyssteen, E., Meiklejohn, C., Coetzee, M., Goss, H. and Oranje, M. (2010). An overview of South Africa's metropolitan areas – dualistic, dynamic and under threat. *European Spatial Research and Policy.* 17(2): 23 – 40. de Gruyter. Available at: http://dx.doi.org/10.2478/s10105-010-0008-2 and http://www.degruyter.com/view/j/esrp.2010.17.issue-2/s10105-010-0008-2/s10105-010-0008-2.xml Accessed on 3 Dec 2014.

van Niekerk, W. (2013). Translating disaster resilience into spatial planning practice in South Africa: Challenges and champions. *Jàmbá: Journal of Disaster Risk Studies*. 5(1): Art #53, 6 pages. AOSIS OpenJournals. Available at: http://dx.doi.org/10.4102/jamba.v5i1.53 Accessed on 3 December 2014.

van Schalkwyk, A. (1998). Legal aspects of development on dolomite land in South Africa. *Environmental Geology*. 36(1-2): 167 - 169. Springer.
van Westen, C.J., van Asch, T.W.J. and Soeters, R. (2006). Landslide hazard and risk zonation – why is it still so difficult? *Bulletin of Engineering Geology and the Environment.* 65: 167 - 184. Springer.

van Westen, C. and Kingma, N. (2008). *Guide Book: Session 5: Vulnerability assessment.* International Institute for Geo-Information Science and Earth Observation (ITC), Faculty of Geo-Information Science and Earth Observation. Twente University, Netherlands.

Velleman, L. (2013). Sinkgat: hoës gryp in. *Centurion Rekord*. 9 August 2013. Centurion.

Vogel, R. (2008). *Compromise Programming (Flächenbewertung mittels).* Presentation presented at GIS-Kolloquium, Leibniz Institute of Ecological and Regional Development. 7 February 2008. Dresden, Germany.

Wagener, FvM. (1982). *Engineering Construction on Dolomite.* Unpublished Ph.D. Thesis, University of Natal, Durban.

Wagener, FvM. and Day, P.W. (1986). Construction on Dolomite in South Africa. *Journal of Environmental Geology.* 8(1-2): 83 - 89. Springer.

Wang, P. and Gao, J. (2012). Research on the Open Space in Urban Areas of Taiyuan. 2nd *International Conference on Electronic and Mechanical Engineering and Information Technology* (EMEIT). Paris, Atlantis Press. pp. 487 – 490.

Warfield, C. (n.d.) *The Disaster Management Cycle*. Available at: www.gdrc.org Accessed on 12 September 2016.

Warner, S.B. Jr. (1962). *Streetcar Suburbs: The Process of Growth in Boston: 1870 – 1900.* Cambridge, MA: Harvard University Press.

Warwick, D.W. and Roux, R. (2004). *Thembelihle Township, Lenasia: Review of Studies by Intraconsult and Council for Geoscience of the Dolomite Risk in the Area of the Township.* Johannesburg, SRK Consulting.

WaterLex. (2011). *Disaster Risk Reduction and Human Rights.* Available at: http://www.waterlex.org/new/wp-content/uploads/2013/08/2011-DRR_FAQ.pdf Accessed on 4 December 2014.WaterLex.

Waters, K. (2002). *A Lexicon of Cave and Karst Terminology with Special Reference to Environmental Karst Hydrology.* EPA/600/R-02/003. pp 221. Washington, DC; Environmental Protection Agency (EPA).

Weakly, D. (2013). *Recognising Vulnerability and Resilience in Informal Settlements: The Case of Kya Sands, Johannesburg, South Africa.* Research Report, MSc Town Planning. University of the Witwatersrand, Johannesburg.

Webler, T., Kastenholz, H and Renn, O. (1996). Public participation in impact assessment: A social learning perspective. *Environmental Impact Assessment Review*. 16(6): 443 - 463. Elsevier.

Wedley, W.C. (1990). Combining qualitative and quantitative factors: an analytic hierarchy approach. *Socio-Economic Planning Sciences.* 24: 57 - 64.

Westonarea Local Municipalilty (WLM). (2010). *Integrated Development Plan.* Available at: Mfma.treasury.gov.za/…/GT483%20Westonaria%20-%20IDP%20-%20Chapter Accessed on 23 July 2015.

