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Urban morphology dynamics and environmental change in Kano, Nigeria

Aliyu Salisu Barau, Roy Maconachie, A.N.M. Ludin and Adnan Abdulhamid

Abstract

In recent years, a critical understanding of human–nature interactions has become central to studies exploring the dynamics of urban morphology and the sustainability of growing cities in the developing world. Accordingly, numerous scholars have employed the coupled human and natural systems (CHANS) framework as a tool for understanding how cities are evolving in times of profound global change. Focusing on the case of Kano, northern Nigeria’s largest city, this paper explores the potential of the CHANS framework in the analysis and interpretation of the human–nature interface in cities of the global south. Drawing on the qualitative analysis of graphic information and classical and contemporary literature, the centuries-old spatial morphology of Kano is traced and analysed. In the process, the paper highlights how change in the roles of traditional institutions of urban land administration has triggered the degeneration of the city’s resilient indigenous urban morphology. Field investigations and the analysis of a variety of 19th, 20th and, 21st century images reveal significant change in the city’s traditional building materials, roofing styles, street forms, distribution of ponds, and green and open spaces. Population pressure on urban land has also been a major driving force behind the unfolding changes. One catastrophic outcome of these changes has been the exacerbation of recurrent floods. In drawing attention to wider lessons for urban planners in other developing country contexts, the paper stresses the need to analyse any notable spatial and non-spatial events in cities in relation to the changing dynamics of urban morphology.

1. Introduction

Urban morphology – the study of the form of human settlements and the process of their formation and transformation – entails the spatial analysis of urban structures, land use, street patterns, buildings, and open spaces (Conzen 1988; Gauthier and Gilliland, 2006). By its very nature, it is an interdisciplinary field of study (Moudon, 1997) that researchers have relied

upon for urban landscape modelling and measuring a wide range of urban characteristics, including air quality, traffic noise, and accessibility (Cionco and Ellifson, 1988; Hiroyuki and Omae, 2005; Webster, 2010; Edussuriya et al. 2011; Wang and Kang, 2011). A number of critical scholars, however, have suggested that an analysis of urban morphology can also provide important new opportunities for researchers to explore complex, multifaceted urban sustainability issues that have proved difficult to analyse in the past (Van Diepen and Voogd, 2004; Wu, 2008).

There is now widespread consensus amongst scholars that multiple environmental challenges confront most cities and towns in developing countries. One very significant challenge is the increased prevalence of urban flooding, which the UN Habitat (2011) has identified as an overwhelming threat to urban sustainability. The urban poor are often exposed to high degrees of vulnerability that can be exacerbated by flooding, which can spread disease, displace populations and devastate livelihoods and infrastructure. Flooding is thus a multifaceted problem that demands a combination of policy, scientific, and technical responses.

While spatial planning is both a science and policy response, and has been used as a valuable tool for flood risk management (Tunstall et al., 2009; Burch et al., 2010), its success largely depends on the nature of a given urban area's social and economic standing. For example, the Hyogo Framework of Action mandates countries to apply disaster reduction modalities relevant to their land use systems (Schanze, 2009). But unfortunately, due to low adaptation and coping strategies, some developing countries do not possess the capacity to actualise this mandate (Satterthwaite, 2008). Many African cities are a case in point, where urban planning systems have not been satisfactory and have been constrained by a wide range of factors, including rapid population growth, weak institutions, dependence on foreign expertise, and political instability (Parnell et al. 2009; Parnell and Simon, 2010). In order to address urban morphology related challenges in developing countries, a better understanding of the nature of urban socio-ecological systems is first needed.

In such contexts, it becomes critical to understand the morphology of cities within the broader context of their socio-ecological systems. Accordingly, researchers focusing on issues concerning urban sustainability have stressed the need to integrate human and earth system histories to facilitate the analysis and interpretation of human and natural systems (Costanza et al., 2012). However, there are few examples of analyses which have employed

indigenous urban morphology and land use systems in the context of sub-Saharan Africa (Kajoba, 2002; Awuah et al., 2010). As such, Baker (2000) has urged planners to incorporate a better appreciation of African indigenous concepts in their urban planning strategies. Indeed, the landscapes of many African cities provide excellent vehicles for understanding environmental change and its connection to institutions, resilience, and sustainability dynamics.

Urban areas are complex arenas that emerge through the interaction of both natural and human agents. Hence, any satisfactory diagnosis of urban sustainability challenges must be able to employ an interdisciplinary lens. One of the emerging interdisciplinary frameworks that sustainability scientists are increasingly using is the coupled human and natural systems (CHANS) framework. Researchers have employed the CHANS approach to develop frameworks that examine the relationships and linkages between the human and natural dimensions of environmental change in a wide range of different landscape settings (Liu et al. 2007a; Marina et al., 2011; Fu et al. 2013). Turner II et al. (2003) further note its significance for landscape research, particularly in its ability to identify gaps in socio-ecological processes and facilitate a more systematic understanding of vulnerability in a landscape system. This model is instructive for examining urban morphology dynamics because its flexibility allows researchers to pursue a more holistic and interdisciplinary approach by integrating a diverse range of theories and techniques to explain the dynamics of human-nature interactions (An, 2012; Wandersee et al., 2012).

Some urban researchers consider the CHANS framework to be a variant of socio-ecological systems approaches (Alberti 2011; Wang et al. 2011), which recognise the key role of institutions in regulating the interface of biophysical and social environments (Kluvankova-Oravska and Chobotova 2007). At the same time, however, the CHANS approach seeks to promote enquiry into integrated solutions (Kangas et al. 2005; Cordell and Kerschner 2007). While urban areas are in the rank of the most important hubs of human-natural systems interactions, in many cases they also represent examples of the dichotomisation of human and natural systems. As such, Marcus and Colding (2011) have advocated for the 'spatial morphology of social-ecological systems' as a strategy to fuse the roles of urban planning, design and governance.

