# [SSC02] KEY PRINCIPLES FOR ADAPTING SOUTH AFRICAN SETTLEMENT PATTERNS TO CLIMATE CHANGE

**Llewellyn VAN WYK** [1]

[1] *Built Environment, CSIR, Email: lvwyk@csir.co.za*

**Keywords**: variables, hazards, urban morphology types, planning

## Abstract

The aim of the paper is to identify key principles for adapting SA settlement patterns to climate change. Section 1 reviews the range of climate-related impacts likely to affect SA settlements using climate change models and scenarios as a context for the generation of principles for South African settlement patterns. The impacts on settlements are then characterised by hazard type. Section 2 reviews literature pertaining to settlement patterns and the relationship between settlement pattern and climate change. The section also reviews contemporary global city adaptation plans and collates the principles identified in their adaptation plans. Section 3 describes the research methodology used. Section 4 prepares a set of key principles for adapting SA settlement patterns to climate change and discusses the findings. Section 5 concludes with recommendations for future research especially with regard to the use of urban morphology types as a basis for integrating climate responsiveness into city spatial development plans.

## 1. Introduction

The projected impacts of climate change is renewing the focus of planning analysis and policy on the complexity and uncertainty of economic, social and environmental systems. This realisation is likely to change both the context and the nature of spatial planning at all levels. As Davoudi, Crawford and Mehmood (2009) note, planners will have to reconcile, trade-off and, at times, overturn short-term and long-term development expectations. Davoudi et al (2009) note that planners will need to "address questions such as: what will low-carbon, 'climate-proof' settlement look like in terms of barriers to effective planning for such development; what are the implications for governance, from transnational to local levels, and the relationship between these levels; who will bear the risks and what are the implications for equity and social development?"

It is also increasingly recognised that the "spatial configuration of cities and towns and the ways in which land is used and developed have significant implications for both adaptation to the adverse impacts of climate change and reduction of the emissions that are causing the change" (Davoudi et al 2009).

### 1.1 Climate Change Projections in South Africa

It is projected that climate change is likely to impact drastically in southern African during the 21st century under low mitigation futures (Niang, Ruppel, Abdrabo, Essel, Lennard, Padgham, and Urquhart, 2014). The southern African region is projected to become generally drier under enhanced anthropogenic forcing (Christensen, Hewitson, Busuioc, Chen, Gao, Held, Jones, Kolli, Kwon, Laprise, Magana Rueda, Mearns, Menendez, Raisanen, Rinke, Sarr, Whetton, 2007; Engelbrecht et al., 2009; James and Washington, 2013; Niang et al., 2014).

Climate change impacts will also manifest through changes in the attributes of extreme weather events including more frequent occurrence of dry spells over most of the interior (Christensen et al., 2007; Engelbrecht et al., 2009); cut-off low related flood events are also projected to occur less frequently over South Africa (e.g. Engelbrecht et al., 2013); and intense thunderstorms are conceivably to occur more frequently over South Africa in a generally warmer climate (e.g. Engelbrecht et al., 2013). A summary of potential climate impacts is provided below (Engelbrecht 2016; (e.g. Christensen et al., 2007; Engelbrecht et al., 2009).

### 1.2 Potential Impact on SA Settlements

The climate variables identified in 1.1 have direct impacts on SA settlements: Table 1 tabulates these projected impacts per hazard types (Engelbrecht 2016).