Whitman, D. and Gubbels, T. (1999). Application of GIS technology to the triggering phenomena of sinkholes in Central Florida. In: Beck, B.F., Pettit, A.J., Herring, J.G. (Eds.). *Hydrogeology and Engineering Geology of sinkholes.* Seventh multidisciplinary conference on sinkholes and the engineering and environmental impacts of karst. Harrisburg, Pennsylvania. pp. 67 - 73.

Whitman, D., Gubbels, T. and Powell, L. (1999). Spatial interrelationships between lake elevations, water tables, and sinkhole occurrence in central Florida' a GIS approach. *Photogrammetric Engineering and Remote Sensing* (PE & RS). 65: 1169 - 1178. The Imaging & Geospatial Information Society. ASPRS. Maryland (USA).

World Health Organisation (WHO). (n.d.(a)). *People Living in Informal Settlements.* Available at: http://www.who.int/ceh/indicators/informalsettlements.pdf Accessed on 5 December 2011.

World Health Organisation (WHO). (n.d.(b)). *Slum residence: situation and trends.* Available at: http://www.who.int/gho/urban_health/determinants/slum_residence_text/en/ Accessed on 5 June 2014.

Yamazaki, F. and Muao, O. (2000). Vulnerability functions for Japanese buildings based on damage data from the 1995 Kobe earthquake. *Implication of Recent Earthquakes on Seismic Risk, Series on Innovation and Construction*: 2: 91 – 102. Imperial College Press (ICP).

Yodmani, S. (2001). *Disaster Risk Management and Vulnerability Reduction: Protecting the Poor.* Unpublished paper presented at the first Asia and Pacific Forum on Poverty, organized by the Asian Development Bank. Manila, Philippines.

Zhou, W., Beck, B.F. and Adams, A. (2003). Application of matrix analysis in delineating sinkhole areas along highway (I-70 near Frederick, Maryland). *Environmental Geology.* 44(7): 834 - 842.

BIBLIOGRAPHY

Personal communication:

Camper, M. (2015). Geotechnical Engineer. Personal Communication. Centurion. 24 June 2015.

City of Tshwane Metropolitan Municipality (CoT). (2013b). Personal communication with the Geologist at the Geology office of the CoT (do not want to be identified/named). Centurion offices, Rabie Avenue, Centurion. 14 November 2013.

Cooke Fuller Garrun (CFG). (2014). Cooke Fuller Group, Insurance brokers. Personal communication with insurance broker (do not want to be identified/named). Park Lane, Kloof, KZN. 23 June 2013.

Cowie, V. (2012). Environmental GIS Consultant. Personal communication. Centurion. 15 October 2012.

Davis, H. (2013). Geotechnical Engineer: At the time Geotechnical Division Manager, AECOM. Personal Communication. Hatfield, Pretoria. 2 November 2013.

Grobler, P. (2014). Divisional Head: Property Management. Real Estate Department, Ekurhuleni Metropolitan Municipality. Personal communication. Kempton Park. 9 June 2014.

Gualandi, B. (2016). Disaster Risk Management Specialist, OXFAM. Personal communication. Centurion. 25 February 2016.

Hathorn, M. (2012). Lawyer at Webber Wentzel Bowen. Personal communication. Illovo, Johannesburg. 8 June 2012.

Heath, G. (2011). At the time Geologist at the Council for Geoscience. Personal Communication. CGS office, Silverton, Pretoria. 12 October 2011.

Huchzermeyer, M. (2013). Associate Professor in the School of Architecture and Planning, University of the Witwatersrand. Personal comments in writing. January 2014.

Huchzermeyer, M. (2014). Associate Professor in the School of Architecture and Planning, University of the Witwatersrand. Personal communication in writing and via e-mail. February 2013.

Huchzermeyer, M. (2015). Professor in the School of Architecture and Planning, University of the Witwatersrand. Personal comments in writing. July 2015.

Kheva, S. (2014). Focal Point: Mpumalanga Region of the Department of Water Affairs (DWA) Disaster Management Technical Task Team. Personal communication. Nelspruit. February 2014.

Kleynhans, I. (2012). Geotechnical consultant. Personal communication. Ekurhuleni. August 2012.
Lesupi, S. (2016). Director: Disaster Risk Management, Dr. Keneth Kaunda District Municipality. Personal communication. Kempton Park. 26 February 2016.

Martini, J. (1998). Geologist and Karst Specialist. Member of the South African Speleological Association (SASA). Personal communication. Johannesburg. 1998.