As will be explored in this article, the CHANS model is a useful tool for the analysis of complex urban environmental problems that elude technological and policy responses. It

provides a valuable point of departure for the analysis of flooding events, a prime example of a biophysical and social problem that intertwines human and natural systems of the urban environment. This paper, therefore, aims to contribute to the literature on urban environmental change by exploring the role and responses of indigenous urban morphology to flood risks. Drawing on the case of Kano, northern Nigeria's largest city, the paper explores the relevance of a socio-ecological systems approach in determining vulnerability and resilience of urban morphology. In doing so, the analysis underscores the importance of integrating the social, spatial, ecological and temporal dimensions of urban systems in the developing world. The paper concludes that studies of this nature are imperative for understanding and designing more sustainable solutions for environmental problems in the world's most rapidly urbanising areas.

2. Materials and Methods

2.1 The Study area

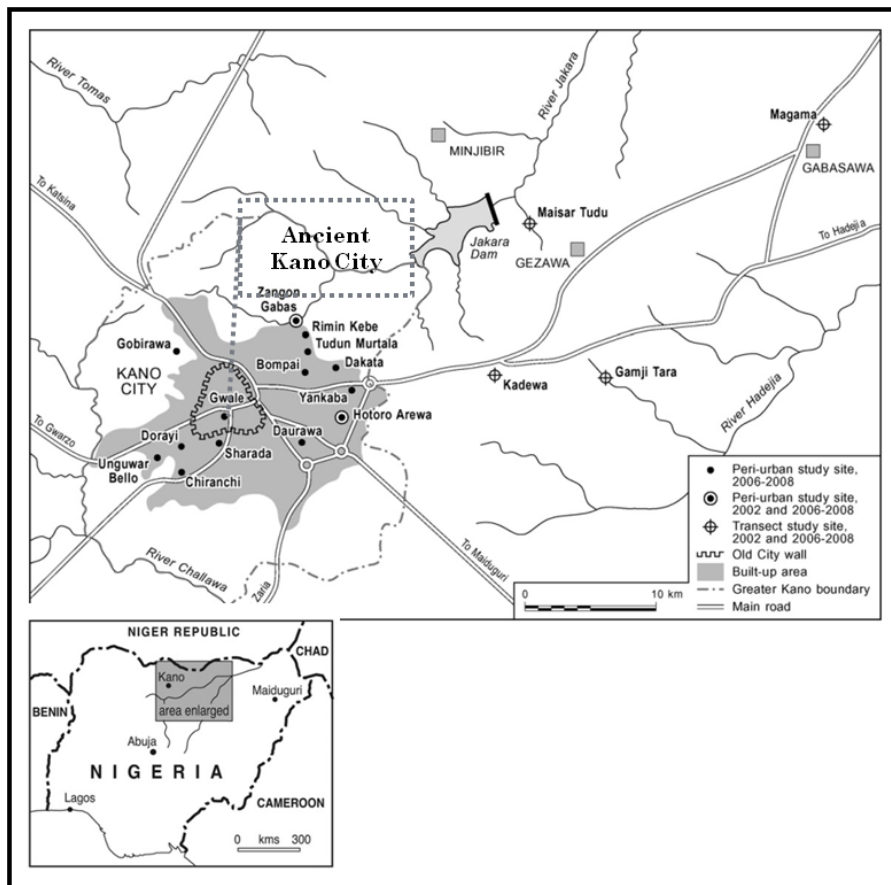
The ancient walled-city of Kano dates from the late 10th century and at that time was one of the most important hubs on the Trans-Saharan Trade route. The city's walled perimeter covers an area of 29 km², sitting between latitude 12°02'N and longitude 08°30'E. Its topography of undulating plains is underlain by basement complex rocks of Precambrian age (Olofin, 1987). The natural vegetation of this area is classified as Sudan savannah, but has been transformed into a derived savannah region due to human impact (Ahmed, 2010). Its tropical wet and dry climate is marked by seasonal rainfall (April to October) with a mean annual temperature of 30°C (Buba, 2000).

By the mid-16th century, its 7500 houses made Kano the third largest city in Africa after Cairo in Egypt and Fez in Morocco (Last, 1979). At that time, the area of the walled city was roughly 5400 acres, out of which only 2000 acres were actually inhabited by people (Frishman, 1977). Over time, metropolitan Kano and its urban population have continued to expand, having a significant influence on land-use and ownership, economic activities and labour markets (Maconachie, 2007). According to Paden (1973) Kano's population density was the highest in sub-Saharan Africa during the 1960s, and today, Kano (the ancient city and metropolis) is the second largest city in Nigeria with an estimated population of 3.19 million in 2007 (UN-Habitat, 2008) (see Figure 1). A summary of trends in Kano's population change is presented in Table 1.

Table 1: Population trends of Kano city

<i>Year</i>	<i>Observer</i>	<i>Estimated population (ancient city)</i>
1820s	Hugh Clapperton	30, 000 – 40,000
1851	Henry Barth	60,000
1903	Freidrich Lugard	30,000 (Kano market alone)
1932	Colonial government	83,000
1952	Colonial government	131,000
1963	Nigerian government census	250,000
1991	National population commission	Around 1.5 million
2006	National population commission	Around 2 million

Source: Barth (1857); Maiwada (2000); Barau (2010)

Figure 1: Map of the study area and its surroundings

Source: Adapted from Maconachie et al. (2009)

Though many interacting factors have shaped the morphology of Kano over time, these factors cannot be disconnected from changing geography and rainfall patterns. While rainfall variability in Kano has been described as being ‘normal’ between 1931-1960 (Ati et al., 2008), since the 1960s the rainfall received in the Kano region has exhibited notable fluctuations (NIMET, 2008; Ati et al., 2008; Ahmed, 2010). Not only has the quantity of rainfall fallen to below the 1000mm annual range, but Kano also faces skewed rainfall distribution. Buba (2000) points out that in the late 1980s, each year 80% of rains in Kano fell within just three months (July to September), putting increasing stress on natural drainage systems. Alongside these changes in rainfall patterns, however, some researchers have also noted that anthropogenic processes, such as the loss of open spaces, blocked drainage and declining space for urban agriculture have been major contributing factors to the recurrent floods (Lynch et al., 2001; Ahmed, 2010).

At times, flooding has had disastrous consequences for the population of Kano. It was reported that between 2003-2007, urban floods in Kano affected 16, 730 households and resulted in 14 deaths and the displacement of hundreds of thousands of people (Barau, 2008). While planners have identified a number of simplistic reasons to explain these events, it is important to note that changes in the morphological composition of the city have not gone unnoticed by local researchers as a factor contributing to environmental problems. Imam (2002), for example, observed that between 1990-2000, Kano lost over 30 open spaces of different sizes and functions, a process that was largely driven by change in the city’s traditional morphology, demography and land administration. Understanding such underlying processes and their implications for Kano’s urban fabric is central to the focus of this paper, and provides the point of departure for the research questions that underpin the study. These are: what role do socio-ecological systems play in explaining urban morphological change? How does urban morphology change impact upon flood resilience in Kano? And what are the social and ecological implications of urban morphology change in Kano?

2.2 Study Approach

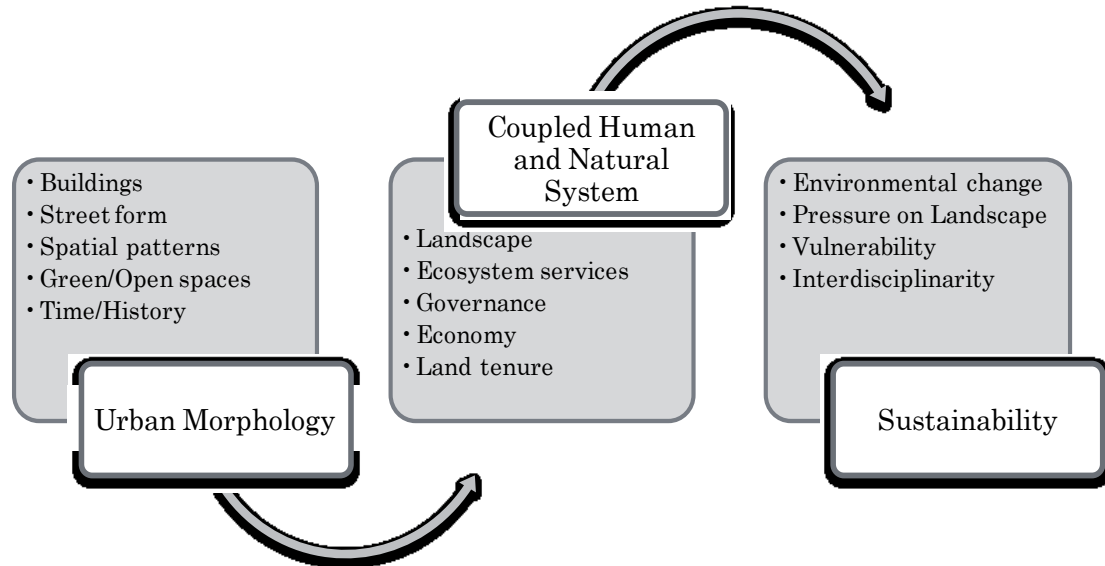
The flexibility of the CHANS framework makes it suitable and adaptable to many studies involving complexity and different scales of socio-ecological analysis (Turner II et al. 2003; An, 2012; Wandersee et al. 2012; Fu et al. 2013). However, what makes the CHANS approach unique from other frameworks is its underlying assumption that human and natural systems are coupled via reciprocal interactions, which are usually understood as flows (McConnel et al. 2011). While there are many different interpretations and applications of the

CHANS framework, most approaches center on linking different sub-models to create coupled models that are capable of depicting both human and natural sub-systems, and the interactions between them (Liu et al, 2007b). However, as noted by McConnel et al., 2011: 219), "...just what counts as a "model" varies considerably across disciplines and projects, and might include, inter alia: conceptual diagrams that map out relationships and processes among system components, graphical and analytical models, numerical models with hypothetical or empirically derived parameters, or computer simulations, including agent-based models."

In this study, the CHANS approach was a suitable guiding framework because of its flexibility and capacity to link the social, biophysical and temporal dimensions of urban morphology to urban environmental changes. As with other applications of the CHANS approach, a simple graphic model was developed (see Figure 2) to help the researchers identify the crucial system components and flows between Kano's urban morphology and processes that concern sustainability. While the graphic model was not employed to explicitly explain this relationship, it served as a useful tool to facilitate discussion about the structure of the systems under investigation, and more specifically, how different sub-systems might be linked. Focusing upon the biophysical and socio-cultural aspects of Kano's urban landscape described in the previous section, the researchers used the model as a guide to critically analyse literature sources and images, which could help identify the variables that underpinned the interactions and linkages between the city's morphology and sustainability issues.

While there have been a number of previous studies in developed countries that have focused on the socio-ecological dimensions of flooding (e.g. see Ashley et al., 2007; Grunfest, 2009), the application of the CHANS approach in this study has been useful to move beyond their shortcomings. The integrative ability of the CHANS framework is particularly valuable in developing country contexts, where there may be a dearth of data and weak planning institutions, which can undermine urban sustainability research. In this study, the CHANS framework helped the researchers to systematically establish or identify which event induced what reaction or feedback to the state of Kano's urban landscape over time. This contributed to the ability of the researchers to trace the patterns of human impact and related responses that have shaped Kano's urban morphology and contributed to urban environmental change.

Figure 2: CHANS Conceptual framework integrating urban morphology and sustainability linkages in a context of traditional African city



Using this framework as a guiding conceptual tool, the methods employed in the collection and analysis of data were selected to allow for a comprehensive study of the real and perceived impacts of urban environmental change on Kano. Following the principle of triangulation, a multiplicity of qualitative data sources were drawn upon to enhance the reliability, depth and richness of explanation. Most notably, image and map analysis formed the backbone of the study. The researchers authenticated the images by naming and recognising places that appeared in maps and photographs, in line with the document-based question (DBQ) model commonly used in historical sciences (Noonan, 1999). Ground truthing was undertaken to validate objects, patterns and processes identified in the historical images, and involved a combination of transect walks, key informant interviews, focus group discussions and oral histories at selected sites. These methods not only allowed for a richer and more nuanced understanding of historical processes, but also helped to facilitate comparisons to the contemporary environment in 2010.

The main fieldwork observations were carried out between 2010 and 2011, when the authors analysed eight different images to explore the land use and spatial configuration of Kano between the 19th and 21st centuries, in line with Costanza et al. (2012)'s call for a more longitudinal approach to mapping long-term environmental change. The images analysed

were diverse and included: coloured aerial photographs, panchromatic air photo mosaics, conventional coloured and black and white photographs, topographical maps, and satellite images. The use of graphic data has been successfully used in a number of recent environmental studies, which have effectively used graphic images dating from one to five centuries ago, to investigate flooding (Coeur and Lang, 2008; Kron, 2007; Roo et al., 2003).

In this study, five different urban morphology variables were considered in our comparisons – building materials, roofing types, street form, distribution of ponds, and green and open spaces (see Table 2). These variables were crucial in analysing and interpreting the spatial and temporal dynamics of the indigenous urban morphology. They were also used in comparisons of spatial patterns, which were made between images dating from the 19th and 21st century (following Reddy, 2008). These images provided pictorial narratives of the spatial, structural and historical dynamics of morphological transformation of Kano, and offered visual evidence for comparative analysis of past and recent urban morphology settings. The maps, images and photographs were acquired from various sources (e.g. Wikimedia, Google Earth, the Kano Museum, Kano Emirate Facebook pictures, journals and private collections) and analysed by 10 local researchers (four historians and six geographers) who were selected because of their knowledge of, and research experience in, Kano city. The diversity of the images prohibited the use of a uniform method of analysis and so direct observations, interpretations and an estimation of the five selected variables was made based on forms and patterns.

Finally, the researchers developed an historical spectrum, based on old and recent literature which highlighted complexity in the cause and effect of changes that affected urban morphology in Kano. The results of these morphological changes were described according to time content attributes. For example, a Google Earth image of 2010 was used to identify and measure ponds, open spaces and streets and also served as a control image that provided the most recent picture of Kano's morphology. The pairing of the methods into an interdisciplinary stream is a defining principle of the CHANS framework, which in this case was employed to help the researchers achieve broader understanding of the vulnerability and sustainability dynamics of Kano's urban morphology.

3. Results

Referring to Table 2, the nature of changes in Kano city's morphology is summarised, particularly with respect to how these changes have increased vulnerability to flooding. Of

particular note are the urban morphology changes which took place in 1980, which had a dramatic and lasting impact on Kano's urban ecological fabric.

Table 2: Kano city landscape spatio-temporal change

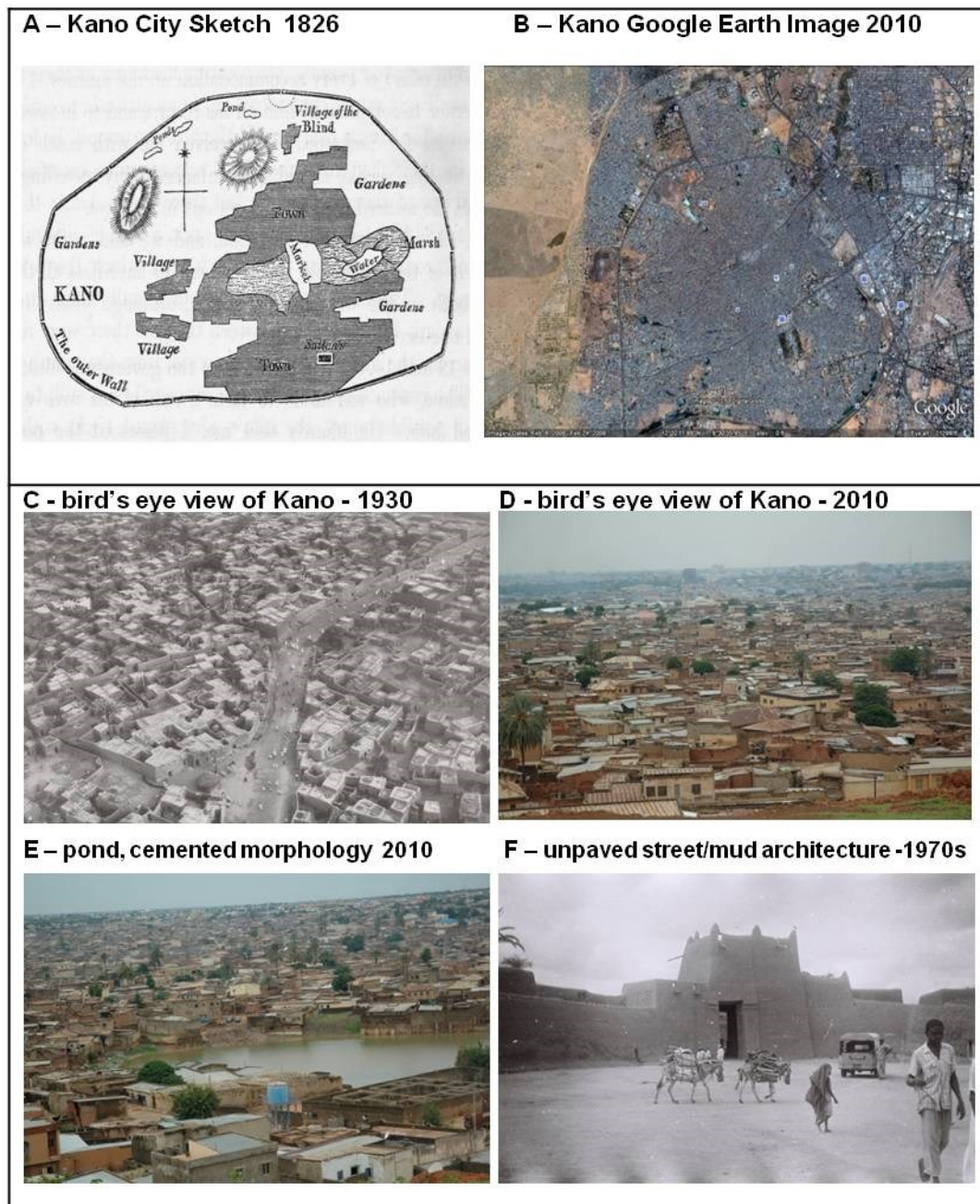
S/N	Image Type & Year	Observed roofing types	Observed building materials	Observed Street types	Observed ponds	Observed open/green spaces
1	1826 sketch map of Kano by Dixon Denham (Wikimedia)	None	None	Not available	3 ponds shown	Sizable gardens, marshes, open spaces
2	19 th century map of Kano (Geographical Review, 1937)	None	None	33 unpaved thoroughfares counted	About 100 small and large size ponds/pits	Cemeteries, fields, gardens
3	1933 Kano photograph from hilltop (Swiss pilot Mittelholzer-Wikimedia)	All flat mud roofs	All mud/clay brick houses	Several narrow and unpaved streets	None	Few open spaces within built up areas
4	1903 -1910 sections of the Kano walls. (Gidan Makama, Museum)	Flat mud roofs	All mud/clay brick walls	Open space pathways	Several	Several
5	1980 Kano panchromatic Airphoto mosaic (Kenting Africa)	Few mud roofs, more corrugated iron sheet roofs and concrete roofs	Less mud used, more OPS houses	All the major historic streets paved and widened	More than 50 ponds counted	Western parts of the city are fairly undeveloped
6	1991 Kano city coloured airphotos (selection by Geonex)	Much fewer mud roofs; more metallic & concrete roofs	Declining mud houses, increasing use of cement and duplex structures	Fewer than 20 important streets are unpaved	Fewer than 40 ponds within built up areas	Densification sets in all directions
7	Selection of 2010 pictures and Google Earth 2010	Impervious roofs >90%, with more metallic roofs	Plastering and use of cement in over 90% of the buildings	No unpaved major/important street observed	Only 20 ponds were visible	Only cemeteries and public buildings provide open and green spaces

Source: Authors' fieldwork

The information presented in Table 2 was obtained through the analysis of both archival and recent images. The six images (A - F) are shown in Figure 3, and served as a valuable tool for explaining urban flood vulnerability in the context of Kano. For instance, picture (A) suggests that in the early 1800s, Kano's resilience to floods was largely a product of its significant distribution of open spaces, green areas and other wetlands. The situation depicted is incomparable to the 21st century as represented by image (B). The visual evidence on how streets morphology, roofing systems and building materials have changed

(images C-F) also helps to explain why flood vulnerability in Kano has increased in recent years.

Figure 3: Pictorial evidence of morphological change over time. Credits: Dixon Denham-1826 (A); Google Earth-2010 (B); Walter Mittelholzer -1930 (C); Ibrahim Ado-Kurawa 2010 (D and E); Kano Emirate Facebook (F)



From the analysis, it is apparent that the city has witnessed a rapid and sharp decline in the number of vital morphological and ecosystem components that previously helped the city to withstand or prevent crippling urban floods. This is particularly so with respect to the

relatively recent and rapid changes that have affected the city's spatial organisation, types of building materials and open spaces during the postcolonial era. The graphical and field-based evidence of these changes are also supported with historical accounts drawn from selected archival literature sources that were based on classical geographical thought. For instance, the 19th century German geographer, Henry Barth (1857), reported that during the mid-1800s, Kano was an excellent example of a city with a well-established indigenous African urban morphology. In Barth's words:

[T]he whole scenery of the town in its great variety of clay houses, huts, sheds, greens open places affording pasture for oxen, horses, camels, donkeys and goats, in motley confusion, deep hollows containing ponds overgrown with the water plant, the *Pistia stratiotes*, or pits freshly dug up in order to form the materials for some new buildings, various and most beautiful specimens of the vegetable kingdom, particularly the fine symmetric gonda or papaya, the slender date-palm...silk cotton-tree... the people in all varieties of costume formed a most animated and exciting scene (1857: 492-493).

From the above excerpt, it is apparent that Kano's urban morphology once represented a symbiotic interface for humans and the environment, which demonstrated both resilience and durability over a long period of time. This feature also attracted the attention of Nigeria's first British Governor General, Lord Lugard, as is apparent in his comments in a 1904 edition of the *Bulletin of the American Geographical Society*:

Kano alone, among cities of Africa which I have seen...is worthy of the name of city, for its houses are of solid mud with flat roofs impervious to fire and lasting through centuries...Traces of Moorish architecture are visible everywhere (1904:157).

However, on the other hand, more recent literature on Kano provides a contrasting picture of the old city to that portrayed above. Much of this literature highlights the implications of recent growth intensification, which have induced the collapse of the inherent resilience and morphological structure of the city. In this regard, Orok (2011) attributes the dramatic increase in the occurrence of floods to rapid change in the spatial morphology of the city. Based on Landsat satellite data calculations, our research provides further verification of these changes, revealing a 96.6% change in land use between 1990 and 2000 alone. Similarly, the period between 2000 and 2009 saw an increase of 21% in new land development in Kano.

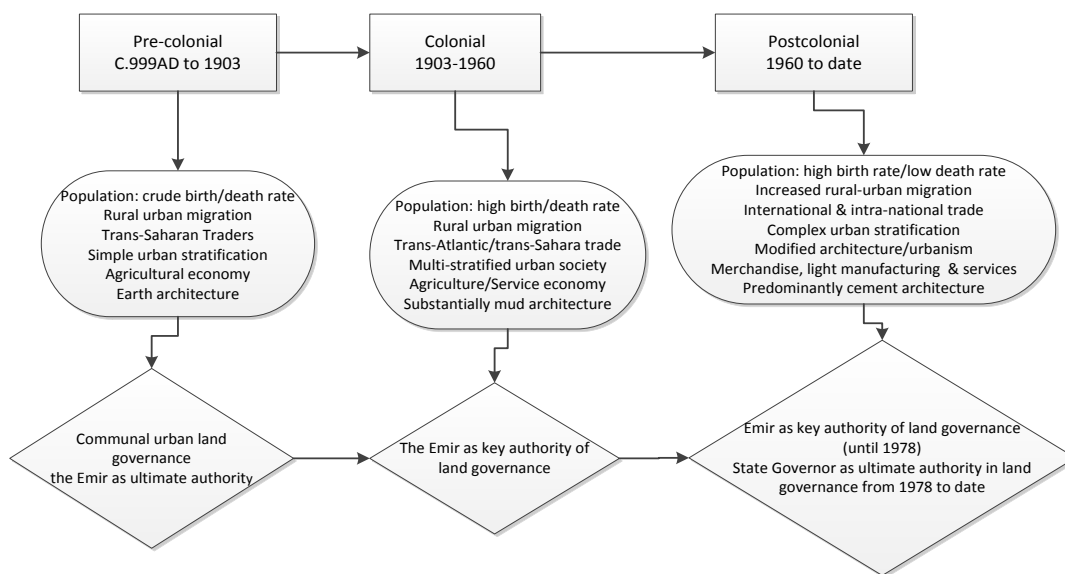
In tune with the longitudinal focus of our study, a spectrum of changes are apparent in Table 3, indicating trends in the morphology of Kano during the pre-colonial (before 1903), colonial (1903-1960) and postcolonial (after 1960) periods. This spectrum traces interactions of the human and natural systems in Kano in a way that reflects how changing institutions, demography, economy, architecture and urban morphology tilted the balance within a few decades. These identified changes in the city's socio-ecological systems have undoubtedly contributed to the pressures that have exacerbated sustainability risks, particularly the recent flood incidents that have become recurrent in the city.

Table 3: A spectrum of changes in the morphology of Kano city

Period	Pre-colonial	Colonial	Postcolonial
Natural	Undulating plains of Sudan savannah vegetation, marked by seasonal rains and dryland drainage system	Undulating plains of Sudan savannah, residual twin hills	People progressively dominate the city's landscapes (wetlands, green areas, open spaces) with flooding as a recurrent and worsening challenge to morphology
Social	City walls; plants, market, mosque, ponds, animal powered transportation (Barth 1857); Stratified society (aristocrats, merchants, clergy, artisans, commoners) each class has unique architecture; Islamic rules of built environment, centralized land tenure	Few motorized and widened roads, animal powered transport; electricity and petroleum as part of urban energy system; civil servants and politicians added to social stratification; western knowledge system introduced.	Roads for motorized transport crisscross the city; merchants, politicians, civil servants, labourers and petty traders and unemployed form the social stratification; techno-based measures applied in solving environmental problems
CHANS perspectives	Semi-natural urban society mainly dependent on nature and indigenous knowledge and skills	A mixture of indigenous rules of the built environment & modern technical measures of problem solving	Engineering and urban planning solutions exclusively applied in top-bottom and fragmented way
References	Barth (1857); Barau (2010); Lubeck (1981); MacBride (1938); Whittlesey (1937)	Liman and Adamu, (2003); Muhammad-Oumar (1997); Nast (1992) Paden (1973)	Ahmed (2010); Barau (2008,2010,2011); Famariyo (1987); Lynch et al. (2001); Maconachie (2007); Orok, (2011)

On one hand, the loss of open spaces and green areas which invariably have played a crucial role in urban flood management are connected to change in institutions of land governance (Figure 4). The change in Kano's land governance architecture was initiated as recently as the late 1970s, but this situation has resulted in rapidly diminishing cultural and ecological values of the urban landscape. With the onset of new demands for modernisation and urban expansion, for example, many ponds, scrublands and farmlands have been lost to new land allocation for various built up land uses.

Figure 4: Spatio-temporal dynamics of land governance in the context of urban morphology change in Kano



In this study, the CHANS framework has proved itself as an important tool to begin understanding the complexity of sustainability, vulnerability and resilience in the context of African urban morphology. Given the non-linear nature of many variables, conventional research paradigms that favour barriers among disciplines are not useful. The relative landscape resilience that has been historically enjoyed in Kano has strong connections to the role of traditional authorities in land management, and the interdisciplinary nature of the CHANS approach has helped the researchers understand how recent changes in architecture, the prevalence of urban agriculture, climate change, urbanisation and modernisation are all linked to flooding events in Kano. It is important to stress, however, that what has underscored the effectiveness of the CHANS framework in this research has been its ability to couple different methods, materials and theories. This, in turn, has played an important part

in helping the researchers to understand how spatial, social, temporal and ecological systems are currently challenging the complex adaptive systems of Kano's urban landscape.

4. Discussions

In re-visiting our three research questions outlined in section 2, in this section we discuss the wider implications and perspectives of the study. An appreciation of the resilience of urban areas in many developing countries depends upon a systematic understanding of the sustainability and vulnerability surrounding them. However, some researchers appear to confuse climate and land use changes in the process of explaining urban vulnerability in Africa (Mosha, 2011). For example, many do not take on board the key role of urban morphology in managing flooding in an era of changing climate (Orok, 2011). This study suggests that in resolving such contentions through the CHANS framework (Figure 2), a better appreciation is needed of the interconnecting linkages between time, space, ecology, economy, morphology and social institutions. A framework that reflects such an understanding is urgently needed in present situations where urban planning is not satisfactory in addressing the complex sustainability problems associated with many African cities (Parnell et al. 2009; Parnell and Simon, 2010).

Thus in returning to our first research question – what role do socio-ecological systems (SES) play in explaining urban morphological change – the SES approach has been central to understanding the complex inter-linked processes that have shaped Kano's urban fabric over the past four decades. Although a number of other studies in northern Nigeria have examined human-nature interactions in the process of environmental change, the complexity of coupled systems has not been well understood particularly in the context of urban areas. However, a recent study on Kano palace gardens (Barau et al. 2013) indicates that a more systematic understanding of the long-time human and nature interface is desirable for understanding wider urban morphology dynamics. The strength of the SES approach, and its operationalization through the CHANS framework, lies in its interdisciplinary capacity to understand problems and solutions in a more integrated manner. In this study, our analysis demonstrates that people and nature interact reciprocally and form complex feedback loops. Moreover, by using CHANS as a guiding framework, our analysis has identified and linked the seemingly fragmented cultural and natural aspects of the dramatic changes in Kano's urban morphology. Simply put, Kano's changing morphology, and increasing susceptibility to flooding events, can best be understood as a process that is inextricably linked to social and cultural factors. Both social and cultural processes have been instrumental forces in a

series of changes to Kano, most notably in urban land governance, the types of materials used for urban architecture, street network patterns and the distribution of green and open space.

There is now a vast body of literature which explores the role that institutional factors play in determining adaptation to environmental change (Adger, 2000; Bakker, 1999). Here, institutions can refer to formal organisations, such as environmental authorities or planning departments, but they may also be understood as informal entities that embody ‘rules, procedures and norms which define roles, rights, responsibilities and guide the social practices of different actors’ (Lebel et al., 2009: 46). Some commentators have pointed out that strong institutions can affect the social distribution of vulnerability and can play a role in determining the capacity of individuals to adapt successfully (Naess et al., 2005: 125-26). But at the same time, weak or dysfunctional institutional arrangements may increase vulnerabilities to environmental events such as floods, making their impacts even worse for the poor. While an extended discussion of the role that institutions can play in enhancing or reducing the vulnerability of communities in the context of urban environmental change is beyond the scope of this paper, our study clearly indicates that they are an important force in shaping urban socio-ecological systems.

Based on the findings of this study, it therefore becomes clear that flood management should not be seen as a physical problem based on ‘techno-fix’ solutions alone. Change in building materials, street morphology, roofing systems, and the distribution of green and open spaces all play a role in changing a city’s resilience over time. For instance, both Table 2 and Figure 3 illustrate how Ordinary Portland Cement (OPC) buildings have replaced the centuries-old adobe architecture of Kano. This is indeed a major change that affects the building characteristics of the city, which most certainly has contributed to evacuating more run-off water into the neighbourhoods from the now less absorbent buildings. The assessment of the changing nature of building materials and their impact on water absorption is beyond the scope of this study. But generally, it is well known that cement plastered buildings are more resistant to water impacts (Garvin, 2005). Further research is needed to assess the retention capacities of adobe and OPC building materials, particularly when they are mixed as commonly found in ancient city of Kano. Such knowledge could help to inform better strategies for mitigating environmental problems and for formulating more effective responses to recurrent flooding.

Similarly, the flat mud roofs of Kano that impressed early visiting Europeans such as Barth (1857) and Lugard (1904) are no longer common. Field investigations and image analysis suggest an overwhelming change in the roofing styles in contemporary Kano. The roofing systems have changed both in their materiality and form. Presently, water resistant roofing materials (metallic sheets, concretes) have replaced the traditional *deleb* palm and mud flat roofs that Sa'ad (1986, 1989) identified with the artistic and historic heritage of Hausaland. Naturally, watertight and slanting roofs reduce rainwater absorption and evaporation from the buildings. At the same time, the slanting roofs drain more water directly into the neighbourhoods.

On the other hand, the data presented in Table 3 further imply that the streets network of Kano has also radically changed over time, as it has been transformed from one of unpaved laterite roads into one of mainly bitumen/asphalt streets. Watson and Adam (2011) stress that impervious road networks discourage runoff contact with more absorptive soils and vegetation. Similarly, Matthew (2011) has argued that this condition of hard surfacing dramatically increases the risk of flooding. This idea is supported by our image analysis, which suggests that the dominance of paved streets in Kano began in the early 1970s. Invariably, the combination of changes witnessed in the architecture, streets morphology, roofing systems and rainfall trends have all contributed in exacerbating floods in Kano.

The 21st century images of Kano indicate that the city is affected by rapid urbanisation and densification. For example, a Google Earth image of 2010 shows a serious decline in the distribution of ponds, open and green spaces in the city. This observation is in sharp contrast with the situation in the 1970s when, as noted by Frishman (1977), there was a fair distribution of ponds in the core of the city and its periphery. For instance, in the 2010 image, the largest pond adjacent to the southern part of the city wall measured 1.5 km², while the size of the now rare ponds in the city core varied from 100m²-500m². By and large, the almost total disappearance of ponds around the city wall in the northern parts of the city presents a different picture of the city's morphology than that portrayed by Dixon Denham's 1826 sketch map of urban Kano (Figure 3). Such images indicate that ponds and open spaces were prevalent to the level described by explorers such as Barth (1857) or other historical researchers (Frishman, 1977; Sa'ad, 1986, 1989 etc). Apart from the declining size and number of city ponds, the images also show a progressive decline in the number of open spaces, confirming the findings of previous studies by Imam (2002).

The sparse distribution of date-palm trees rising above Kano's seemingly flat cityscape can be observed in both old and recent images (Figure 3). However, a comparison of the old and recent images reveals that the greenery observed in 19th and 20th century is all but absent in the recent images. This suggests the disappearance of their associated ecosystem services as well. The absorptive capabilities of vegetation and open spaces in managing flooding are noted by Adam and Watson (2011) and Maiwada (2000) in the context of Kano. The older images analysed, such as the 1980 air-photo mosaic (Figure 3), show that green areas and open spaces were once fairly distributed across the walled city. However, most of these green areas and ponds have now disappeared, as is apparent in the 2010 Google Earth image (see Supplementary Figure).

The analysis of time-sequence imagery, such as that carried out for this study, can be a vital tool for helping researchers and policymakers understand the complexities of African cities. This is perhaps an important first step in the process of identifying and designing more appropriate and sustainable solutions to such challenges. Indeed, understanding the historical interactions of natural and human histories can help researchers to appreciate the genesis of contemporary urban challenges, and this has been influential in other contexts. For example, narratives of the pre-Islamic age in Kano have been an important consideration in the research of Last (1980), particularly in his studies of early settlement patterns in Kano. More recent historical analysis by Barau (2010, 2013) highlights how natural-cultural narratives often fuse into each other, and in turn reshape the urban morphology. This kind of understanding is crucial for policymakers, planners and engineers who would benefit from a better appreciation of how historical processes have left an imprint of the urban morphologies of traditional cities in developing countries.

Closely related to this, our research findings also suggest that it is imperative to place more importance on the history of land tenure and land governance in shaping African urban societies, if meaningful and sustainable solutions to contemporary urban challenges are to be sought. Scholars such as Frishman (1977) have suggested that approximately two-thirds of the walled city of Kano was once constituted by open spaces in the past. It is important to highlight that such lands controlled by the Emir of Kano were traditionally held in trust for the people's needs, to provide food, animal feed and ecosystem services. This practice existed from pre-colonial times through the postcolonial eras, but the favoured collective social and ecological interests faded in 1978, driven by changing land governance structures. Famariyo's (1987) work provides a good illustration of how the 1978 Land Use Act created

grounds for rampant corruption in land allocation and total disregard for the complex interactions embedded in Kano's urban morphology. The author maintains that land allocation for urban agriculture was reduced to barely 1.8%, while public officers acquired over 90% of land allocations. These land allocations are now assigned to previously undeveloped lands including environmentally sensitive areas such as floodplains along the ancient city walls spaces for used for urban gardening (Lynch et al. 2001). This scenario clearly shows that the individual land interests of the rich, public servants and politicians often override the collective interests that benefitted the city for centuries.

In a related vein, it is important to recognise that adequate responses to flooding are critical for safety, security and the well-being of the urban poor. In some parts of urban Kano, flooding has created gully landscapes which constitute a threat to settlements of low-income groups. Flooding induced environmental destruction has resulted in the displacement of thousands of people, has created threats to public health through outbreak of diseases like cholera and the pollution of groundwater sources, and in some cases has resulted in the death of numerous people (Barau, 2008; Adagbada, 2012; Ali, 2012; Shah and Ranghieri, 2012). At present, it is apparent that explicit strategies on how to address flooding in Kano are lacking, and are unconnected to recommendations for best practices identified by international research and policy circles such as the Hyogo framework (Schanze, 2009). Recent efforts by the Kano State government to embark on the channelisation of River Jakara and attempts by both the State and Federal Governments to initiate disaster relief efforts, have not addressed the root challenges of the flooding hazard. In most cases, poor people are left to their fate as such interventions remain insufficient and irrelevant to their needs. Measures designed to address urban flooding in Kano, or other cities in the Global South, should be tailored to a Local Resilient Action Plan (LRAP). This type of plan, which is lacking in Kano at present, has been effectively used in other contexts as an integrated tool for mainstreaming adaptation and resilience plans, in response to a wide variety of disasters in developing countries (Khailani and Parera, 2013).

5. Conclusions

The CHANS framework can provide researchers with an important framework for building insight into the closely-knit relations and interactions of human and natural systems of urban landscapes. The application of the model in the case of Kano, a populous and ancient city in a dryland environment, reveals the significance of employing an interdisciplinary perspective in unravelling the complexities of urban growth challenges in the Global South. While the

city's morphology exhibited resilience to social and demographic pressures for centuries, while maintaining some level of human living comfort and ecological attributes, within a few decades this balance has suffered blows with dire ecological consequences. As has been clearly shown in the analysis presented in this paper, this dramatic shift followed on directly from a series of changes to Kano, most notably in urban land governance, the types of materials used for urban architecture, street network patterns and the distribution of green and open space.

The complexities associated with the case of Kano may be applied to explain scenarios of other traditional cities in Africa and beyond. In both the social and natural sciences, the barriers that maintain rigid borders between disciplines are increasingly breaking down in favour of the integration and sharing of ideas for the benefit of society and sustainability. Thus, socio-ecological systems can provide the space for consensus building among policymakers and scientists, promoting interdisciplinarity and support for decision-making processes that concern complex adaptive system within and around urban areas. This potential should also encourage researchers to explore historical sources of information, which may help in providing rich or new insights into understanding the origin of urban problems and the solutions needed. In many parts of the Global South there are numerous pre-colonial towns and cities that hold large populations, while at the same time maintaining aspects of their traditional morphology and indigenous urban forms. However, the evolution of environmental problems in such towns and cities are rarely understood thoroughly through western planning concepts alone. Hence, this paper suggests that researchers, practitioners and urban policymakers must engage with the past experiences of cities and towns in order to fully understand their dynamics, and to devise effective responses to change in the wake of interactions between natural and human environments.

In the process, however, it also remains important to pay attention to the considerable changes affecting the institutions of governance, culture and their links to natural environmental systems. Although the dynamism of Kano's urban morphology has been praised for centuries, it has more recently undergone significant transformation in the period of just a few decades, largely as a consequence of changes to the system of land administration. The experience of Kano suggests that the sustainability of urban environments in developing countries may therefore be less resilient than anticipated. In addition to this, urban managers must understand that the solutions to environmental crises in cities of the Global South do not merely lie in physical planning alone. Understanding values,

ecological wisdom, culture and indigenous governance systems, and placing them in historical context, is a critical part of meeting the urban challenge in the developing world, both presently and in the years to come.

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