*Table 1: Climate Change Impacts on SA Settlements*

| Hazard Type | Impact |
|---|---|
| **Temperature** | Temperature increases will have significant impacts on energy demand (higher cooling demand), and water insecurity (drought, evaporation).<br><br>Temperature increases may impact on human and animal health through increased heat stress.<br><br>Temperature increases are also conducive to a higher incidence of veld and forest fires. |
| **High fire-danger days** | An increase in veld and forest fires will undermine the resilience of ecosystems. Combating veld and forest fires will further exacerbate water insecurity.<br><br>Veld and forest fires may lead to an increase in loss of life and also increase the health risks to settlement dwellers from exposure to smoke and ash pollution. |
| **Rainfall, including extreme rainfall** | A decrease in rainfall will impact negatively on water demand and increase water insecurity.<br><br>The need to take into account a range of different rainfall futures, often of different signals (i.e. drier and wetter), complicates the development of adaptation strategies. Settlements will have to radically rethink their approach to urban water use. |
| **Wind speeds** | The decrease in wind speeds in some parts of the country may aggravate heat stress.<br><br>The increase in wind speeds in some parts of the country raises the threat of veld fires and pollution spread.<br><br>Depending the extent of increase, it may require more stringent wind loading structural codes. |

## 2. Literature Review

### 2.1 Settlement Pattern

A human settlement can be described as a place inhabited more or less permanently: it includes buildings which the inhabitants use and the streets over which they move. A settlement pattern refers to the general shape of a settlement i.e., how the buildings are distributed across a landscape and how they relate to one another. The description of a settlement pattern is therefore based on the observable distribution of sites. Settlement patterns illustrate how people responded to a given landscape and what resources they choose to live by (water, arable land, transportation networks, etc.) (Roy, Domon, and Paquette 2002). Settlement patterns essentially reflect the social organization of a human settlement and how it evolved over time. Because the settlement pattern reflects the way people within the community relate to their environment and one another, it can be considered a 'blueprint' that sets out how, where and when development will occur in the future.

Settlement patterns and their impacts on the use of natural resources and levels of emissions are influenced by many complex factors, including "available building technologies, land and property markets, the investment strategies of public and private institutions, public policies (related to, for example, planning, housing, transport, environment and taxation), institutional traditions, social norms and cultures, and individual lifestyle choices and behaviour" (Davoudi *et al*., 2009). Roy et al 2002 found in their study that the three main factors that affected early settlement patterns were physical access; the soil features; and the presence of supportive neighbours (2002).

Settlement patterns can be categorized as 'dispersed' (a number of buildings spread out over a large area); 'nucleated' (a number of buildings grouped together around a central core); and 'linear' (the buildings are arranged in lines that generally follow the route of a road, a body of water, or contours of the land). Further patterns can be discerned within the nucleated and linear types. Generally this can be described as CBD, inner city, inner suburbs, and outer suburbs: the distribution pattern will also become less dense as it shifts from CBD to outer suburbs. Davoudi *et al*. (2009) further suggests that there are three main types of settlement interventions that can be adopted to accommodate new development, namely urban infill, urban extension and entirely new settlement. The settlement patterns described will dictate, to a varying degree, which interventions are possible.

## 2.2 Settlement Pattern and Climate Change

Extensive literature exists commenting on how human settlements both contribute to and are affected by climate change. Van Staden (2014) found that “many emerging climate change risks are concentrated in urban areas” and “climate change impacts on cities are increasing and include rising temperatures, heat stress, water security and pollution, sea-level rise and storm surges, extreme weather events, heavy rainfall and strong winds, inland flooding, food security, and ocean acidification.” The Urban Climate Change Research Network (UCCRN) notes that “accurate diagnosis of climate risks and the vulnerabilities of urban populations and territory are essential” (2015). However, researchers are also arguing that “$CO_2$ emissions from land-use change have been substantially underestimated because processes such as tree harvesting and land clearing from shifting cultivation have not been considered” (Arneth, Sitch, Pongtaz, Stocker, Ciais, Poulter, Bayer, Bondeau, Calle, Chini, Gasser, Fader, Friedlingstein, Kato, Li, Lindeskog, Nabel, Pugh, Robertson, Viovy, Yue and Zaehle, 2017). Of particular interest is the observation that “contextual conditions determine a city’s challenges, as well as its capacity to integrate and implement adaptation and mitigation strategies” (2015). More specifically Burton, Challenger, Huq, Klein, Yohe, Adger, Downing, Harvey, Kane, Parry, Skinner, Smith, and Wandel (2001) argue that the “adaptation of the built environment will be primarily concerned with ‘changes in processes, practices, or structures to moderate damage or realise opportunities, as well as adjustments to reduce the vulnerability of communities, regions or activities’.” Furthermore they note that “research has shown that the type and severity of impact on the urban environment varies according to neighbourhood type, for example city centre, restructuring, densifying suburbs, new build” (Burton et al. 2001). More pertinently they conclude that ‘placed-based’ integrated assessments appear to hold greatest potential for exploiting any synergies that do exist, with an effective planning system and innovative urban design crucial for combining mitigation and adaptation measures and hence promoting more effective climate-proofing of the urban environment” (Burton *et al*., 2001). Their argument is supported by Altvater, de Block, Bouwma, Dworak, Frelih-Larsen, Görlach, Hermeling, Klostermann, König, Leitner, Marinova, McCallum, Naumann, Osberghaus, Prutsch, Reif, van de Sandt, Swart, and Troitzsch, (2012) who conclude that “existing policies related to urban built environment and open spaces do not explicitly address the climatic pressures and impacts which can be expected in the future as potentially harming urban built environment.” In this regard the UCCRN study suggests four strategies namely: improving the efficiency of urban systems; modifying urban form and layout; the use of heat-resistant construction materials; and increasing vegetative cover (2015).

The UCCRN study also speaks to scale and specifically metropolitan region, city, district/neighbourhood, block and building. They also argue for the adoption of measures that benefit both mitigation and adaptation while yielding a “higher quality of life for urban citizens as the key performance outcome” (2015), a goal that is expanded further under ‘transformative adaptation’ later in this paper. The City of Copenhagen adopted a similar approach in their adaptation plan tabulating levels of adaptation against geographical levels, namely region, municipality, district, street, and building (2011).

Settlement pattern will also influence and be influenced by climate change impacts. Stoney and Rodgers (2007) found that “lower density patterns of residential development contribute more radiant heat energy to surface heat island formation than higher density development patterns.” They recommend “compact moderate-to-high density new construction” as policy strategies for mitigating the effects of urban development (Stoney and Rodgers 2007). Davoudi, Crawford and Mehmood (2009) state that with regard to urban form and flooding “the goal of a city layout must be to stop water flowing in from areas beyond the city limits and the rapid disposal of excess rainwater.” They note further that the “extensive paved surfaces of suburban neighbourhoods offer both advantages and disadvantages in relation to flooding.” With regard to urban form and wind speeds, Bosselmann, Arens, Dunker and Wright found that winds along relatively wide streets lined with buildings up to four stories in height were “only 25 percent to 50 percent as strong as winds in the open countryside” whereas in streets with several highrise towers the “wind speeds were equal to or higher than those measured at the weather station” (1995). They found that a consistent building height had the least effect on wind speeds.

A critical component of spatial planning going forward is the reduction of settlement vulnerability with regard to economic, social and environmental systems. They can be affected directly through projected changes in climate (temperature, precipitation, etc.) and indirectly through projected impacts on the environment, natural resources, and agriculture. Indirect pathways to impacts include expected changes in the availability of natural resources, geographic shifts in climate-sensitive resource industries, effects on environmental quality and health from changes in ecosystems, and other effects resulting from changes in environmental service functions (IPCC 1997: IPCC 2014a: IPCC 2014b). Thus spatial planners will need to have a clear understanding of the risk profile of their city or town which is the outcome of climate change projections, vegetation cover, settlement pattern, and infrastructure typologies.

References to form, layout, urban fabric, and scale suggest that the study of urban morphology may be useful in preparing adaptation plans. Urban morphology aims to understand the spatial structure and character of a metropolitan area, city, town or village by examining the patterns of its component parts and the process of its development (Simendi, 2011). Urban morphologists agree that the “city or town can be ‘read’ and analysed via the medium of its physical form” (Moudon 1997; Levy 1999). They also agree that at its most elemental level, morphological analysis is based on three principles namely, (i) urban form is defined by three fundamental physical elements i.e., buildings and their related open spaces (plots or lots) and streets; (ii) urban form can be understood at different levels of resolution corresponding to the building/lot, the street/block, the city, and the region; and (iii) urban form can only be understood historically since the elements of which it is comprised undergo continuous transformation and replacement.

Thus form, levels of resolution, and time constitute the three fundamental components of urban morphological research" (Moudon, 1997). Studies also focus on the 'plan unit': "plan units are groups of buildings, open spaces, lots, and streets, which form a cohesive whole either because they were all built at the same time or within the same constraints, or because they underwent a common process of transformation" (Moudon, 1997). Gill, S., Handley, J., Ennos, A., Pauleit, S., Theuray, N., and Lindley, S. 2008) notes that "studies have suggested that the distinction of UMTs or urban structural types at a 'meso'-scale (i.e. between the city level and that of individual plots) is a suitable basis for the spatial analysis of cities for environmental and landscape planning." The relative importance of this approach is that it "has a close affinity to land use categories commonly used in urban planning, thus enhancing the transfer of ecological information into the planning process" (Gill *et al*., 2008).

## 2.3 Contemporary Settlement Adaptation Responses to Climate Change

A comparative literature review was undertaken to assess what other global cities had identified as key principles to be applied in their adaptation plans. From the review the following key principles are included in climate change adaptation plans (Lindley, S., Handley, J. Theuray, N., Peet, E. and McEvoy, D. 2006; City of Toronto 2008; City of Copenhagen 2011; City of Sydney 2014; UN-Habitat 2015), viz.: adaptation to short-term climate variability and extreme events is included as a basis for reducing vulnerability to longer-term climate change; policies and measures are assessed in a developmental context; adaptation occurs at different levels of society; adaptation strategies are ambitious, fair, transparent, comprehensive, integrated, relevant, actionable, and evidenced-based; adaptation strategies are politically sustainable, economically efficient, socially inclusive, and environmentally supportive; and adaptation strategies are flexible and dynamic and able to evolve and respond to unexpected trends and consequences.

## 3. Research Methodology

This study relies on a literature review to assess what impacts climate change may have on human settlements and what key principles should be applied by urban and town planners when considering adaptation measures concerning human settlement patterns.

The literature review involved summarising what is already known about climate change impacts in southern Africa in general, and on human settlements in particular. This was done to generate a body of knowledge through the synthesis and critical analysis of the data to seek new perspectives.

A comparative literature review was used to assess what other cities had identified as key principles. The comparative literature review involved collecting data from a number of cities. The selection of the cities was based on climate compatibility to the South African context, and/or cities in countries known to be leaders in promoting climate change adaptation and mitigation measures. Comparative analysis is useful for providing data of a qualitative nature. The findings were used to generate new understandings of the approaches and responses adopted by cities around the world.

## 4. Findings and Discussion

From the above the paper finds that there are very specific projected climate changes and consequential impacts for South African settlements over the next 100 years. Key principles for South African settlements will have to specifically address these settlement-related hazard types from the climate variables, namely temperature, high fire-danger days, rainfall and wind speeds.

## 4.1 Climate Change and Settlement Pattern Adaptation

From the literature review it is possible to collate settlement pattern type and hazard risk exposure derived from Table 1. This collation is depicted in Table 2: it must however be noted that there are many factors, as alluded to in section 2, that will influence the risk exposure. Table 2 should therefore only be considered a point of departure for further analysis for each settlement type and climate change related impacts. Nonetheless it does suggest that some basic principles can be applied.

*Table 2: Settlement Pattern Types and Associated Hazard Risk Exposure*

| Hazard | Dispersed | Nucleated | Linear |
|---|---|---|---|
| **Temperature** | May result in higher levels of exposure due to large surface area. | May result in lower levels of exposure especially if settlement pattern is compact and pavement- and building surface area is minimised. | Levels of exposure may vary from CBD to inner city, inner suburbs, and outer suburbs. |
| **High fire-danger days** | May result in higher levels of exposure to veld fires. | May result in lower level of exposure to veld fires. | Levels of exposure may decrease from CBD to inner city, inner suburbs, and outer suburbs. |
| **Rainfall** | May result in higher levels of exposure to flooding due to larger catchment area. | May result in lower level of exposure to flooding due to smaller catchment area. | Levels of exposure may vary from CBD to inner city, inner suburbs, and outer suburbs. |
| **Wind speeds** | May result in higher levels of exposure. | May result in lower levels of exposure due to protection provided by adjoining buildings. | Levels of exposure may vary from CBD to inner city, inner suburbs, and outer suburbs. |

The question Table 2 raises is whether combining urban morphology type mapping with a climate hazard analysis is an approach that could also be applied to planning for climate change impacts in South African settlements? Section 26(E) of the Local Government: Municipal Systems Act, No. 32 of 2000 (the "MSA") requires all municipalities to compile Spatial Development Frameworks (the "SDF") as a core component of Integrated Development Plans (the "IDP"). The compilers of the SDF are required to "investigate the spatial form and development of the municipality, including the bio-physical, socio-economic and built environment status quo" (RDLR: 2011). The spatial analysis includes "patterns and trends" while the bio-physical analysis includes "geology, soils and climate" which "gives rise to hydrological, topographical and bio-diversity patterns" (RDLR: 2011). This would seem to suggest that climate-related hazards could readily be incorporated into SDFs.

There would therefore appear to be a strong case for using UMTs as a generic base from which to prepare adaptation strategies. Given the resources and capacity constraints that exist at local government level, the UMT approach may enable local authorities to only collate the UMT strategies into their SDFs.

### 4.2 Key Principles for Adapting South African Settlement to climate change

Table 3 collates a number of principles identified in the comparative literature review. From this it is possible to develop a set of key principles having regard to the specific impacts of climate change on human settlements analysis as described in Table 1 and settlement patterns as described in Table 2. These are set out in Table 3 below.

*Table 3: Key Principles for Adaptation of South African Settlements*

| Issue | Guiding Principles |
|---|---|
| **I. Climate modelling, projections, scenarios, potential impacts and uncertainty** | |
| **Models, projections and scenarios** | 1. A range of climate projections and scenarios should be used for adapting settlement patterns. |
| | 2. There should be a clear understanding of the assumptions made and the uncertainties related to those assumptions. |
| | 3. The best climate change model or scenario for a certain region or a settlement pattern should be decided on a case-by-case basis because of the variability in projections across South Africa. |
| | 4. Climate projections and scenarios together with the assumptions made should be periodically reviewed and adjusted as necessary. |

| **II. Settlement adaptation and management** | |
|---|---|
| **Overall guiding principles for settlement planning** | 1. Settlement pattern adaptation should protect and enhance the economic, social and environmental systems of the settlement pattern from becoming compromised by climate change impacts.<br>2. Coverage of data (e.g. meteorological, hydrological, water quality, soil moisture data, damage cost data, etc.) should be evaluated as it becomes available.<br>3. Issues of climate change impacts on the settlement pattern should be incorporated into city development plans.<br>4. Adaptation measures should improve the efficiency of urban systems.<br>5. Adaptation measures should modify urban form and layout to reduce risk and vulnerability.<br>6. Adaptation measures should include the use of heat-resistant construction materials.<br>7. Adaptation measures should increase vegetative cover. |
| **Settlement pattern adaptation based on uncertainty of Projections and scenarios** | 8. The best available scientific information should be taken into account: planning decisions should always be evidence- and placed-based.<br>9. Settlement pattern adaptation to short-term climate variability and extreme events should be included as a basis for reducing vulnerability to longer-term climate change. |
| **Reducing vulnerability** | 10. Development in zones at risk of landslides should be resisted.<br>11. Development on coastal zones subject to sea level rise and sea surge should be resisted.<br>12. Systems should be designed with multiple nodes rather than a central node to ensure that failure of one node does not cause the entire system to fail.<br>13. Decentralise the provision of infrastructure services to the lowest possible level, i.e. household, block, precinct, and city.<br>14. Strategic landscape patterns and critical ecological processes should be preserved and strengthened and threaded through the settlement pattern.<br>15. Urban infill should be developed in preference to urban extension and new settlement formation.<br>16. The settlement pattern should be compact with higher densities and a consistent building height.<br>17. Mixed land uses should be pursued.<br>18. Climate change risks should be integrated into infrastructure investments (climate-proofing).<br>19. Eco-efficiency should be integrated into new infrastructure and retrofit projects. |
| **Drought and water scarcity adaptation and management** | 20. When considering urban infill, urban extension and new settlement development, determine, on the basis of robust scientific evidence and on a case-by-case basis, the risks for a prolonged drought and water scarcity and take into account climate change predictions in this case-by-case approach.<br>21. When considering urban infill, urban extension and new settlement developments, take into account long term forecasts of supply and demand and favour options that are robust to the uncertainty in climate projections.<br>22. Choose sustainable adaptation measures, especially those with cross-sectoral benefits, and which have the least environmental impact, including GHG emissions.<br>23. Avoid adaptation measures that modify the physical characteristics of water bodies (e.g. reservoirs, water abstractions) and deteriorate water status.<br>24. The settlement pattern should be amended to facilitate the harvesting and reuse of all stormwater. |
| **Flood risk adaptation and management** | 25. Understand and anticipate as far as possible increased exposure, vulnerability and flood risk due to climate change, for establishing areas of potential significant flood risk. |

| | |
|---|---|
| | 26. The review of flood maps should incorporate climate change information.<br>27. Development within 50 year flood zones should be resisted.<br>28. Development in high-risk flood zones should be resisted.<br>29. Existing development in high-risk flood zones should be progressively relocated.<br>30. The zoning scheme should be amended to promote the most desirable use of land in low- and moderate-risk flooding zones.<br>31. The zoning scheme should be amended to mitigate the effects of elevated and flood-proofed buildings on the streetscape and pedestrian activity.<br>32. Riverine systems running through the settlement pattern should be stabilized and protected.<br>33. Sustainable Urban Drainage Systems (SUDS) should be preferred over hard engineering solutions.<br>34. Existing urban drainage systems should be re-engineered in line with SUDS principles.<br>35. All recreational open spaces including school properties and sports fields, should be altered to capture stormwater.<br>36. Urban infill, urban extension and new settlements should be responsive to flood risk.<br>37. More than one access route to settlements should be established.<br>38. The settlement pattern should be amended to facilitate flood-water capture and release in moderate- and high-risk flood zones.<br>39. Urban infill, urban extension and new settlements should be structured along contour lines, especially transit routes. |
| **Heat stress adaptation and management** | 40. The settlement pattern should be adapted to facilitate the use of prevailing cooling winds to reduce the heat island effect.<br>41. The settlement pattern should be adapted to reduce the heat island effect, i.e., reduce pavement area.<br>42. Urban infill should be preferred to urban extension and new settlements.<br>43. The settlement pattern is amended to prevent and restrict the spread of veld fires and facilitate rapid access for fire-fighting services and systems. |
| **Transformative adaptation and management** | 44. Adaptation policies and measures are assessed in a developmental context i.e., meeting the needs of the community.<br>45. Adaptation measures should support mitigation measures as well.<br>46. A greater place for nature should be made in the settlement pattern.<br>47. All new infrastructure investments conform to green infrastructure precepts.<br>48. Areas and communities of greatest vulnerability are adapted first.<br>49. New developments strengthen relationships between communities, i.e. CBD, peri-urban, and suburban. |

## 4.3 Discussion

Firstly, it is possible to prepare an extensive list of key principles as reflected in the various adaptation plans included in the case study. For purposes of this study however the identification of key principles was based on those that most accurately address the specific climate-related hazards projected for settlement patterns in South Africa. The projected climate impacts for South Africa are fairly clear: human settlements will have to cope with a hotter and drier climate. What is less clear is how particular human settlement patterns are likely to behave, or what the preferred settlement pattern or urban form would be. The global city comparative literature reviewed was not helpful in this regard: this raises the question as to why settlement pattern or urban form adaptation is not included in city adaptation plans. It would seem that since South African cities are projected to become hotter and drier, valuable lessons can be learnt from desert cities.

Secondly, these potential impacts will need to be examined in more detail. Existing policies related to urban form will need to explicitly address the climatic hazards which can be expected in the future. This adaptation will require, inter alia, improving the efficiency of urban systems; modifying urban form and layout; the application of heat-resistant approaches for buildings and settlements; and using green infrastructure as a heat- and water management strategy.

Thirdly, using the hazard types described in section 1 and settlement pattern types described in section 2 it is possible to generate a more detailed hazard/UMT classification system than that shown in Table 3. This merits further investigation: it may well be that the adoption of an UMT approach would enable the adoption of new practices and processes into municipal SDFs.

Fourth, very few of the global city adaptation plans reviewed acknowledged the transformative role of adaptation measures if applied to settlement patterns beyond the ability to contribute towards mitigation as well. Examples of this would could include overcoming segregated spatial planning patterns of the past (race, income group, land use, access to services), climate-proofing infrastructure, and incorporating green and blue infrastructure into the settlement pattern.

## 5. Conclusion and Further Research

With the exception of extreme weather events, the projected climate impacts for southern Africa are fairly clear. Essentially the challenge for human settlements in South Africa is to cope with a hotter and drier climate.

Notwithstanding a substantial body of knowledge developing around climate change and impacts on settlements, few adaptation plans identify the transformative potential in adaptation. Adaptation plans need to seize the opportunity for the planning and design of existing and future settlements with regard to infrastructure planning, design, operation, and maintenance in a manner that will strengthen the resilience of communities to cope with the potential impacts of climate change, while also addressing the country's developmental goals.

The question regarding the combining of urban morphology type mapping with a surface analysis for planning for climate change impacts in South African settlements merits further research. Given the resources and capacity constraints that exist at local government level, this approach may be useful in assisting local authorities in including climate change strategies into their SDFs.

## 6. Acknowledgement

The paper acknowledges the grant funding by the Canadian International Development Research Centre (IDRC) for the purpose of developing a set of guidelines – called the Green Book – to adapt existing and future South African settlements at risk to climate change impacts.

## 7. References

Altvater, S., de Block, D., Bouwma, I., Dworak, T., Frelih-Larsen, A., Görlach, B., Hermeling, C., Klostermann, J., König, M., Leitner, M., Marinova, N., McCallum, S., Naumann, S., Osberghaus, D., Prutsch, A., Reif, C., van de Sandt, K., Swart, R., and Troitzsch, J. 2012. *Adaptation measures in the EU: Policies, costs, and economic assessment*. "Climate Proofing" of key EU policies, ZEW Gutachten/ Forschungsberichte, pp. 62.

Arneth, A., Sitch, S., Pongtaz, J., Stocker, B., Ciais, P., Poulter, B., Bayer, A., Bondeau, A., Calle, L., Chini, L., Gasser, T., Fader, M., Friedlingstein, P., Kato, E., Li, W., Lindeskog, M., Nabel, J., Pugh, T., Robertson, E., Viovy, N., Yue and Zaehle, S. 2017. Historical carbon dioxide emissions caused by land-use changes are possibly larger than assumed. *Nature Geoscience* 10, pp. 79-84.

Bosselmann, P, Arean, E., Dunker, K., and Wright, R. 1995. "Urban form and climate: case study, Toronto." *Journal of the American Planning Association*, 61:2, 226-239, DOI: 10.1080/01944369508975635.

Burton, Challenger, Huq, Klein, Yohe, Adger, Downing, Harvey, Kane, Parry, Skinner, Smith, and Wandel 2001. *Adaptation to Climate Change in the context of Sustainable Development and Equity*. Intergovernmental Panel on Climate Change (IPCC). Cambridge: Cambridge University Press, pp. 778-912.

Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I, Jones R, Kolli RK, Kwon W-T, Laprise R, Magana Rueda V, Mearns L, Menendez CG, Raisanen J, Rinke A, Sarr A, Whetton P (2007). Regional climate projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, A., Tignor, M., Miller, H. (eds)]. Cambridge University Press, Cambridge.

City of Copenhagen 2011. *Copenhagen climate adaptation plan*. Copenhagen: City of Copenhagen, pp. 57-90.

City of Toronto 2008. *Ahead of the storm: preparing Toronto for climate change*. Toronto: City of Toronto, pp. 21-38.

City of Santa Cruz 2011. *Climate adaptation plan*. Santa Cruz: City of Santa Cruz, pp.9.

City of Sydney 2014. *Adapting for climate change: a long term strategy for the City of Sydney*. Sydney: City of Sydney, pp. 20.

Davoudi, S., Crawford, J., and Mehmood, A. 2009. *Planning for climate change: strategies for mitigation and adaptation for spatial planners*. New York: Routledge.

Engelbrecht, C. 2016. *Detailed projections of future climate change over South Africa*. Pretoria: CSIR, pp. 3-8.

Engelbrecht CJ, Engelbrecht FA and Dyson LL (2013). High-resolution model projected changes in mid-tropospheric closed-lows and extreme rainfall events over southern Africa. *Int J Climatol* 33 pp. 173–187. doi:10.1002/joc.3420.

Engelbrecht FA, McGregor JL and Engelbrecht CJ (2009). Dynamics of the conformal-cubic atmospheric model projected climate-change signal over southern Africa. *Int J Climatol* 29 pp. 1013–1033.

Gill, S., Handley, J., Ennos, A., Pauleit, S., Theuray, N., and Lindley, S. 2008. Characterising the urban environment of UK cities and towns: A template for landscape planning. *Landsc Urban Plan* 87 pp. 210-222 http://dx.doi:10.1016/j.landurbplan.2008.06.008

James R and Washington R (2013). Changes in African temperature and precipitation associated with degrees of global warming. *Climatic Change* 117 pp. 859–872. DOI 10.1007/s10584-012-0581-7.

Levy, A. 1999. Urban morphology and the problem of the modern urban fabric: some questions for research. *Urban Morphology* 3(2), pp. 79-85

Lindley, S., Handley, J. Theuray, N., Peet, E. and McEvoy, D. 2006. Adaptation strategies for climate change in the urban environment: assessing climate change related risk in UK urban areas. *Journal of Risk Research* 9(5) pp. 543-568.

Moudon, A. 1997. Urban morphology as an emerging interdisciplinary field. *Urban Morphology* 1, pp. 3-10.

Niang I, Ruppel OC, Abdrabo M, Essel A, Lennard C, Padgham J, Urquhart P, 2014:Africa. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V., Field, C., Dokken, D., Mastrandea, M., Mach, K., Bilir, T., Chatterjee, M., Ebi, K., Estrada, R., Genova, R., Girma, B., Kissel, E., Levy, A., MacCracken, S., Mastrandea, P., and White, L. (eds)]. Cambridge: Cambridge University Press, pp. 1199-1265.

RDLR 2011. *Guidelines for the development of municipal spatial development frameworks*. Pretoria: Department of Rural Development and Land Reform, pp. 12-19.

Simendi, P. 2011. *Urban morphology*. [Online] Available from:

https://www.scribd.com/document/54935517/Urban-Morphology [Downloaded: 02 February 2017], pp. 1-8.

Stone, B. and Rodgers, M. 2007. "Urban form and thermal efficiency: how the design of cities influences the urban heat island effect." *Journal of the American Planning Association*, 67:2, 186-198, DOI: 10.1080/01944360108976228

UCCRN 2015. *Climate Change and Cities*. Columbia University: Urban Climate Change Research Network, pp. 4-7.

UN-Habitat 2015. *Guiding principles for city climate action planning*. Nairobi: UN-Habitat, pp. 1.

Van Staden 2014. *Climate change: implications for cities*. London: University of Cambridge and ICLEI, pp. 7-9.