McLuckie, C. (2015). Geotechnical Engineer. Personal Communication. Centurion. 24 March 2015.

Nene, L. (2014). Geotechnical Engineer. Personal Communication. Centurion. 12 January 2015.

Nenweli, M. (2012). Climate Change researcher and at the time PhD Candidate at University of the Witwatersrand. Personal Communication. Pullen Farm, Mpumalanga. 24 October 2012.

Planact (2015). Urban Planners. Personal communication (do not want to be identified/named). Johannesburg. 29 July 2015.

Snyman, L. (2016). Attourney. Centre for Applied Legal Studies (CALS). University of the Witwatersrand. Johannesburg. February, 2016.

Stoch, E. (2012). Environmental consultant. Personal communication and guidance regarding and during site visits. Carletonville. June to September 2012.

Stoch, E. (2014). Environmental consultant. Personal communication. Fourways. May 2014.

Warwick, D.W. (2011). Engineer at SRK consulting. Personal communication. Johannesburg. Various times between July and November 2011.

Watermeyer, R. (2013). Geologist. Personal Communication. Johannesburg. 13 June 2013.

Williams, J. (2011). Geologist, at the time at the City of Johannesburg. Personal communication. Johannesburg. Various times between July and October 2011.

Other sources of information and spatial data:

City of Johannesburg (CoJ). (2012). *Discussion with residents of Thembelihle*, 21 March 2012. Johannesburg, CoJ Disaster Management Cross-Boundary Forum.

City of Johannesburg (CoJ). (2009a). *2.5m resolution aerial photography.* Johannesburg, City of Johannesburg Corporate GIS.

City of Tshwane Metropolitan Municipality (CoT). (2013a). *Wall maps.* Centurion offices, Rabie Avenue, Centurion.

Ekurhuleni Metropolitan Municipality (EMM). (2012). *Vosloorus Extension 28 Apartments: Preliminary Design.* Planning Department, EMM.

Eskom. (2013). *SPOT building count*. Midrand, Eskom.

Gauteng City Region Observatory (GCRO). (2011a). *GIS geodatabase.* Johannesburg, GCRO.

Gauteng City Region Observatory (GCRO). (2011b). Discussion related to the GCRO project entitled '*Conceptualising the Gauteng City Region'*. June 2011. Johannesburg, GCRO.

Gauteng City Region Observatory (GCRO). (2011d). Discussion related to the GCRO project entitled '*Conceptualising the Gauteng City Region'*. June 2011. Johannesburg, GCRO.

Gauteng City Region Observatory (GCRO). (2012a). *Workshop with Protea South residents*, 13 April 2012. Johannesburg, GCRO.

Gauteng City Region Observatory (GCRO). (2012b). *Photography of settlements in the Gauteng City Region*. Johannesburg, GCRO.

Gauteng City Region Observatory (GCRO). (2015). *GIS geodatabase and maps.* Johannesburg, Gauteng City Region Observatory.

Johannesburg City Parks (JCP). (2008). *GIS and field visit records to Melville Koppies Stone Age and Iron Age site*. JCP, Johannesburg.

Lightstone. (2010). *DemprokeyX data*. Available from: Johannesburg, GCRO. Copyright: Lightstone.

Field Observation Form:

Name of suburb/area visited: ____

Name of settlement and/or extension in settlement: _______________________________

Other name(s) settlement known as (if applicable): __________________________________

Location: top right and bottom left corner GPS coordinates (if available):

Top right corner: __________________________

Bottom left corner: ________________________

Description of location: (any identifying features that is not expected to change much over the next few years) ____

____

____

Map indicating boundaries: add to this form a printed hard copy map on which the boundaries of the area in question is indicated: there may thus be more than one form for any given settlement, each with unique GPS locations and a map indicating its position and extent, based on the settlement type.

Settlement type /description: ___________________________

Select the most appropriate option in each of the tables hereafter. Indicate in the comments section if there is any indicator or field in an indicator that does not match, does not fit in any of the options or that should be noted during the evaluation:

Income – perceived opinion: ____

____

General comments about the settlement location or type: _______________________________

____

____

____

____

Hazard (this section completed using available geotechnical assessment/report data, based risk assessment(s) done for the area, based on guidelines and standards applied for development on dolomite):

Pr(h)	**High**	**Medium**	**Low**		
	1	0.8	0.6		
I(h)	**Large sinkholes**	**Medium size sinkholes**	**Small sinkholes**		
	1	0.8	0.6		
E(d)	**High**	**Medium**	**Low**		
	1	0.8	0.6		
O®	**High**	**Medium**	**Low**		
	1	0.8	0.6		
F®	**1:10 years**	**1:20 years**	**1:50 years**	**1:100 years**	**> 1:100 years**
	1	0.8	0.6	0.4	0.3

Vulnerability (completed on-site and in-office based on available data/information)

Ss	**A1 (dense shacks)**	**A2 (as A1, less dense)**	**B1 (shacks +houses, dense)**	**B2 (as B1, less dense)**	**C1 (houses , dense)**	**C2 (as C1, less dense)**	**D (houses with backyard units)**	**E1 (Raft founda-tions)**	**E2 (Walk-up/ hostels)**	**F (Flats)**	**No settlement (natural condition)**
	0.9	0.6	1	0.7	0.8	0.5	1	0.2	0.3	1	0.1
Ts	**Unknown**		**Long term unchecked/ undetected /unfixed leakage (>6 months)**			**Medium term unchecked**		**Short term unchecked/ unfixed**		**No development**	
	1		1			0.8		0.6		0.1	
Ps(n)	**N/A**	**In river channel**	**20 year floodline**	**50 year floodline**	**100 year indicative floodline (if known)**			**200 year indicative floodline (in known)**			**Natural condition**
	0.01	0.9	0.8	0.6	0.5			0.4			0.1
Ps(ip)	**Porous, old, clay/cement pipes/new clay pipes**			**PVC single-lined pipes and non-approved fittings**			**PVC double-wand pipes and approved fittings**			**None/not applicable**	
	1			0.8			0.4			0.1	
Ps(ir)	**None/ infor-mal**	**Formal canals without lining**		**Canals with cement lining/ cement pipes**		**Canals/pipes with PVC or single-surface lining**		**Canals with appropriate lining/double-wand PVC pipes and approved fittings**			**Natural area**
	1	0.9		0.8		0.6		0.4			0.3
Ps(gt)	**Predominantly no ewes or gutters**		**Gutters with direct run-off into ground, <1m away from structure**			**Gutters leading 1-3m away from structure**			**Gutters leading >3m away from structure**		**Natural area**
	1		0.8			0.6			0.4		0.1
Ps(is)	**Porous, old, clay/ cement pipes/ new clay pipes**	**PVC single-lined pipes & non-appro-ved fittings**	**PVC double-wand pipes and approved fittings**	**Portable toilets**	**VIP/ contain ment on site without lining**	**VIP/containment on site cement lining**		**Containment on site approved lining ('honey-sucker'-type)**		**Bucket-system**	**Natural**
	1	0.8	0.4	0.2	1	0.9		0.6		0.3	0.1

Comments and observations:

Comments on observations of other elements that may introduce risk:

Gardening practices: ____

Schools and public spaces in the area? ____

Interaction with natural streams/watercourses: Water collection/extraction from river e.g. via buckets or pumped/piped? ____

Water supply (additional): Rainwater tanks? Water by car/cart? _________________________

Stand pipes: Type of interventions: good, limited, none? ______________________________

Stand pipes: Illegal connections? ____

Recreation: swimming pools etc.? ____

General comments and observations: ____

Manageability:

M(o)	**Full ownership**	**Sectional title**	**Body corporate**		**Shack-lords**	**No ownership (rental/illegal)**	
	0.1	0.5	0.4		0.8	0.9	
M(m)	**By-laws re: ground water level control**	**Level of engagement**	**Protocols**	**Processes and guidelines**	**Community awareness programmes (including brochures and DVD's)**	**Fixed long-term contracts in place with approved service providers to plan, test & respond**	**Development planning applications go through a defined set of steps to ensure safety on dolomite**
	Yes = 0.01; No = 0.9	High = 0.1; low = 0.9	In place & implemented = 0.01; none = 0.8	In place & implemented = 0.01; none = 0.8	In place & implemented = 0.01; none = 0.8	In place & implemented = 0.01; none = 0.8	In place & implemented = 0.01; none = 0.9

Comments and observations:

Capacity:

C(e)	**High**	**Medium**	**Low**	
	0.3	0.5	0.8	
C(b)	**Undetermined**	**Poor**	**Average**	**Good**
	1	1	0.7	0.3
C(i)	**Poor**	**Not too poor**	**Comfortable**	**Wealthy**
	1	0.8	0.6	0.4

Comments and observations: