



A spatial econometric approach to examine the determinants of residential land prices and housing affordability: the case of Khartoum, Sudan.

Ahmed Mohamed Adam Ali

A research report submitted to the Faculty of Engineering and The Built Environment, University of the Witwatersrand, to fulfill the requirements for the degree of Master of Urban Studies in the field of Urban Management.

Johannesburg, 2021

Declaration

I, Ahmed Mohamed Adam Ali, declare that this research report is otherwise indicated in my original Research. It is being submitted for the Degree of **Master of Urban Studies in the field of Urban Management** to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

A handwritten signature in black ink, appearing to be 'A. Ali', is written over a horizontal line.

September 7th 2021

Abstract

Housing affordability is one of the most pressing issues of urban development globally, and especially in developing countries. In Sudan, the housing provision system falls in between, land legislation and regulations, socio-economic structure of the society, and the state and private housing finance. This system produced a housing provision tiers based on income groups, high-income (first class), medium-income (second class), and low-income (third class) with land size and construction codes to suit the income levels. On one side, the literature suggests that basic housing is unaffordable for most Sudanese due to high construction costs. On the other side land value further increases the housing cost. The research examined the spatial determinants of residential land prices and the housing affordability index of 18 neighborhoods in Khartoum to explore their effect on Khartoum's physical expansion. To examine the spatial determinants, generally the research employs the Ordinary Least Squares [OLS], a non-spatial global model, and the Geographically Weighted Regression [GWR] spatial regression method for drawing spatial variations across the study area. The main research finding support the literature that suggest a medium-income household cannot afford their designated medium-income housing class, but they can afford the low-income housing class due to insufficient income. The OLS model explained 83% of the variation in residential land prices and 71% of the variations in housing affordability. The GWR on average explained 86% of residential land prices, and explained 90% of the neighborhood's housing affordability variation. However, the visual interpolation of the housing affordability suggest that a medium-income household have to meet their housing need on the periphery of Khartoum city, which create sprawling effect. The regression models indicate that plot prices can be explained depending on the explanatory variables; two models emerged with distance to secondary roads and average distance to the Central Business District [CBD] as mutual variables between both models, and average length of the plot's façade in the first model, while the average distance to police stations in the second model. Housing affordability is determined by the neighborhood class, distance from schools, hospitals, and the CBD. GWR models for plot prices and housing affordability have explained spatial variations by indicating the explanatory variables' weights on the plot prices and the affordability index. This research illustrates the dynamic and interconnected factors that influence land value and housing affordability, the indirect impact of urban planning on distribution of amenities and subsequently land value and housing preferences, how income can influence locational preference of housing and therefore the impact on the physical expansion of the city. The research also elaborate on the interdisciplinary nature of urban studies and how spatial analysis can complement quantitative urban studies.

Key words: Land prices, Housing affordability, Regression analysis.

Dedication

This research is dedicated to my parents, who taught me the most in this life, my brothers and sisters.

Acknowledgments

First and foremost, praises are to Allah, the one, the all mighty, and the maker for the uncountable blessings, for everything I have, for everything I had, and for everything I will have. Praise is to Allah by whose grace good things come to fruition.

Above all, my deepest gratitude goes to my parents Mr. Mohamed Adam Ali & Mrs. Zainab Yassin Mohamed Ali, whom I'm grateful for everything, my brothers and sisters who stood by me during the sweet and sore. No words of gratitude are enough to thank my supervisor Professor Aly Karam who saved no effort in guiding me every step of the way and his precise guidance throughout this research, unceasing encouragement, support, and full attention. I am also grateful to ones who know and who gave me a reason to pursue this research and guide it to See the light.

Sure, I would like to extend my gratitude to faculty staff and course instructors, Namely Prof. Marie Huchzermeyer, Prof. Alison Todes, Ms. Rashika Padarath, Ms. Taki Sithagu Dr. Brian Boshoff, for their outstanding efforts and providing an excellent environment at Wits, even during the unprecedented Covid-19 pandemic.

I'm also grateful to my friends Walaa-Aldeen Hayder, Mohamed Musa, Mojahid Ibrahim, Ahmed Abd-AlWahid, and Malaz Abbashar, Fatima Adil, Razan Abdullatif for their support. As well as my colleagues Walter Semordzi, Samson Faboye, Violet Phiri, Mitchel Sonono.

Special acknowledgment

The words of gratitude are extended to Wits-TUB Urban Lab Interdisciplinary Program's leadership, the principal investigators (Professor Marie Huchzermeyer and Professor Philipp Misselwitz), and the principal coordinator (Ms. Taki Sithagu). I am a beneficiary of the 2020 Wits-TUB scholarship with support and funding from the German Academic Exchange Network (DAAD) and the Federal Ministry for Economic Cooperation and Development (BMZ).

Contents

Declaration.....	I
Abstract.....	II
Dedication.....	III
Acknowledgments.....	IV
Contents.....	V
List of Figures	IX
List of tables	XI
Chapter One: Global and local perspective on urbanization and housing issues	1
Introduction and background	1
Problem Statement and rationale	2
Aim and Objectives	3
Research Questions	3
Main Question	3
Sub-questions.....	3
Highlights on the methods, ethics of sample collection, and limitation	4
Research method	4
Ethics of samples collection	4
Limitations.....	4
Chapter's outline.....	5
Chapter One	5
Chapter Two.....	5
Chapter Three	5
Chapter Four	5
Chapter Five	6
Chapter Two: Navigating the research through the relevant theories, concepts, and methodology	7
Urbanization and housing issues	7
Conceptualizing housing affordability	9
International trends in affordable housing.....	9
The locational theory in housing and econometric analysis.....	12
Residential areas within the urban setting	13

Urban economics and housing prices	14
The literature on spatial econometric analysis of land prices and housing prices	15
Highlights on the econometric analysis literature	18
Conceptual framework	18
Chapter Three: The econometric approach to the research issue and the context of Khartoum city...	20
Methodology.....	20
Concepts.....	21
City expansion.....	21
Spatial analysis	21
Housing Affordability	21
Housing Affordability Index	22
Data acquisition	22
Analysis procedure.....	23
Measuring affordability.....	24
Spatial analysiss	25
Ordinary Least Square.....	25
Geographically Weighted Regression	26
Spatial Interpolation	24
Urbanization and housing affordability in Khartoum	27
Demographics	27
Socio-economic and access to finance housing.....	28
Urbanization and housing system in Khartoum.....	29
Housing within Khartoum’s master plans.....	31
McLean 1912.....	31
Doxiadis 1960 and MEFIT 1975.....	32
The period from 1975 to 1990.....	34
Doxiadis and Mustafa 1990 – 2000.....	35
The master plan 2000 – 2007	37
The Structural plan 2007-2033	37
Land prices and housing affordability.....	38
Conclusion.....	40
Chapter Four: The preliminary findings: Discussing the determinants of residential land prices and housing affordability in the context of Khartoum expansion	41

Fieldwork and data collection	41
Data preparation	43
Descriptive statistics	44
Derivation of housing affordability index and the interpolation analysis	46
Housing affordability index findings	47
Regression analysis	49
Regression analysis of residential land prices.....	51
Exploratory regression	51
Ordinary Least Squares	53
OLS for the first set of variables.....	54
OLS for the second set of variables.....	54
Geographical Weighted Regression.....	55
Visualization of Geographical Weighted Regression model for land prices	57
Regression analysis of housing affordability.....	61
Exploratory regression	61
Ordinary Least Squares	62
Geographical Weighted Regression.....	64
Discussion of the findings	70
Similarities and differences.....	70
Modeling methods.....	70
Modeling residential land prices.....	70
The state of housing affordability.....	71
Modeling housing affordability with regression and interpolation	71
Analysis summary	71
Conclusion.....	75
Chapter Five: Conclusion and recommendations	77
Summary of the key findings	77
Housing affordability and the city expansion	77
The determinants of residential land prices	78
The determinants of housing affordability	78
Housing affordability between regression analysis and spatial interpolation	79
Limitations of the research	80
Data and sample	80

Analysis results.....	80
Recommendations	81
Acknowledging the expanding city	81
Normalizing land prices and housing affordability spatially	81
Sprawl modeling and future planning.....	82
References	83
Appendix.....	97
Appendix A: Attribute tables of a neighborhood sample.	97
Appendix B: Neighbourhoods attribute tables with dependent and explanatory variables.....	98
Appendix C: Variables' abbreviations.	98
Appendix D: Exploratory regression model criterion	99
Appendix E: The first GWR summary of results for the residential land prices.....	99
Appendix F: The second GWR summary of results for the residential land prices.	100
Appendix G: The GWR summary of results for housing affordability.....	100
Appendix I: Plagiarism declaration.	102

List of Figures

Figure 1 Conceptual framework (Source: Author's Own 2020).....	19
Figure 2 The map shows the places of interest for the analysis and the neighborhoods representing the sample (Source: Author's Own 2020).	22
Figure 3 Research steps (Source: Author's Own 2020).....	23
Figure 4 The map shows Khartoum's context regarding land use with the sampled neighborhoods (Source: author's own 2020).....	27
Figure 5 McLean's 1912 Plan for Khartoum (Source: Hamid and Bahreldin 2013).	32
Figure 6 Doxiadis's 1960 Plan for Greater Khartoum (Source: Habitat 2009).	33
Figure 7 MEFIT's 1975 Plan for Greater Khartoum (Source: Habitat 2009).....	34
Figure 8 Squatter settlements around Khartoum in the 1980s (Source: HABITAT 2009).	35
Figure 9 Doxiadis and Mustafa 1990 – 2000 (Source: Zuhail 2016).	36
Figure 10 The structural plan 2000-2007 (Source: Hamid and Bahreldin 2013).	37
Figure 11 Khartoum Structural Plan 2007-2033 (Source: Ministry of Physical Planning and Development 2010).	38
Figure 12 Data description (Source: Author's Own 2021).	42
Figure 13 Average residential land price, Construction Cost, and the total housing cost (Source: Author's Own 2020).....	44
Figure 14 Housing affordability index per neighborhood (Source: Author's Own 2020).	47
Figure 15 Interpolation surface for housing affordability of Khartoum (Source: Author's Own 2020).....	48
Figure 16 shows the spatial analysis and regression procedure (Source: Author's Own 2020).....	51
Figure 17 Exploratory regression summary of results for residential land prices (Source: Author's Own 2020).	52
Figure 18 Shows the diagnostics for the first OLS model of land prices (Source: Author's Own 2020).....	54
Figure 19 OLS report for the first ER model of residential land prices (Source: Author's Own 2020).	54
Figure 20 Diagnostics for the second OLS model of residential land prices (Source: Author's Own 2020).	55
Figure 21 OLS report for the second ER model of residential land prices (Source: Author's Own 2020). .	55
Figure 22 The map shows the local variations in R^2 values of the first GWR Model for plot prices (Source: Author's Own 2020).	57
Figure 23 The map shows the coefficients of the average distance to secondary roads from the second GWR model for plot prices (Source: Author's Own 2020).	58
Figure 24 The map shows the coefficients of the average distance to the CBD from the GWR second model for plot prices (Source: Author's Own 2020).	59
Figure 25 The map shows the coefficients of the average length of the plot façade from the second GWR model for plot prices (Source: Author's Own 2020).	60
Figure 26 Summary of Exploratory regression for HAI (Source: Author's Own 2020).	61
Figure 27 OLS diagnostics for HAI model (Source: Author's Own 2020).	63
Figure 28 Results summary for OLS model for HAI (Source: Author's Own 2020).	63
Figure 29 The map shows the local variations in R^2 values of the GWR model for the HAI (Source: Author's own 2020).	65

Figure 30 The map shows the neighborhood class's coefficients From the GWR model for housing affordability (Source: Author's Own 2020).	66
Figure 31 The map shows the coefficients for the average distance to schools of the GWR model for housing affordability (Source: Author's Own 2020).	67
Figure 32 The map shows the coefficients of the average distance to hospitals from the GWR model for housing affordability (Source: Author's Own 2020).	68
Figure 33 The map shows the coefficients for the average distance to primary roads of the GWR model for housing affordability (Source: Author's Own 2020).	69
Figure 34 shows the difference in coefficients for the average distance to secondary roads for Plot Prices GWR models (Source: Author's Own 2020).	72
Figure 35 The figure shows the difference in coefficients for the average distance to the CBD for plot prices GWR models (Source: Author's Own 2020).	73
Figure 36 Housing affordability surface of greater Khartoum (Source: Author's Own 2020).	74
Figure 37 Average residential land price, construction cost, and the total housing cost (Source: Author's Own 2020).	75

List of tables

Table 1 shows the housing classes and building specifications (Source: Pantuliano et al., 2011).	43
Table 2 Descriptive statistics for the Sampled residential land prices (Source: Author's Own 2020).....	45
Table 3 Descriptive Statistics for the explanatory variables (Source: Author's Own 2020).	46
Table 4 OLS diagnostics.....	49
Table 5 GWR diagnostics.....	50
Table 6 Summary of exploratory regression variable significance for plot prices (Source: Author's Own 2020).	53
Table 7 Summary of GWR models diagnostics (Source: Author's Own 2020).....	56
Table 8 Summary of the Variable Significance for the exploratory regression of the HAI (Source: Author's Own 2020).....	61
Table 9 Summary of the GWR model diagnostics for the HAI (Source: Author's Own 2020).	64

Chapter One: Global and local perspective on urbanization and housing issues

Chapter One sets the stage for the research's theoretical scope, problem, and rationale, the research questions, and provides brief highlights on the research method and the limitations encountered throughout the research. This chapter is divided into seven sections: the first reviews urbanization globally, regional, and locally to the study area with a background of the study area where the research issue is articulated. The second section deals with scoping the research problem and provides the rationale for this research. The third section presents the research aim and objectives, which leads to the research questions in section four. Section five gives a highlight on the research limitations and ethical considerations adhered to throughout the research stages. The final section describes the structure of the research report.

Introduction and background

According to the United Nations Department of Economic and Social Affairs report [UN-DESA] (2019), 55.3% of the world population lives in urban settlements. By 2030, urban areas are projected to house 60% of the people worldwide. Moreno (2016) states that cities account for 80% of the Gross Domestic Product [GDP] globally due to innovation, trade, and production by providing a mixture of formality and informality that generates opportunities for the public and private sector. The distinction between urbanization and sprawl or squatter settlements that drive a city expansion is crucial for developing a profound understanding of the urban boundary. This distinction helps plan for the future by tackling the conventional planning approaches to implement the New Urban Agenda [NUA] on housing. Africa's urban population grew at a high rate, from about 27% in 1950 to 40% in 2015, and is projected to reach 60% by 2050 (Teye, 2018). Urbanization demands a housing approach that accommodates the increasing populations with service and infrastructure to avoid future ramifications.

Habitat III (2016) stresses the issue of housing and land consumption by urbanization, where housing provision consumes more than 70% of the urban land use globally. Housing also shapes the urban form and stimulates agglomeration economies. Tipple and Alemayehu (2014) highlight the lack of knowledge about the spatial patterns affecting housing markets. It demands in-country or city-level intervention in Sub-Saharan Africa to inform affordable housing provision, rapid population, and informal settlements.

In the Republic of Sudan, rapid, unorganized, and unregulated urban growth is becoming the norm, as many scholars confirmed (Eltayeb 2003; Hafazalla 2006; Choplin and Franck 2010; Elagib 2011; ELKHEIR 2012; Mohammed and Alawad 2015; Steel et al., 2020). From the Anglo-Egyptian colonial government in 1898 till independence in 1956, Sudan's successive governments introduced several policies and plans that respond to the different issues associated with population growth and economic development. Provision of enough land for all urban activities and investments related to housing, retail, business, industry, and other uses is crucial in urban planning (Habitat, 2009). Sudan's housing approach is of two-tier systems, market-based sites and services, and a government-focused approach that spanned from independence to the present. According to Feather and Meme (2019), the housing market responded to

the demand of three income-groups, lump-sum purchases for the high-income households, mortgages for the employed medium-income households, and the low volume of microloans allows few low-income households to access microfinance credit to finance housing. In Khartoum, the housing policy and practice affect the city's expansion by pushing the low-income housing provision to peripheries.

The conventional approach that households prefer is constructing their own home due to the high construction costs (Feather and Meme, 2019). Onour (2017) indicates that the lack of effective oversight on the informal currency exchange limits the government's ability to maintain a steady and satisfactory exchange rate, and therefore destabilize the construction industry and make it expensive for low-income households with no access to microloan mortgages. The property speculator opts to purchase land, develop it, then sell it on the market to sustain their profits. Land prices increased due to land commodification and segregated the urban land based on affordability (Steel et al., 2020). As a result, the market excluded the low-income to the peripheries and to own land near areas of proper serviced areas which is too expensive. Land commodification with the increasing construction costs complicated access to housing for the medium and low-income households (Feather and Meme, 2019; Steel et al., 2020). Despite the government's efforts to provide public affordable housing, the issue of housing cost (land and construction) makes it harder for the medium and low-income to attain their housing needs.

Khartoum's housing issues are widely addressed throughout the literature on urban development suggesting different approaches to solving the problem. The literature discussed policy analysis (Hafazallah 2006; Habitat 2009), market-based analysis (Hamid and Elhassan 2014), housing finance (Ahmad et al., 2002; Elhadary and Ali 2017; Feather and Meme 2019), and socio-cultural change (Eltahir., 2005; Ibrahim et al., 2020). However, the spatial determinants of land prices have not been investigated. Housing policy has pushed Khartoum's limits by creating low-density for the medium and low-income housing and coupled with insufficient infrastructure, sanitation, education, and health services (Habitat 2009).

Problem Statement and rationale

On the one hand, 34.1% of homes in Khartoum are single-floor houses, and 80% of Sudanese households are landowners. This indicates a higher land consumption of land than multi-floor dwellings, reducing cities' density and, therefore, leads to expansion to meet the growing demand (Sudan and UNICEF 2016). Housing policy has pushed Khartoum's limits by creating low-density for low-income households and coupled with insufficient infrastructure, sanitation, education, and health services (Habitat 2009). Elzobier's (2009) article highlighted the increasing land and housing prices in Khartoum, suggesting what was causing this increase.

From the literature on housing issues in Sudan, affordable housing is bound by direct and indirect forces. The unofficial exchange market highly influences the cost of construction materials, which is more flexible and offers higher rates compared to the official market. Land and real estate market are also influenced by the unofficial exchange rate, Elzobier (2009) mentioned that rentals and property markets in Khartoum favored oil companies and UN agencies operating in Sudan who pay in US Dollars. This trend extended to land sales and prices estimates were rated in US Dollars per square meter, prices in Khartoum center ranges between 750\$ to 2000\$ per square meter, these prices are subject to the level of services,

proximity to amenities, and the CBD (ibid). Commodification of land is another reason for increasing land prices through land speculation for profit (Steel et al., 2020). Higher construction cost and land prices has left many of residential plots undeveloped, and housing unaffordable for medium and low-income.

Elzobier (2009) nor the literature on housing in Sudan explained the spatial determinants of residential land prices and housing affordability and how these dynamics influence the physical expansion of Khartoum. However, there is a need to investigate the spatial determinants of residential land prices and housing affordability, and how housing affordability influence the physical expansion of Khartoum city.

Aim and Objectives

The research aims to build on the knowledge established in the literature that urban planning in Khartoum falls short on dealing with land prices, housing provision, and affordability issues. The approach to objectives is to investigate the spatial determinants of residential land prices and housing affordability, and their impact on Khartoum's expansion. To this end, the research looks into dissecting the spatial determinants of residential land prices and housing affordability using spatial analysis techniques to emphasize the impact of housing affordability on Khartoum's physical expansion. The objectives of this research are as follows:

- Illustrate how housing affordability in Khartoum's sampled neighborhoods can be used to look at Khartoum's physical expansion using regression analysis (spatial) and spatial interpolation.
- Explore residential land prices' determinants using the residential land's characteristics, the average distances to central amenities, primary and secondary mobility networks, and local services.
- Explore housing affordability determinants using the residential land's characteristics, the average distances to central amenities, primary and secondary mobility networks, and local services.
- Illustrate how housing affordability can be explained differently depending on the spatial analysis method.

Research Questions

The research question contextualizes the problem statement to achieve the research objective and fulfill its aim, and this research has a single main question and three sub-questions. The main question and sub-question respond in sequence to the research objectives.

Main Question

How does housing affordability affect the physical expansion of Khartoum city?

Sub-questions

- How the residential land characteristics, the average distances to the central amenities, main mobility networks, and local services affect plot prices?
- How the residential land characteristics, the average distances to the central amenities, main mobility networks, and local services affect housing affordability?
- How can housing affordability be explained differently using regression modeling and spatial interpolation?

Highlights on the methods, ethics of sample collection, and limitation

This section briefly summarizes the research method, the ethical consideration adhered to throughout the research, and the limitations of these ethical considerations.

Research method

The research adopts a quantitative approach built upon primary sample data in the form of residential land price and construction cost estimations collected from real estate agencies and contractors in Khartoum. The secondary data collected from reports, geographical data used for the spatial analysis.

Modeling residential land prices and housing affordability on a city level requires a comprehensive modeling approach, which takes in consideration the spatial heterogeneity of the urban. The science behind the research issue, method and concept is Tobler's First Law of Geography, which exemplifies the complexity of spatial relationships based on distance and spatial proximity. This principle is used in this research to identify the determinants of a sampled residential land prices, derived housing affordability from the sampled neighbourhoods, and deriving the spatial pattern of housing affordability. Ordinary Least Squares OLS and GWR modeling techniques are used to investigate these relationships. For deriving the spatial pattern of housing affordability, ¹Kriging interpolation will be used to generate a continuous affordability surface and highlight the change in affordability through space. The method collectively meets the objective requirements and employs mixed analysis for better explanation of the research issues.

Ethics of samples collection

University of the Witwatersrand's Ethics Committee is keen on the ethical aspects of research that involve interactions with fellow humans, especially protecting the researcher and participant's interest and ensuring no conflicts of interest occur during data collection and sharing the research results. To this end, an ethics clearance is mandatory before proceeding to the fieldwork and data collection. Therefore, an application to the School's Ethics Committee was made to obtain the ethics clearance. The clearance was awarded for obtaining estimations of residential land prices and construction costs from real-estate agencies and contractors. It is imperative to mention that there are no conflicts of interest to any of the parties involved or the researcher. The data used in this research are single-stage samples of estimated residential land prices and construction costs (price in US Dollar per square meter of land) obtained from real-estate agencies in Khartoum, Sudan.

Limitations

Throughout the commencement of any research work, various limitations face the research's during their work which is not about time and resources availability alone. Firstly, time was essential from the start, as the researcher was a full-time student and had to coordinate the coursework's presentations, assignments, and exams. Between the end of March 2020 and April 2020, most countries went into

¹ Kriging is the most commonly used interpolation technique to generate a continuous surface of unknown value from existing known values based on the change in value with distance. Usually, Kriging result are validated using different spatial interpolation techniques, validation in this case has not been performed for the purpose of using interpolation stated. More details about the Kriging are provided in chapter three.

lockdown due to the Covid-19 breakout, including Johannesburg, South Africa, and Khartoum, Sudan. International travel was banned in both countries during the lockdown, which affected the entire fieldwork. The researcher had to collect the samples remotely. This situation limited the researcher to collect more samples from the study area.

Secondly, the data collection instrument changed from fieldwork to obtaining the samples by sending out maps of the targeted neighborhoods to the real-estate agencies. This method was a result of two factors related to the Covid-19 lockdown. Travel was banned and reduced the risk of having a third party collect the sample from the field, which limited the number of the sampled neighborhoods to 18 neighborhoods due to time and availability constraints.

Chapter's outline

The research report is structured in five chapters described below. The first chapter complements as an introduction to the study setting out the broad scope and field, introduces the research aim, objective, and questions. This section describes the document chapters briefly.

Chapter One

Chapter One serve as introduction the research context and issue through scoping the global context of urbanization and how housing issues fit within urbanization to formulate the research problem, aim, objectives and questions. This chapter is titled 'Global and local perspectives on urbanization and housing issues. The chapter concludes with highlights on the research method, ethics, and limitations.

Chapter Two

Chapter two is titled 'Navigating the research through the relevant theories, concepts, and methodology'. It provides the concepts to frame the research, reviews the urbanization and housing issues from a global perspective, the locational theory in housing, and econometric analysis of land prices and housing. A chronological review of the literature and case studies about econometric and spatial analysis of residential land prices and housing costs is also provided. The chapter concludes with the conceptual framework for this research which is derived from the literature.

Chapter Three

Chapter three is titled 'The econometric approach to the research issue and the context of Khartoum city'; this chapter has two main sections. The first section dissects the research method and provides the techniques used to model residential land prices and housing affordability and provide the housing affordability's interpolation surface. The second section introduces the Khartoum context in terms of demography, socio-economic and access to housing finance, the state of housing in Khartoum's master plans, and land prices and housing affordability.

Chapter Four

Chapter four is titled 'The preliminary findings: Discussing the determinants of residential land prices and housing affordability in the context of Khartoum expansion'. This chapter consists of two parts. This

chapter is divided into two main parts. The first part is divided into two sections: the first section introduces the fieldwork and data collection, consisting of data preparation and descriptive statistics. The second section deals with preparing the residential land prices models, housing affordability, calculating the housing affordability index, and using the interpolation to generate the continuous surface for housing affordability and present the findings. The second part of this chapter consists of two sections. The first section presents the data analysis derived from the OLS, GWR regression models, and the HAI findings' spatial interpolation compared to the literature. The second section concludes with a summary of the findings and analysis presented and leads to the report's conclusion.

Chapter Five

Chapter five titled 'conclusion and recommendations' provide the link between the research chapters to summarize the research report by answering the research questions, responding to the research objectives, and achieving the research aim. They provide recommendations derived from the findings and analysis and conclude with the research limitations to summarize the report.

Chapter Two: Navigating the research through the relevant theories, concepts, and methodology

This chapter consists of two main sections. The first deals with broad concepts to frame the study's scope: urbanization and housing affordability in terms of agendas and trends internationally and within the context of the study area. The second section from theoretical perspective deals with the locational aspects that affect housing affordability and pricing in urban planning and economic impacts and econometric modeling applications from a wide-range of literature.

Urbanization and housing issues

The global population growth and urbanization are accelerating at a fast rate. The inequality index is growing, especially in Sub-Saharan Africa (Sulemana et al., 2019). Tipple and Alemayehu (2014) stated that population growth and urbanization are transforming Sub-Saharan Africa [SSA], and despite the low urbanization rates in Africa and Asia, the urban population proliferates. According to UNDESA (2019), 55.3% of the global population lived in cities in 2018. By 2030, urban areas are projected to house 60% of the population globally (Ritchie and Roser 2018). Van Doorn et al., (2019) suggest that cities are the source of and solution to the socio-economic and environmental challenges, featuring sustainable, affordable housing as one of the most critical issues facing cities. However, international organizations such as the UN-Habitat and the World Bank advocate for creating frameworks emphasizing the principles of the Sustainable Development Goals [SDGs], the 11th goal which is about creating sustainable cities and communities to guide the built-environment policies. Access, adequacy, safety, and affordability of housing and essential services and slum upgrades are the pillars of target 11.1 (Habitat III 2016).

The literature on the relationship between urbanization and housing recognizes housing and affordability's unprecedented challenges due to population growth, socioeconomic realities, and rapid urbanization. The United Nations Program on Human Settlement [UN-Habitat] is a major international agency concerned with human settlements to promote the sustainable development of the built environments in terms of the economy, society, and the environment (Staff 2003). However, socioeconomic, environmental sustainability, and adequate-affordable housing are inseparable, and adequate housing is bound with policy, economic, and legal burdens that correspond the achievement of other SDGs targets. Housing affordability comes as the third dimension of the housing policy framework of the United Nations agenda on housing (Habitat 2015).

The mid-1990s marked the emergence of the international frameworks for urban development. The United Nations agencies initiated the NUA in Habitat Agenda 1996, Urban Agenda 21 in 2000, and the Millennium Deceleration on Cities in 2001. Globally, population growth and urbanization stand out as the order of the century; according to UNDESA (2019), the world population increased by 200 million between 2015 and 2017, from 7.4 to 7.6 billion in developing countries.

UNDESA (2019) suggests that the global urban population increased exceeded four-folds from the 1950s to 2018, which averaged a 2.54% annual increase in 2018, from total urbanized 30% in 1950 to 55% in 2018, and 68% urbanized projected by 2050. Regionally, Northern America is 82% urbanized, followed by Latin American and the Caribbean by 81%, Europe 74% urbanized, and Oceania 68% (ibid).

China and India alone are about half of the world's population. The two countries are experiencing growth in population, urbanization, and socioeconomic status, requiring governments' efforts to provide services and housing to accommodate the growing population (Chauvin et al., 2017). Sub-Saharan Africa was recognized as the fastest urbanizing region, with 472 million in 2018 and 944 million projected in 2043 (Saghir and Santoro 2018). Urbanization is positively linked to economic development, and the 143 SSA cities account for 50% of the regional GDP (ibid).

The bulk increase of population globally urged the need to prioritize adequate and affordable housing (Habitat III, 2016). Assembly (2016) estimated that 13% of the world's cities have fair, affordable housing. King et al., (2017) estimated 330 million households globally would live in inadequate accommodation, projected to increase to 440 million (1.6 billion people) in 2025 and 2.5 billion people by 2050.

Addressing the housing deficit within the projected population growth coupled and the economic constraints pose one of the most significant challenges governments face (Habitat III 2016). However, there is an urgent need for a competent and diligent response to deal with housing and the growing population and inequality. Habitat (2015) framed the challenges, priorities, and implementation mechanisms as guidance for housing policy development to ensure the delivery of adequate housing into four elements:

- a. Accessibility to essential services: the term adequate housing implies a satisfactory and equal access level to water and sanitation in urban and rural contexts and energy and waste disposal to reduce informal settlements' occupancy.
- b. Habitability: refers to the tolerable state of housing, which the subject of proper building codes, zoning, and regulatory framework that shape the household to be protective from natural conditions, hazards, and diseases to ensure the safety and well-being of the occupants.
- c. Affordability: affordability refers to the costs of affording to own or rent a house and living expenses. Affordability involves collaborative efforts between government, communities, developers, and investors to account for households' income, expenditure, and housing costs.
- d. Security of tenure: tenure security refers to the legal rights to property ownership and compliance to legislation through the different means of property ownership to ensure protection from threats to tenure. To the effect mentioned above, tenure security implies access to use, land, and property control.

Seto et al., (2013) identified five global trends in urbanization, one of which articulate land consumption for urban uses for population and suggest most of the growth will occur in areas of limited economic development and institutional capacities. From another perspective, Seto et al., (2013) argue that urban areas are expanding more than urban populations. The authors featured the United Nations projections that the urban population will double or increase to 70% or 6.3 billion between 1900 to 2050.

Roy (2009) points to the struggles of mega-cities using Bangalore, India; despite the massive infrastructure projects, planning is facing immense growth and urbanization that outpace planning and the lack of future-proof planning to accommodate the unpredicted growth. The new Bangalore airport, which reflects that political intervention and privatization in planning at the expense of housing and services, is part of the problem. The leading countries in urbanization and economic growth, such as China and India,

have developed housing policies that feature economic growth through optimum housing planning and maintain affordability (Cheng et al., 2014).

Gabay and Ilcan (2018) suggested despite the SDG 11 and MDG 7-11 goals and their targets, hundreds of millions of households are still excluded from accessing adequate, affordable housing and essential services. Realizing universal access to housing requires examining the core housing policy documents normalized through neoliberalism to de-commodify basic needs such as housing (ibid).

Conceptualizing housing affordability

The broad concepts of affordability refer to the overall household expenses compared to income. Habitat (2015) emphasizes that affordability should not affect households' needs. Menon et al., (2019) suggest four components to make sense of financial housing affordability, two elements relate to the cost of buying a house, the others about keeping the house. The cost of purchasing a home involves house purchase price such as land, infrastructure, building materials, labor, and the lender's profit, and financing down payment of the house, including savings, debt, and loan amounts. The cost of keeping the house has two components; the first is house occupation cost which is about the land lease, home insurance, property tax, rent, and maintenance cost. And the second is the ability to finance service loans such as the loan interest rates, tenure, income, and non-housing expenses (Habitat 2015). In the matter of challenges facing housing affordability, Menon et al., (2019:8) identified a broad spectrum of challenges:

- a. The disproportionality between housing prices and income.
- b. The gap between affordable house demand and supply.
- c. The scarcity of land suitable for affordable housing.
- d. Demographic challenges include household size, population growth, an aging population (low-income senior citizens) which adds to the housing demand.
- e. Energy poverty, which means the high cost of energy to low-income households.

Menon et al., (2019:9) state that '*There is no universal standard for affordable housing because ideas differ by region and culture in regards to household's income..., capacity..., energy costs..., providers..., housing tenure..., occupation..., formality*'. Hafazalla (2006) discussed households' socioeconomic characteristics with financial ability to own a house as an aspect of the housing supply, emphasizing low-income housing as a global concern in housing policy.

International trends in affordable housing

The challenges identified in the policy paper by Habitat (2015), speaks to accessibility, equity, and fairness to affordable housing, has been further elaborated in (Menon et al., 2019). A significant challenge is recognizing adequate housing as a constitutional right backed with legislation, provision, and managing institutions. The majority of countries formed policies geared to adequate housing but not constitutional rights. In South Africa, the right to housing is articulated in chapter two, section 26 of the constitution; Canada enforced the right to housing as a law in July 2019. In the USA, the right to housing varies with states and jurisdictions.

The challenges above address housing adequacy and affordability at the national government level, providing constitutional grounds for developing housing policies and regulations. The local government's

role in developed and developing countries regarding housing provision considering decentralization and the distribution of powers and responsibilities between national and local governments is another challenge.

Various finance options are crucial to different types of housing, such as social housing, rentals, and self-help housing. A cross-subsidy mechanism between commercial and housing land uses and low-cost, and high-cost housing encourages mixed development (Habitat 2011). Various and integrated infrastructure types in planning and design will allow for fast growth and future upgrades (ibid).

According to Habitat (2011), to achieve adequate and sustainable housing, governance and management of housing should ensure adherence to regulation, planning, and implementation frameworks in the following:

- a. Tenure systems: a continuum of tenure systems to secure ownership rights², ensure household welfare, and consider social minorities and the vulnerable.
- b. Governance: Inclusivity and government autonomy empower local communities to manage and upgrade housing through an integrated partnership between owners, tenants, and local improvement committees.
- c. Management and maintenance: Can provide local communities with a regular income for low-income communities and strengthen the sense of belongingness.

From a financial and investment perspective, property and real estate markets can provide a fertile ground for investment and employment opportunities (Menon et al., 2019). However, tackling housing affordability issues requires short-term fixes on long-term strategies addressing the pressing issues, including public and private sectors, supply and demand in housing markets (ibid).

World Economic Forum identified four issues on housing supply, which are in alignment with what Habitat (2011) defined in terms of policy at the city level; Menon et al., (2019:6) identified the following to tackle housing affordability issues:

- a. Land acquisition and title: the legality of land suitable for investment in housing is crucial. Land acquisition strategies such as land-pooling of undeveloped land, property rights formalizing rights rather than evictions, and community partnerships with land trusts can utilize property on behalf of the community.
- b. Land use: government uses zoning and regulations to steer development and housing; the World Economic Forum suggests strategies such as expanding development along with transport networks and infrastructure Transit-Oriented Development [TOD], zoning that will increase community vibrancy and encourage developers, integrated mixed-use development based on proximity to jobs and services, shift taxation from property to the land value and include taxes on vacant lands.
- c. Secure finance: as investors beginning to see affordable housing as a low-risk investment, and provide opportunities for workers in public service, increase profit for the private sector. The

² Secure tenure protects ownership rights by protecting the residents against forced evictions or arrange for sufficient compensation to residents when eviction occur.

world economic Forum suggests alternative funding for housing, such as giving tax incentives and grants or exemption for private developers. Create government-bonds providing affordable and long-term finance to a community-based organization to develop and manage affordable housing. And implement investment models such as real estate investment funds, Islamic finance, and impact investing. The Islamic approach to securing finance is based on the principle of structuring mortgages on non-interest contracts called "*Murabaha*." The lender and the borrower agree on the cost-plus profit paid in packages set as part of the agreement. This arrangement reduces the risk associated with interest-based lending and does not inflate the original paid amount, and creates a future obligation.

- d. Design and construction: as far as construction and design, the land is often the highest cost in housing, but sometimes construction exceeds the land cost; World Economic Forum suggests reducing bureaucracy such as administrative fees and expenses to comply with building and zoning codes, apply technology to construction such as the Internet of Things and Artificial intelligence, alternative and low-cost building materials, and Public-Private Partnerships [PPP] for capacity building in the construction sector.

On the demand side of the housing market, Menon et al., (2019) suggest strategies to increase affordable housing access that target the society's most vulnerable. In contrast, including a different form of tenure into housing options, regulating rent costs and considering future supply, and considering subsidy risks in the short and long term.

To conclude, Menon et al., (2019) suggest that to deliver affordable housing effectively, strategies on both side of the housing market should consider the following:

- Local governments should consider and define long-term housing supply strategies that balance the need and supply to reduce urban sprawl using density, include the political dynamics that might affect housing and development. Ensuring housing development has adequate infrastructure improves the quality of life and provides regulatory ground for private and non-profit sectors.
- The private sector should utilize innovation and technology in building, designing, and working with the government to provide skilled labor and consider solutions in finance and tenure models.
- Non-profits and community-based organizations such as land trust, housing cooperative, and microfinance institutions have an essential role in bridging the gap between the private sector and the government to improve housing affordability and increase awareness around housing options for the public.

The insight report by Menon et al., (2019) has set the guidelines for fixing affordable housing delivery globally before population growth and income gap growth. Australia, Canada, China (Hong Kong), Ireland, New Zealand, Singapore, the UK, and the USA have the most critical housing markets (Hikichi et al., 2020). The survey aimed to contrast housing affordability data to Singapore's context during the last 60 years. Singapore had the worst slum housing back in the early 20th century. With scarce land and a growing population, Singapore faced one of the biggest challenges in providing housing.

Singapore established the Housing Development Board [HDB] in 1960 to ensure the delivery of affordable housing. Homeownership is the cornerstone of the HDB policy to encourage the household's work ethics to maintain their homes (ibid). Singapore housing policy reflects the World Economic Forum (2019) guidelines, emphasizing land acquisition and tenure, secure finance, and design and construction to deliver affordable housing. In contrast, Hikichi et al., (2020) survey ranked the least affordable major housing markets due to finance and land issues; Australia, New Zealand, and China are the least affordable housing markets.

According to Habitat (2011), the provision of affordable land and housing remains a challenge to most countries, especially in Africa, and adequate housing is unaffordable for most of Africa's urban population. Financial access to land, secure tenure constraints, and underdeveloped financing framework stand as the major obstacles to affordable housing in Africa (Habitat, 2011). North Africa improved affordable housing and slum upgrading, but it is insufficient to cope with the growing informality. Except for Ethiopia and South Africa, compared to SSA, there is no affordable housing, wherein the latter, housing programs do not exist or not affordable and insufficient (ibid).

To bridge the housing gap in Africa, government agencies, specialized institutions, and financial bodies are engaged in housing and finance (Habitat 2011). Many case studies reflect on the issues of land tenure and cross-subsidy finance as the pillars of affordable housing programs (Pillay and Naudé 2006) South Africa, (Hjort and Widén 2015) Ethiopia, (Pomeroy 2018) Canada, (Chen and Deng 2014), China, (Austin et al., 2014, Yates 2016) New Zealand and Australia, and (Mulliner and Maliene 2011) in the UK.

As land value is a central concern for policy development to ensure affordable housing, it is essential to consider the setting within which housing occurs. The locational theory in housing applications looks at the factors affecting land value and affecting housing affordability.

The locational theory in housing and econometric analysis

The book *Residential Location Choice: Models and Applications* by (Pagliara et al., 2010) build on Evans (1973, 2008) to theorize residential location choice. According to Pagliara et al., (2010), residential location modeling lies at the heart of contemporary social sciences to cope with the rate of change and utilize prediction to benefit effective planning. Practical planning demands “*What if?*” forecasting capability is available using computer models since the urban elements are complex. Brueckner (1987:82-829) illustrated the residential location choice using different models. The first is ‘*Intracity analysis*’ which looks at commuting to a CBD job along dense radial roads. The second is ‘*Comparative static analysis*’ which assumes similarity invariant spatial structures to draw accurate predictions for preferences. The third is ‘*The close-city case*’ which focuses on one city to measure the change in the parameters affecting the housing preferences across the city. This model looks at the shift in preference caused by the difference in housing parameters. The fourth model, ‘*The open-city case*’ uses an observable parameter to derive the analysis of location preferences (Brueckner 1987:30-37).

The models explained by Brueckner (1987) are built on the assumption that cities are monocentric and did not include polycentric cities with secondary employment centers besides the CBD. However, the suburbanization of jobs can lead to change in other facets such as commuting time and access to services. Recently, economists have suggested that residential location is determined by income, commuting time,

and workplace destination (Lee et al., 2010). Arguably, there is an interchangeable effect between the economy and urban planning when analyzing urban phenomena such as housing. This effect, perhaps, can be contextualized when addressing the different subjects within the urban realm. The interrelation between different aspects of the urban realm necessitates comprehensiveness in analyzing the urban problems.

According to Evans (2008), the USA and UK's approaches to urban problems are based upon two opposing views from the economic and the urban planning perspectives. On the one hand, the economical solution to the urban problem advocates addressing the urban economy's supply-demand through econometric modeling. On the other hand, urban and town planning practitioners can solve urban challenges through complete and autonomous planning regulation and practice control.

Evans (2008) suggested that future private land-use is to be determined by market forces; this approach necessitates economists and other social scientists to model the residential location choice. Within this context, housing preferences are dynamic, based on activities and changing circumstances that can be measured and analyzed. The econometric analysis relies on metricizing how income, commuting time, and life-style can determine their housing location.

Residential areas within the urban setting

Ratcliffe et al., (2004) refer to the American planning system and suggest that modern planning systems are a post-war invention derived from the Town and Country Planning Act 1947. These planning systems highlight the state's role in regulating land use patterns that became universal principles in the field. The American planning systems empowered the private sector to represent the community interests regarding land use and development under a particular set of legislations that would permit or prohibit certain activities regarding land uses, property development, and modifying existing buildings. The planning system's development aims to secure planning policy as the post-war reconstruction (Ratcliffe et al., 2004:2). It means sustainable development of housing on "brown land" or previously developed land conserving the existing stock in the twenty-first century.

Considering the environmental threats that come with development and urbanization, the international policy area introduced many conventions addressing the matter, from Rio de Janeiro 1992, Kyoto 1998, and the world summit on Sustainable Development in Johannesburg 2002 (ibid). Policy frameworks, MDGs, and the SDGs are the virtue of the United Nations efforts to support countries in addressing the urban problems in their social, economic, and environmental dimensions through urban and development planning (Habitat 2015).

The literature on the determinant of housing prices varies in many aspects. San Ong (2013) looked at the macroeconomic factors affecting Malaysia's housing prices and concluded that GPD, population, and real property gains tax are the critical determinants of housing prices. Evans (2008:3) elaborated if the workplace benefits are the same regardless of being a newcomer or not, this would mean households '*will not be very mobile*'.

Urban economics and housing prices

Evans (2008:2) set the basis for the location theory that governs housing pricing but emphasized that it does not apply to every setting. Instead, it gives the general pattern and states: "It will be the group, not the individual, on which we shall fix our attention...". The economics of a household's location choice is a matter of trade-off behavior. Balancing the shelter cost against transportation cost to work, Evans (2008) suggested this model creates a predictable household's locational choices. The importance of proximity to households necessitates variance in rents and transportation costs from the urban center to the suburbs or outer residential areas.

The center-outer significance of the difference is liable to the city size, and the model suggests smaller cities are likely to have minor differences as opposed to larger cities. Evan's work did not address a particular element in housing but suggested an approach through which it's viable to make sense of housing pricing within given urban settings. Addressing residential density and externalities, Evans (2008) suggested missing elements in analyzing the residential pattern; first, certain utilities may distort the pattern, such as an industrial corridor or public-space, to positively or negatively affect residential choices.

Second, the occupant space needs within their units, the general assumption occupants will inhabit regardless of their space need in different densities (Evans 2008). It suggests that economists ignore density in analyzing residential patterns but do not produce optimal models that require low densities. Evans (2008) proposes that inner-city inhabitants have less economic welfare than outer-city inhabitants, as the inner-city is usually occupied by low-income to reduce transport costs, resulting in a systemic reduction in economic welfare.

However, the natural environment influences the allocation of many human activities. Evans (2008:30) cited Richardson et al., (1974) argument that "the quality of the environment is one of the most important determinants of a householder's location." Evans (2008:30) attributed the environment's significance in urban areas to depend on the density and articulated that Mirrlees (1972) associated density with the environmental quality. Evans (2008) concludes with the view that differences in socioeconomic status influence the quality of the environment as superior-good in terms of expenditure differences between high and low-income. Low-income households' density is likely to be higher than the high-income who consume land even more and increase their expenditures.

As for pricing the housing units, Evans (2008) suggest age and quality of housing as primary determinants of unit pricing; the cost of occupying a house is determined by the age and quality of the building, this cost might not be sufficient for a different unit or cost even less. However, there are two ways to choose a residential unit; first, cost minimization, which looks at the residential need only without other specifics such as the unit area and commuting time. The second is the consumer behavior analysis based on the assumption that the consumer is looking to capitalize on effectiveness to model the optimum location and affordability.

Evans's insights suggest that residential areas' pricing varies per behavioral factors, socioeconomic dynamics, and natural factors that create what he called the value gradient. It describes the distribution of housing unit pricing across space. The value gradient differences are caused by the factors discussed above, which are liable to change within different contexts when land ownership is dominant. It's

convenient to look at the factors affecting land prices and affordable housing using spatial analysis and modeling.

The literature on spatial econometric analysis of land prices and housing prices

The literature on real estate econometric analysis varies in context, methodology, and the issues. This section leads into various case studies using different methodologies, spatial and non-spatial analysis of residential properties and land prices.

Mikelbank (2004) studied the association between housing value and investment in transportation infrastructure in the context of Ohio State (in the United States of America) using spatial analysis and geocoding of housing transactions' explanatory variables. The study employed pre-test to OLS variables to avoid spatial multicollinearity and spatial dependence and 68% of the variations were explained. The study concluded that proximity to transportation infrastructure had a substantial depressive effect on local housing since announcing nearby transportation development. Still, due to other factors relating to the political process, environmental impact, and possible opposition, the impact is not insignificant. However, proximity to CBD and retail centers showed a positive and significant relation, broadly Mikelbank (2004) showed that the different dynamics of infrastructure investment could affect the housing market both ways (positively and negatively) in both local and regional economies.

Du and Mulley (2006) explored the link between access to transport and land value because transport infrastructure improves access to employment and facilities; therefore, improved accessibility increases land value. Du and Mulley investigated the relationship using a localized GWR model in the Tyne and Wear region (United Kingdom) and concluded that transport accessibility positively impacts land value in some places and negatively on others, OLS explained 60% of the variations, while GWR explained 73% of the local variations in land value. Du and Mulley (2006) suggest that GWR enables to reveal spatially varying relations, leading to a better understanding of the factors governing land value and the implications of transport-dependent housing on property value.

Huang et al., (2010) used GWR modeling for analyzing house prices. Still, they included temporal data to derive the spatial and temporal changes in housing prices referred to as Geographically and Temporally Weighted Regression [GTWR]. The results have shown that GTWR is more accurate in modeling the spatial and temporal variation in land prices than OLS. Temporal Weighted Regression [TWR] and GWR using the following variables. Living space, land area, garage type, construction type, occupancy type, zoning type, GTWR increase model performance, and reduced model bias and error. The OLS explained 76%, TWR explained 77%, GWR explained 88% and GTWR explained 92% of the variations in house prices. Haung et al., (2010) found that Spatio-temporal heterogeneity prevails in Calgary's real estate market and housing prices (Canada).

Ping and Hui (2010) looked at the Central Business District [CBD], transportation, and infrastructure as factors affecting residential land prices in Beijing (China) using non-spatial approach. The study concluded

that the city infrastructure of "quality of life" affects residential land prices more than CBD, transportation, and infrastructure. Sub-way and high-ways to residential areas show a complementary effect.

Du and Mulley (2012) examined spatial variations resulting from the impacts of access to transport on property prices in the context of Tyne and Wear using GWR with prices as the dependent variable explained by household socio-economic features and defined spatial factors, including the accessibility of the house location. The GWR model results showed that house features and socio-economic classification are overriding factors in determining property prices, transport is also significant, the model showed a significant spatially varying relationship between prices and transport accessibility. As oppose to OLS model which explained 32% of the variations, the GWR explained 46% of the variations in property prices

Koramaz and Dokmeci (2012) used OLS to examine the spatial determinant of housing prices in Istanbul using proximity to CBD, main commuting routes, coast, housing, and neighborhood characteristics as explanatory variables. The OLS explained 66% of the variations in housing prices and concluded that housing prices are significantly influenced by distances to CBD, sub-centers, transportation arteries, and the coast.

Manganelli et al., (2014) employed OLS and GWR to analyze the contribution of intrinsic and extrinsic factors to urban property value and the real estate market and suggested that extrinsic features (infrastructure and the environment) are the determinants of the market price. The OLS model explained 47% of the variations in the housing market, while the GWR explained 64%. Manganelli et al., (2014) concluded that GWR had given the incentive to interpret and analyze the urban property and the real estate market. The model proved useful in guiding the planning, advising investment decisions, highlighting the city development dynamics, and tackling previous planning choices.

Boyle et al., (2014) examined the effects of neighborhood walkability on housing prices based on literature around the topic that suggested a spurious effect of walkability on housing prices which depends on whether an area has low or high neighborhood walkability. The research examined walkability using OLS and concluded that there is a significant factor that affects prices other than walkability.

Zmólnig et al., (2015) employed spatial interpolation techniques (Kriging, Kriging with barriers, and IDW) in analyzing the factors affecting housing prices in Fife (Scotland) using the indicators in the Register of Scotland [ROS] house prices database. Zmólnig et al., (2015) suggested adding more attributes to the ROS database such as house size, date of the building, and the type of the real estate can generate more accuracy if GWR models were introduced to the analysis.

Li et al., (2016) used three hedonic models, OLS, Spatial Lag Regression [SLR], and GWR, to model the housing prices spatially and temporally. The results found that single-family home values influence structural attributes and urban amenities, accessibility factors, air quality, green space, quality of schools, and commuting costs. The OLS explained 39% of the variations in the housing values, while GWR explained 52% of the variations, the SLR model indicated that air pollution and the lack of forest coverage negatively impact housing value over time. However, the GWR model indicates that spatial heterogeneity is evident, and vegetation coverage impacts Salt Lake County's housing prices.

Trojanek et al., (2017) analyzed the impacts of aircraft noise pollution on housing prices using OLS, Weighted Least Squares (WLS) and Spatial Error Model [SEM]. The OLS model explained 65%, WLS explained 66%, the SAR explained 66%, and the SEM explained 65% of the variations in housing prices. The case study found that aircraft noise negatively relates to housing prices and distinguished that aircraft noise pollution affects house prices differently.

Mostafa (2018) did a unique study using OLS investigating the determinants of residential land prices in Kuwait by considering ethnicity as a parameter in modeling land prices, which is different from many other case studies. Mostafa (2018) investigated the influence of Kuwaitis percentage among the total population, the number of schools, traffic accidents, and air pollution on residential land prices. The findings show that residential land prices are mainly driven by population density, the percentage of Kuwaitis, and educational amenities, while air pollution reduces prices, the OLS model explained 60% of the variations in land prices. Mostafa (2018) argued that land prices tend to cluster around high-density areas and form hotspots with distance decay effect between hotspots. Mostafa (2018) argued that OLS seems to be the first choice for modeling land prices, but one can conceptualize their models depending on the variables.

Feng and Humphreys (2018) investigated the impact of sports facilities on residential property values using the OLS and Spatial Two-Stage Least Squares [STLS] hedonic models. The results show a significant impact of sports facilities on the residential property values in Columbus, Ohio (USA). The OLS explained 70% of the variations in residential property prices, while the STLS explained 77% of the variations. Property values tend to fall with distance from the sports facilities. The OLS overestimated the model parameters compared to the STLS model. Feng and Humphreys (2018) suggested that sports facilities' economic benefits drive the local economy's property value.

Namangaya and Kiubsi (2018) adopted three housing development sequences to illustrate the effect of services on housing. The analysis concluded the lack of structure in service provision in both planned and unplanned parts of the city. Furthermore, it stressed that occupation relies on essential services, electricity, public transport, and water services.

Cao et al., (2019) investigated the factors affecting the resale housing prices in Singapore using OLS among GWR and Euclidean distance-based models referencing the house's age, floor area, proximity to parks, CBD, and the nearest mass rapid transit stations. The OLS explained 70% of the variations in residential property prices, while GWR explained 83% of the variations.

Ghasri and Rashidi (2019) investigated the relationship between employed-family commute time to work and residential location using ordinary least squares. They found that adjusting commute time through the residential location is affected by the wife's job's household structure.

Husein et al., (2019) examined how urban form and commuting network, with socio-economic and demographic factors, impact public transit usage for commuting-to-work in Canada's megacities. Husein et al., (2019) have included that the Simultaneous Auto-Regressive model is helpful to account for the OLS spatial dependences and concluded that the socio-economic and urban form is mainly related to the increased public transit usage and commuting-to-work.

Highlights on the econometric analysis literature

The anticipated aim of the research is to provide a general model that explain the determinants of residential land prices and housing affordability in Khartoum's neighborhoods using OLS, the same regression technique used in (Mikelbank 2004; Huang et al., 2010; Koramaz and Dokmeci 2012; Boyle et al., 2014; Li et al., 2016; Mostafa 2018; Feng and Humphreys 2018; Cao et al., 2019). As for deriving local models for each neighborhood, the research employs GWR for weighting the determinants over each neighborhood, the same approach can be found in (Du and Mulley 2006; Huang et al., 2010; Du and Mulley 2012; Manganelli et al., 2014; Zmólnig et al., 2015).

Hedonic modeling of housing prices does not account for distance and proximity as modeling parameters, nor testing housing affordability indices regressed to proximity variables. The literature is oriented towards housing prices and the cost of transport as a comprehensive measure of housing affordability. Nonetheless, there is a great deal of literature on the spatial determinants of housing prices and land costs. Still, direct literature on housing affordability is scarce. In this research, the focus is on exploring the determinants of housing affordability across Khartoum city. The significance of this research lies in directly exploring the determinants of housing affordability using OLS and GWR. To this end, OLS is used to explore the factors affecting housing affordability and the variable causing spatial variations in housing affordability using the GWR.

Conceptual framework

The determinants of residential land prices and housing prices are dynamic throughout the literature resulting in heterogeneity through space, which is the essence of econometric modeling. Figure 1 shows the researcher's conceptual framework to guide the fulfillment of the research objectives. This research's conceptual framework is derived from the literature on econometric analysis of residential land prices and housing prices. Two different models appear in the conceptual framework, and the first has the red arrows linking the explanatory variables to the residential land prices. The second model has black arrows linking the explanatory variables to housing affordability. The dependent variables are the plot characteristics, average distance to central amenities, mobility networks, and local service. The study investigates the determinants of residential land prices and housing affordability from the set of the explanatory variables and how they vary in their impact on residential land prices and housing affordability.

Explanatory variables

1. Plot characteristics:

- Neighbourhood's class.
- Plot Size (Area).
- Length of the plot's façade.

2. Average distance to central amenities:

- Average distance to the CBD.
- Average distance to Khartoum International Airport.
- Average distance to industrial corridors.
- Average distance to commercial areas.

3. Average distance to mobility networks:

- Average distance to primary roads.
- Average distance to secondary roads.

4. Average distance to Local services:

- Average distance to hospitals.
- Average distance to schools.
- Average distance to local Markets.
- Average distance to Police stations.
- Average distance to Mosques.

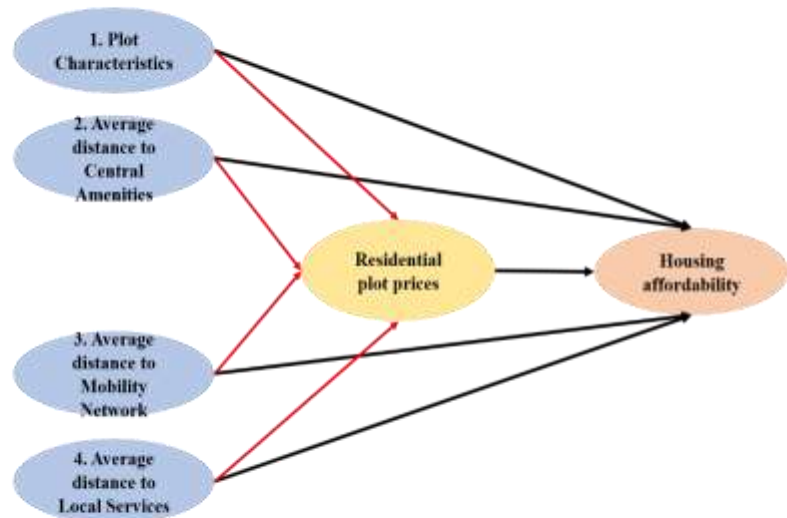


Figure 1 Conceptual framework (Source: Author's Own 2020).

Chapter Three: The econometric approach to the research issue and the context of Khartoum city

This chapter comprises two main sections. The first explores the research method and techniques to analyze housing affordability and the spatial analysis techniques highlighting the significance, advantages, and shortcomings of each technique using case studies. The second section deals with Khartoum's context in terms of location, socio-economics, and demographics structures.

Methodology

The word research's broad meaning is to investigate or explore known, and in some cases, unknown subjects or to investigate systematically. Yet, there are different definitions of word (research), Shuttleworth (2008:3) cited different definitions of research and concluded that research is *'The scientific definition of research generally states that a variable must be manipulated in an experiment'*. However, qualitative research may rely on case studies and purely observational science, and this approach has its own merits and drawbacks.". According to Brookes and O'Neil (2017) the word research refers to collecting information on a subject or an investigation to establish facts. (Rajasekar et al., 2006) refer to research as a rational and organized exploration for valuable data on a specific topic. Cavana et al., (2001:5) defined research as *'an organized, systematic, data-based, critical, objective, scientific inquiry or investigation into a specific problem or issue to find solutions to it or clarify it'*.

On the one hand, the articulated definitions of research imply that research is a structured process with a conceptual framework. The subject is investigated using non-biased procedures, techniques, and approaches that are reliable and testable. Stockemer (2019) suggests that research work can investigate the subject from general to specific, known as quantitative research using statistics, samples, and surveys. On the other hand, qualitative research encompasses a few observations that drive from the observed subject's specifics to generalize the population under investigation.

Somekh et al., (2005:1) traced the roots of research approaches in social sciences to Plato and Aristotle's conceptualization of knowledge, and suggest that *'Fundamentally, social science research is concerned with people and their life contexts...'*. Ruonavaara, (2018) argues that housing as one of the aspects of social science disciplines is not a research field; instead, it's a mutual denominator of numerous fields such as housing policy, housing supply, housing choice, and more. The point made suggests that social sciences research's focus reflects different aspects of the issues under investigation. Kemeny (2013) suggests that housing studies are undertheorized, and little has been done to understand this and address what can be done to rectify, suggesting that housing researchers should be reflexive in analysis and employ many critical approaches.

The research intends to investigate different neighborhoods' housing affordability in greater Khartoum through quantitative correlational analysis of the factors affecting property prices using OLS. For each sample neighborhood, land prices, construction cost, the GWR model, and every single feature in the sample explain the factors that affect the specific feature. Housing affordability will be extracted using price and income ratio (Suhaida et al., 2011).

Concepts

The research questions respond to the research aim and objectives, which is to explore the spatial determinants of residential land prices and housing affordability, and how housing affordability can influence the physical expansion of Khartoum. Using Tobler's concept of proximity, the research will employ regression analysis (Spatial and non-spatial) to illustrate how the variables highlighted in the conceptual framework impact residential land prices and housing affordability. To explore the impact of housing affordability on the physical expansion of Khartoum, the research will employ spatial interpolation (Kriging) to illustrate the spatial pattern of housing affordability, how affordability changes through distance from the CBD. However, it is important to start with defining the terminologies and concepts related to the research and to explain the techniques used to answer the research question and fulfil its aim.

City expansion

According to Burgess (2008), city expansion refers to physical growth, sprawl, and the enlargement of the city's 'urban' boundaries, or the city's development from the city plan's standpoint. The term urban sprawl has been used to illustrate the physical expansion of an urban environment regardless of the density as a character of that expansion (Bruegmann 2015). However, sprawl is likely to happen at any density, low-density sprawl is usually associated with low-income communities such as, while high-density sprawl is associated with both low-and-high income communities (Mouratidis 2019). Urban expansion is used synonymously with city expansion, Fox and Goodfellow (2016) described urban expansion as the increase of built-up area of a settlement or a collection of settlements.

Spatial analysis

Cappelli (2013) practically defines spatial analysis as a diverse and comprehensive capability that includes the accurate visual analysis of maps and imagery, computational analysis of geographic patterns, finding optimum routes, site selection, and advanced predictive modeling. Goodchild et al., (1999) define spatial analysis as that subset of analytic techniques whose results depend on the frame or change if the structure changes.

Housing Affordability

Bieri (2014) broadly defines housing affordability as the cost of obtaining a house or a shelter for rent or ownership relative to an individual's or household's income. However, Bieri's definition limits the concept of property ownership. Anacker (2019) adds household expenditure and income to explain housing affordability in a context similar to Bieri's argument. The World Economic Forum Insight Report by Menon et al., (2019) counters the definitions with maintenance and operations costs. Habitat (2011:3) defines affordable housing as 'housing which is adequate in quality and location and does not cost so much that it prohibits its occupants from meeting other basic living costs or threatens their enjoyment of basic human rights'. The UN-Habitat definition adds quality and access to basic needs. The Housing White Paper of South Africa is the primary policy document on housing affairs, and it attributes two-component to affordability, state affordability, and microeconomic realities of affordability (Africa and Housing 1994).

Housing Affordability Index

Definitions of the Housing Affordability Index [HAI] vary due to the different conceptualizations of housing affordability and its measures. Many definitions revolve around measuring the financial ability to buy a medium house, referencing household income, the qualifying income, and house price (Dorokh and Torluccio 2011). The idea of the housing affordability index measures whether or not a typical household earns enough income to rent or buy a house. For this study, the affordability index employed is in alliance with the general idea of housing affordability (ibid).

Data acquisition

There are two types of data necessary for this research. First is a clustering of vector data (polygons and points), attributing the sampling of plot prices to interpolate the neighborhoods' prices surface (Montero and Larraz 2011; Koramaz and Dokmeci 2012). The second type of data is secondary data on median income, the average construction costs of houses collected from contractors, literature, and census books. Samples are collected from realtors and contractors' estimations of the current plot value and construction costs when the study is in progress to map the affordability index for different income levels. Figure 2 below gives the study area spatial context with illustration to land-uses of the study area, CBD, and Nile junction in Al-Mogran.

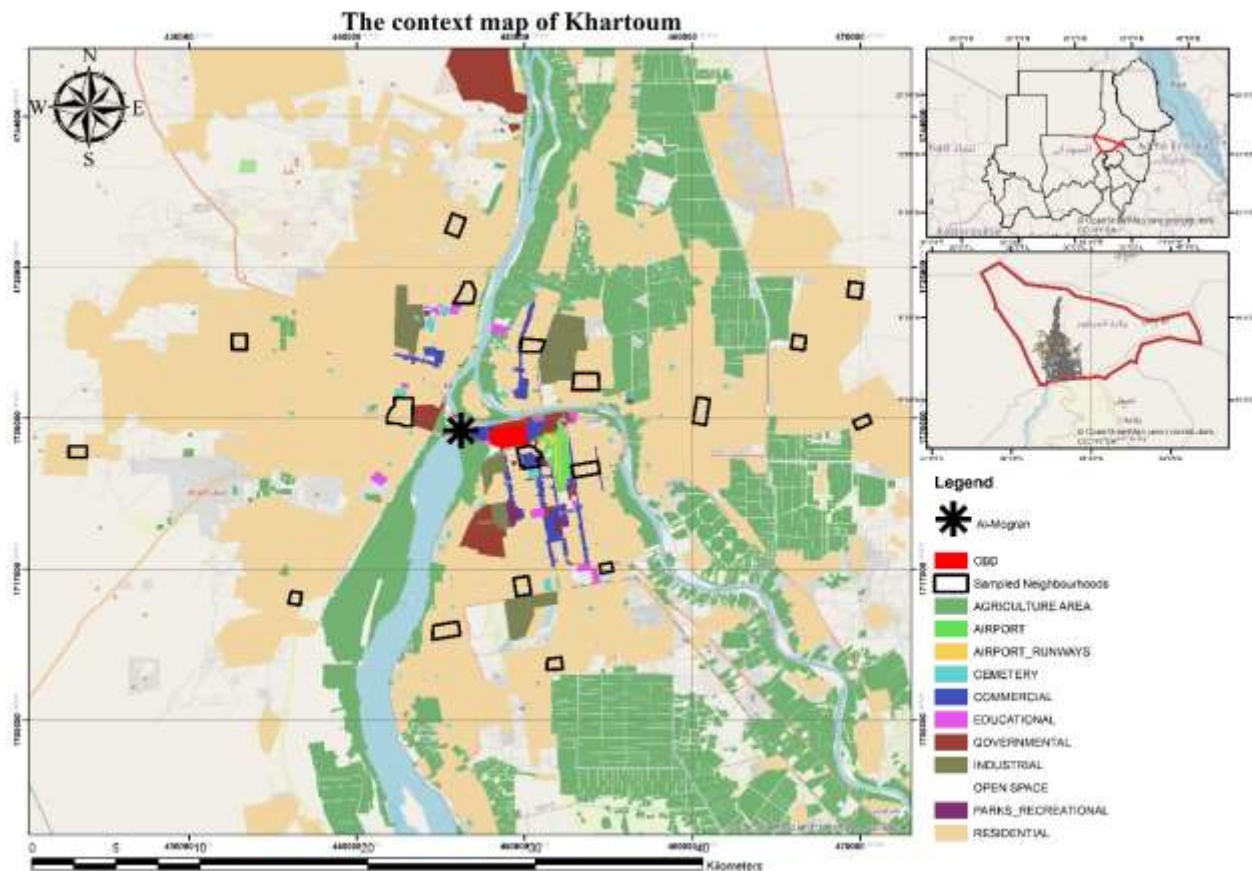


Figure 2 The map shows the places of interest for the analysis and the neighborhoods representing the sample (Source: Author's Own 2020).

Analysis procedure

The first part of the study will use the samples with the construction standards to derive the housing affordability index for Khartoum's sampled neighborhoods based on land class designated by planning and land regulations. The HAI will be used for interpolating values for each neighborhood and generate a continuous surface to show HAI's spatial pattern.

The second part will investigate the determinants of residential land prices and housing affordability using OLS for generating a global model. The GWR examines the impact of the determinants on each neighborhood and compares the regression model findings of model housing affordability and how affordability changes with the CBD distance using the interpolation surface.

The ordinary Least Square creates an equation for the entire study area Saefuddin et al., (2012) and Bohari et al., (2015). However, Geographically Weighted Regression generates an equation for every single feature within the study area, using plot class and size as explanatory factors for the plot prices. Data preparation and georeferencing will evaluate the sample data regarding its distribution within the clusters and the study. The analysis will apply the Kriging interpolation to give a perspective on spatial pattern of housing affordability through Khartoum. Figure 3 below dissects the general flow of the research from data collection to the findings.

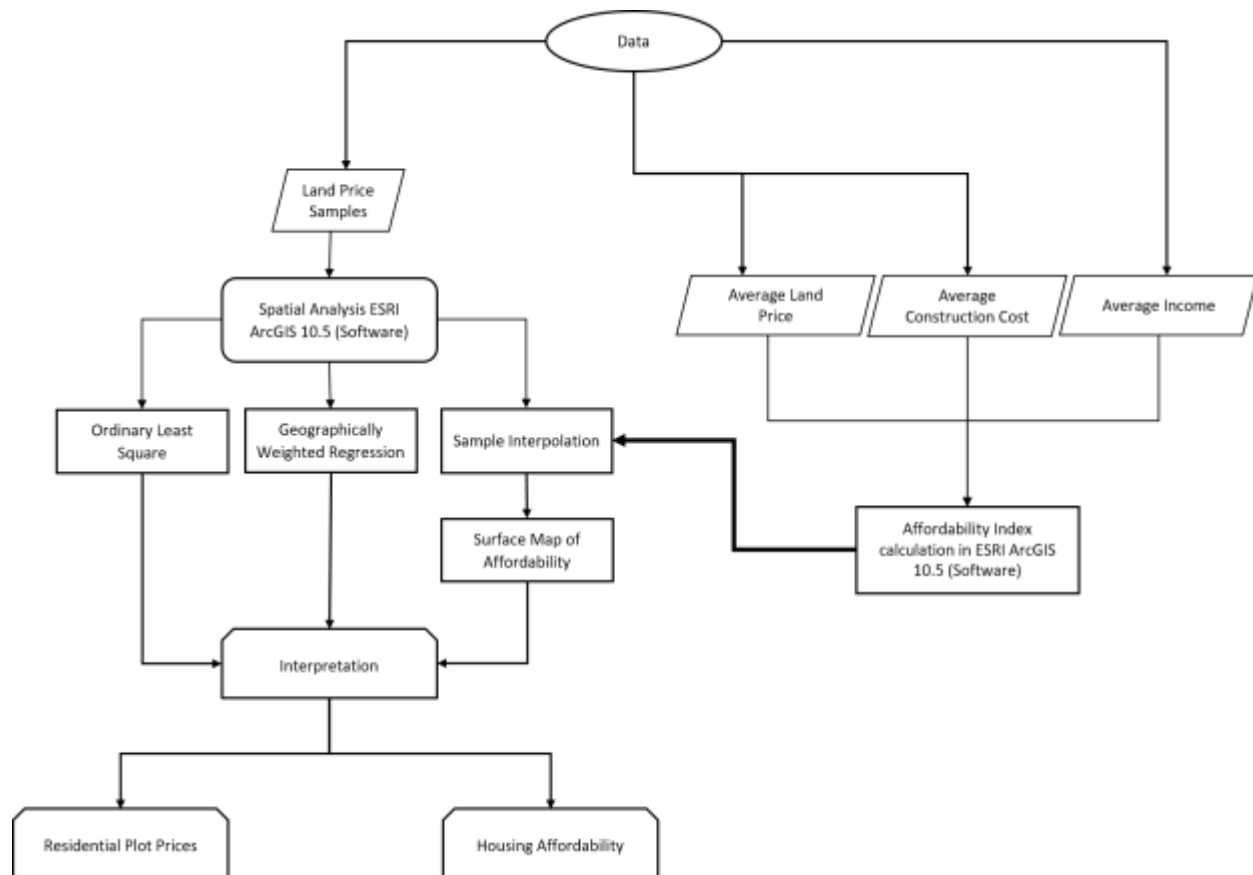


Figure 3 Research steps (Source: Author's Own 2020).

Measuring affordability

Bogdon and Can (1997) suggest measuring housing affordability has been difficult due to the different housing affordability conceptions. The paper spatially analyzes the different housing affordability measures under the United States of America's housing policy set in the National Affordable Housing Act 1990. Bogdon and Can (1997) concluded that understanding the nature and distribution of housing affordability issues is the first step to developing housing policy for the low-income, a model for comparing housing affordability in different settings using market indicators.

Asici et al., (2011) elaborated on (Linneman and Megbolugbe, 1992; Kosareva and Tumamov 2008) definitions of affordability as the ability to purchase a house and emphasized the flexibility of affordability and its measure. Asici et al., (2011) linked quality and consistency of the house as the long-term the dominant factor in housing affordability and the different income levels and finance structures to suit the context.

$$HAI = \left(\frac{MEDINCOME}{QINCOME} \right) * 100$$

MEDINCOME: Household Income

QINCOME: Qualifying Income

$$QINCOME = PMT * 12$$

PMT: Monthly Payment

Spatial Interpolation

Spatial analysis is all about detecting spatial patterns, and point data can be used to visualize a continuous surface showing the variance in data across space. The ideal distribution of the data point in interpolation analysis is the grid shape, where interpolation points are positioned at fixed locations to ensure the data's consistency. There are two types of interpolation techniques: geostatistical and deterministic (Childs 2004).

Deterministic interpolation techniques such as Inverted Distance Weighting (IDW) are based upon the principle of deriving the surface based on mathematical formulas, which looks for similarity in the neighboring data values to calculate the missing value to generate the interpolation surface. Geostatistical interpolation techniques such as Kriging, Co-Kriging are based on statistics, which are more accurate in making predictions (ibid).

There is a great deal of literature on the applications in interpolation techniques (Li and Heap, 2008, 2011 and 2014) in environmental sciences applications (Darmofal, 2006), spatial econometric and political science (Reibel and Bufalino 2005; Weden et al., 2015) demographics and socioeconomic analysis, (Pace et al., 1998; Bin et al., 2005; Anselin and Le Gallo 2006; and Zhang et al., 2019), and in real estate applications (Bin et al., 2005; Anselin and Le Gallo 2006; Szczepańska et al., 2020).

Hu et al., (2013) considered the effect of feature singularity on the result of IDW interpolation and suggested that Multifractal IDW is more accurate in predicting large data sets. Kuntz and Helbich (2014)

suggest using the Kriging (detrended and universal) interpolation technique for small-sized housing samples to predict non-observed locations.

The literature on spatial interpolation suggests no single interpolation method that applies to all spatial research types (Mitas and Mitasova 1999). The validity of interpolation depends on the sample data and surface interpolation generated and tolerance of error estimation. This research applies the Kriging interpolation technique provided in ArcMap 10.5 for accuracy in non-stationary data predictions (Childs 2004; Lam 2013).

Spatial analysis

The principles of spatial analysis are rooted in the first law of geography, which states that "everything is related to everything else, but near things are more related than distant things," known as Tobler First Law [TFL] (Miller 2004). Tobler's law stands as the foundation of the fundamental concepts of spatial dependence and spatial correlation utilized for inverse distance weighting methods for spatial interpolation, such as the Kriging spatial interpolation technique and the inverse distance weighting. Waters (2016:2) suggests that Tobler argued that his principle is not the first declared in geography. Still, distance is the most crucial variable in looking into spatial proximity features, and most features would show '*a-distance decay effect*'.

Geographic Information Systems [GIS] platforms provide cost and time-efficient tools to conduct spatial analysis with capabilities to visualize the distribution of the phenomenon and different outcomes and predictions (Câmara et al., 2004). Spatial Autocorrelation is the most commonly used principle in spatial analysis, relying on Tobler's principle of spatial relations by providing a relational understanding of spatially clustered features (ibid). Miller (2004) suggests that TFL is the principal of spatial autocorrelation statistics and a quantitative technique for analyzing correlations related to distance, proximity, or connectivity relations used in many case studies.

Potoglou et al., (2019) spatially analyzed the impact of bus stops on property value in Cardiff city using exploratory and explanatory analysis and found that residential lands' values tend to change with proximity to bus stops and property type. Namangaya and Kiunsi (2018) analyzed the relationship between service provision and housing development and highlighted land ownership and home construction processes in both planned and unplanned areas in Dar es Salam. Namangaya and Kiunsi (2018) concluded that Dar es Salam development's essential services are better than providing housing. (Namangaya and Kiunsi 2018) adopted three housing development sequences to illustrate the effect of services on housing. The analysis concluded the lack of structure in service provision in both planned and unplanned parts of the city. It stressed that occupation relies on essential services, electricity, public transport, and water services.

Ordinary Least Square

Zdaniuk (2014) suggests that OLS is one of the linear least square approaches for deriving unidentified values in a linear regression model. OLS depends on explanatory variables based on reducing the total squares of the variances amongst the observed dependent variable and the predicted by the linear

function (ibid). Pohlman and Leitner (2003) investigated OLS with logistic regression in terms of their fundamental conventions and results using two different sets of binary data, logistic regression and OLS had similar results, but logistic regression is superior to OLS. It's essential to emphasize that Pohlmann's study did not consider the spatial variable in the study. Scott and Janikas (2010) emphasized spatial analysis techniques. OLS considers distance and proximity in modeling the study area. Briassoulis et al., (2019) cited that spatial analysis applications revolutionized analytical approaches of studying diverse subjects scientific and policy-wise by considering the spatial dynamics (dependence and heterogeneity) of data. Briassoulis et al., (2019) spoke of the benefits of spatial analysis techniques appropriately by reflecting on Western societies' concerns for rapid urbanization and how spatial analysis provided reliable models and feedback to inform planning institutions to regulate housing markets.

The literature above implies the fruitfulness of spatial analysis techniques in examining different aspects related to the dynamics of housing and land value. The emphasis should be on finding the appropriate model and variables representing the case study context without compromising biased models by adhering to each model's standards and ensuring optimum results.

Geographically Weighted Regression

Düzgün and Kemeç (2008:1) defined the concept of Spatial Regression [SR] as '*a global spatial modeling technique in which spatial autocorrelation among regression parameters are taken into account*' and articulated that SR aims to explain association among the dependent variable measured over the spatial zone and other characteristics of the feature.

Düzgün and Kemeç (2008:1) suggested that SR is widely known as a modeling technique in spatial data analysis literature and spatial data mining as a classification method (Anselin 1988; Bailey and Gatrell 1995; Fotheringham et al., 2000; Haining 2003; Anselin et al., 2013). However, the GWR is a common explanatory technique in spatial data analysis for distinguishing local differences in a spatial context. Unlike SR, the result can be affected by variables redundancy. GWR works by fitting the regression equation to each subject within the context based on the distance decay. The distance decay refers to the gradual change in value through space which creates a value gradient effect. Düzgün and Kemeç (2008) articulated the success of SR and GWR in many fields. One of the prominent fields is housing and real estate, public health and medical issues, public safety and crime analysis, economics, transportation, regional development, and natural and environmental sciences.

Urbanization and housing affordability in Khartoum

Khartoum is the Republic of Sudan's national capital and ranked as the sixth-largest metropolitan area in Africa, the second largest capital in North Africa, and the fourth-largest capital in the Arab world. The city is unique to its geographical location, as shown in figure 4, positioned in the Blue and White Nile confluence known as Al-Morgan to form the great River Nile flowing North to Egypt and the Mediterranean Sea. Khartoum's centralized position between 15- and 16-degrees north and 31- and 32-degrees longitude east. Babiker (2003) divided settlements in Khartoum city into state-regulated human settlements, the sprawling of informal settlements, and the historic township on the Blue Nile's southern banks.

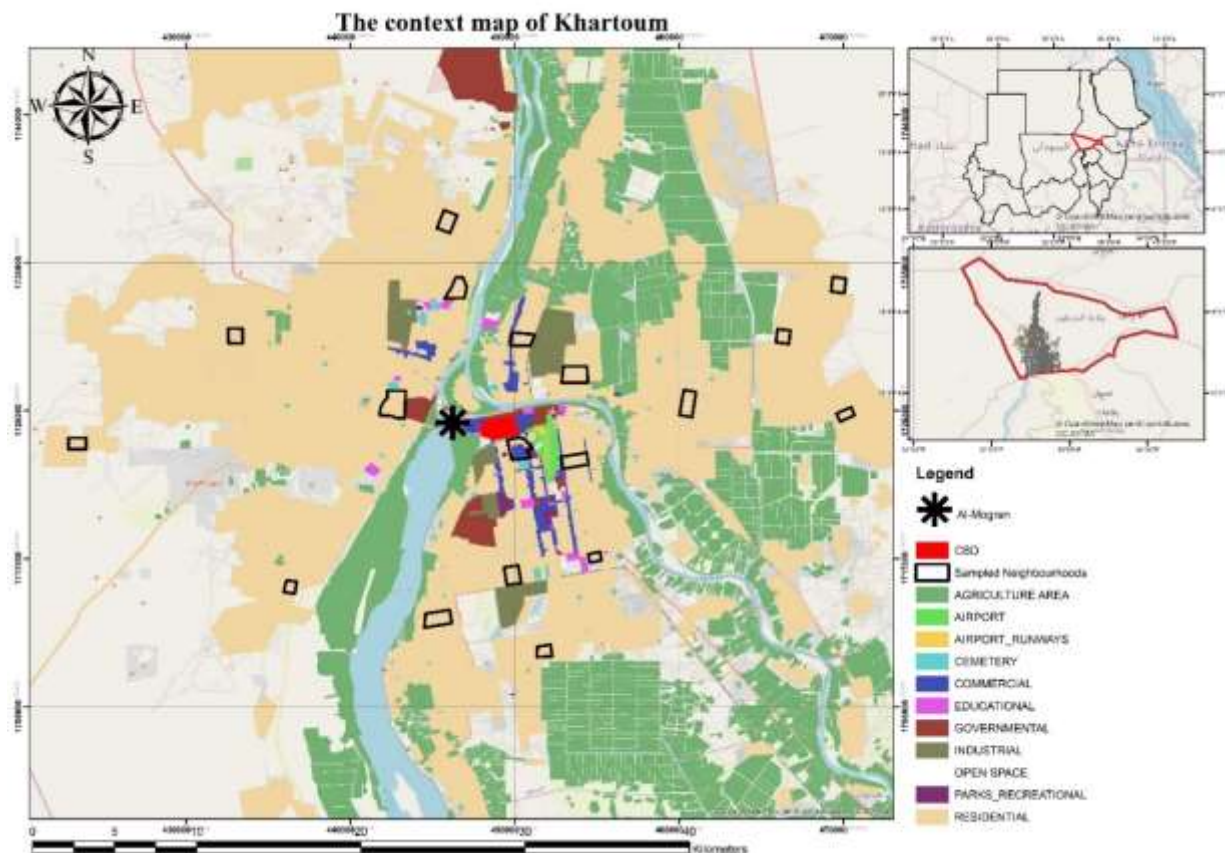


Figure 4 The map shows Khartoum's context regarding land use with the sampled neighborhoods (Source: author's own 2020).

Demographics

During the last sixty-years, Khartoum's population increased from 808.800 in 1973 to 13.52 million projected in 2020, with a bottom-heavy population pyramid, 48.5% below 15 years, 35% are between 18 and 35 years old (Habitat 2009; Habitat III 2016). Even though the city grew in population and size, Khartoum state is vastly unoccupied, with only 6% of the province occupied in 2011 (Sudan and UNICEF 2016). The occupied area is likely to increase due to population growth and the influx of migrants coming to Khartoum. De Waal (2008) suggests there are more than 6 million inhabitants in Khartoum are IDPs.

Sudan and UNICEF (2016) survey revealed that 13.8% of Sudan's population is in Khartoum. Sudan and UNICEF (2016) cited that *'The 1993 census indicated that Khartoum state received about 1.5 million migrants account for 45 percent of all internal migrants in Sudan, constituted about 43 percent of Khartoum state's population 1993, about 3.5 million people'*.

Several push factors influenced the population growth in Khartoum and made the city an attractive node for migration, employment, development and infrastructure, level of services, natural hazards, and safety (Habitat 2009; Pantuliano et al., 2011; Sudan and UNICEF 2016). The Khartoum survey conducted by De Geoffroy (2005), including IDPs and non-IDPs, indicated that 69% of migrants came to Khartoum for work, 11% evading conflict hotspots. Of the migrants, 6% sought shelter and housing, and 5% are looking for better education, and 5% were seeking family reunions. The survey indicated conflicts and better opportunities trigger ethnic drivers of migration. Pantuliano *et al.*, (2011) highlighted different statistics on the effect of internal migration on Khartoum's population and cited that many IDP camps and informal settlements affected its physical structure.

Socio-economic and access to finance housing

Khartoum city is the center of economic and political leadership in Sudan; 43% of Sudan's urban population is in greater Khartoum (Sudan 2020). 30% of Khartoum is urban, and the remaining 70% of the population settle the city's peripheries, and 80% of Sudanese households are classified as low-income with wages below 2019 GPD per capita (Feather and Meme 2019). With the African Development Bank (ADB) aid, the Central Bureau of Statistics in Sudan surveyed between 2014 and 2015 on a national base-line household budget. It concluded that a household is classified as poor if it consumes less than 901.25 USD\$³.

Outlook (2020) the African Development Bank's report on developing workforce attributes the decrease in Sudan's GDP by 2.4% to the underperforming service and investment sectors. The rising debt of Sudan reached 600% of the exports in 2019. As a result, the poverty line in Sudan went from 901.23 USD\$ in 2014 to 120.8 USD\$ 2020 exchange rate⁴. And 25% of Sudan's population is under the extreme poverty line (ADB 2018). Feather and Meme (2019) reported a 2.3% decrease in Sudan's economy in 2019 compared to 2018, with a significant gap between the high-and-low-income.

Socio-economically, the Human Development Index [HDI] indicators such as health and education pushed the HDI from 0.331 in 1990 to 0.473 in 2013 and 0.502 in 2017 (Feather and Meme 2019). Still, the ADB (2016) reported a decrease in socio-economic inequality between 2009 and 2014.

There is 85.5% home ownership in housing and land ownership in Sudan, and suggest the demand outpace the housing supply by 20-25% in the past five years. The increasing housing prices have economic causes (Feather and Meme 2019). There are no estimates on homeownership nor the gap between housing demand and supply for Khartoum. Plot prices in Khartoum range between USD\$ 1500 per square meter in Khartoum center and almost 10th of the amount in preurban areas, detached concrete houses in

³ 1 USD = 5.66 SD (2014 Exchange rate).

⁴ 1 USD = 377.7 SD (2020 Exchange rate).

Khartoum's popular areas ranges from SD 6,799,142.2 (\$150,000) to SD 9,065,523 (\$200,000), and about SD 2,719,056.8 (\$60,000) (ibid).

In qualifying Feather and Meme (2019) point on adequate affordable housing in Khartoum, many challenges remain unresolved to deliver affordable housing to the increasing population. The increasing housing cost is a significant challenge for affordable housing, among the limited access to finance and the difficulties facing the financial sector to be more inclusive and accessible, which pushes most households to remittances from family to afford formal housing (ibid).

Urbanization and housing system in Khartoum

During the last few decades, Khartoum city has experienced rapid and complex urbanization regulated by traditional planning approaches (Habitat 2009). Traditional planning approaches centralize planning practice which is usually strict to the centralized guidelines and frameworks. The centralized planning results in the unbalanced allocation of resources and development, capitalizing informality with its ramifications regarding access to housing, services, infrastructure, and employment opportunities (Pantuliano et al., 2011). The master plans laid out for Khartoum have failed to deal with the pace of change and implementing pro-poor policies (ibid).

The signing of the Comprehensive Peace Agreement [CPA] in 2005 ended the conflict between southern and northern Sudan. The government of Sudan made efforts to help the displaced return to their homeland. However, issues of services, economy, and safety in South Sudan discouraged about 2 million IDPs (Delhaas 2006) from returning home. Instead, it triggered more migration from South Sudan to Sudan. Another driver is the number of migrants and refugees from Ethiopia and Somalia, 31,900 estimated in 2007 by the United Nations Higher Commission of Refugees [UNHCR] (Pantuliano et al., 2011). Compared to the rest of the Sudanese, Khartoum provided better safety, work, and services to IDPs and immigrants, especially during the civil war in the 1980s, which witnessed a massive growth of Informal Settlements (ibid). The internal displacement and immigrants from the neighboring countries push the demand for housing and put more pressure on Khartoum city and the housing industry to accommodate more people.

Hafazalla (2006:118) elaborated using McAuslan (1982) view on the role of government on land policy and stated that *'...on the role of the government in terms of ensuring that land is planned and supplied in the right time, in the right location, at the right price'*, which partially aligned with (Habitat 2011) argument. Governments must consider the spatial-temporal changes that would affect the provision of land, housing, infrastructure, and services appropriately. Therefore, it's essential to develop policies and guidelines that would put in perspective the growing future need to account for the effects of the spatial-temporal changes.

However, a household's land affordability in a context such as Khartoum is crucial to address. (Hafazalla 2006) suggests employing prediction models to assess the appropriate land characteristics that would satisfy a specific demand level in site-and-services housing, with a satisfactory level of services and plot characteristics. The correct prediction models suggest meeting the demand for residential plots with enough institutions to support housing supply (ibid).

Given the conflicts around land and tenure in Sudan, Hafazalla (2006:118-119) proposed adopting from (Gilbert 1984) the politics of land in Venezuela and Latin America as best-practice regarding the state mixture of the policies that support accumulation and sometimes legitimacy of tenure reforms in Sudan through five ways including:

- a. The land is a source for economic stimulation through capital accumulation to lower land prices to enhance construction and create jobs. Construction companies may be offered subsidies and cheap land to support affordable housing.
- b. The state may allocate land in favor of particular groups within the society through grants, public contracting, and planning controls.
- c. Less engagement of political approaches in land allocation to tackle the issues of irrational processes in land allocation.
- d. To Consider the low-income in land allocation for unfair land invasions for political reasons.
- e. Develop land policies that accommodate income and wealth inequalities through pricing to reduce social segregation in residential areas (Gilbert 1994).

(Hafazalla 2006:119) referred to the dysfunctionality of land and planning governance, 'Khartoum is not acting effectively to adopt land policies that could enhance the economy. No clear declared land policies and objectives exist in Khartoum, and no clear land-use planning techniques are adopted'. (Hafazalla 2006) was articulating the flaws in land policies.

Furthermore, the state is selling land as a source of revenue to finance projects. It requires specific marketing policy to incorporate urban planning and housing objectives, critical to compromise between economic and urban planning objectives (ibid). Pantuliano et al., (2011) looked at the government policies to deal with density in cities and towns regarding infrastructure, land acquisition, poverty alleviation, employment creation, and safety net mechanism. They highlighted the relevance to other parts of Sudan.

Hamid and Mohamed Elhassan (2014) Cited there are three types of housing provision in Khartoum. First, unauthorized informal housing does not adhere to the housing standards. It is characterized by the lack of proper planning and design, insecure land tenure in most cases, and flexibility which made it convenient to low-income households. The second is sites-and-services government housing, which grants households access to essential services connected to the property, adherence to planning and building regulations, flexibility in construction through contractors, self-help, and communal support. The third is government core housing which complements the opportunity to settle initially and expand the house. Core housing standards require having essential facilities to the housing unit such as kitchen and bathroom, and sanitation connected to the sewage system.

Land tenure is essential to urban planning, and housing practices; Hafazalla (2006:118) suggests that land tenure and allocation are linked to political frameworks and referenced the UN's 1989 land tenure systems to the case in Khartoum, Sudan. The first housing type is state-owned land which, according to the Land Registration Act 1925, grants the government the right to allocate land uses and secure tenures, and the second is a private market that depends on market relations and customers.

The types of housing mentioned above have subsidiary systems, such as tribal land, across different Sudan parts. In these systems, tribal leaderships have the right to allocate land for housing based on tribal traditions rooted in the colonial period (Hafazalla 2006).

Housing within Khartoum's master plans

There are six master plans developed for Khartoum spanning through five planning periods McLean's plan 1912, Doxiadis 1960 and MEFIT 1975, Doxiadis and Mustafa 1990-2000, the master plan for 2000-2007, and the structural plan 2007-2033. Before McLean's plan, the colonial government conducted a land claims survey in 1910, which classified land and neighborhoods based on the income-level and construction materials. It introduced the first master plan for Khartoum as a result of introducing the Land Registration Act 1925. The second planning period consists of Doxiadis 1960 and MEFIT 1975 master plans, which looked at accommodating Khartoum's growing population and planning for the IDPs squatter settlements to define the urban boundary. The third planning period introduced the master plan by Doxiadis and Mustafa 1990-2000, which recognized Khartoum's leapfrog growth introduced the sites-and-service housing and core housing. The fourth master plan of 2000-2007 was introduced to deal with mobility and adopting the Transit-Oriented Development [TOD] approach to guide development. The latest structural plan 2007-2033 aims to reintegrate Khartoum's neighborhoods through ring roads and transportation systems.

McLean 1912

In 1900 the colonial government conducted a survey that includes verified land claims and assign legal rights. In 1912 McLean Introduced the first master plan for Khartoum. The plan's target was 100,000 of a total population in an urbanized area of 11.5 square kilometers at 87.97 inhabitants per hectare was considered a significant achievement of the colonial period (Habitat 2009). In 1925 all lands with no disputes were registered, and no further land claims were verified by (Habitat 2009). Hafazalla (2006:115) cited MacLean (1910) *'the plan was designed to accommodate a population of 50,000. The plan focused on Khartoum and did not cover Omdurman and Khartoum North'*. Home (1990) Mc lean's plan had a definite hierarchy of roads that allowed for sidewalks and plants (Hafazalla 2006) and improved water and sanitation. It replicated the European design character and beautified city.

On the one hand, the plan regulated land use, zoned the residential purposes, categorized land, and housing into four classes favoring the British administrative officials and investors (Habitat, 2009). The Land Registration Act 1925 regulated land claims and allocated land plots on an income-level basis. First-class plots were allocated to high-income households, second-class plots for middle-income households, and third-class plots for low-income households (Habitat 2009).

On the other hand, Sudanese people settled the third-class neighborhoods, which fitted their fiscal construction abilities contrary to first- and second-class neighborhoods. Squatter settlements were smaller than the third-class housing units and could be built using any material. According to Habitat (2009:14) Under the land registration act, the government designated the remaining land in the name of the state *'the achievement of the colonial administration'* (Babiker 1997). However, Mc Lean's plan shaped the city to define Khartoum's urban boundaries and prevented sprawl. The plan marked the *'golden era'* of Khartoum's history as the plan adopted the modern urban, landscape, and architectural design of the

time. The plan gave Khartoum a European appearance, made it well-tended, and watered more Mediterranean than African city (Home 1990:5; Habitat 2009:15).

Regarding housing, McLean's plan shown in figure 5 regulated housing through income levels, allowing access to plot classes and building materials affordable to the different income groups. According to Hafazalla (2006), regulation articulated that first-class housing should be built using burnt bricks, stone, and concrete for roofing. The second class was to be made of burnt brick for external walls, internal walls, and room to be built out of the mud. Third-class housing could be constructed of mud only without a limited budget (Hafazalla 2006). The fourth class was smaller in size and could be built with any materials. It is essential to cite that each housing class was given a minimum budget for construction. Land ownership was the subject of legal claims regulated and subdivided through land use regulation and zoning before the Land Registration Act 1925. Afterward, most of Mc Lean's rules, such as housing classification systems, housing standards, and specification, and building materials, still guide urban planning to the present (Hafazalla 2006; Habitat 2009).

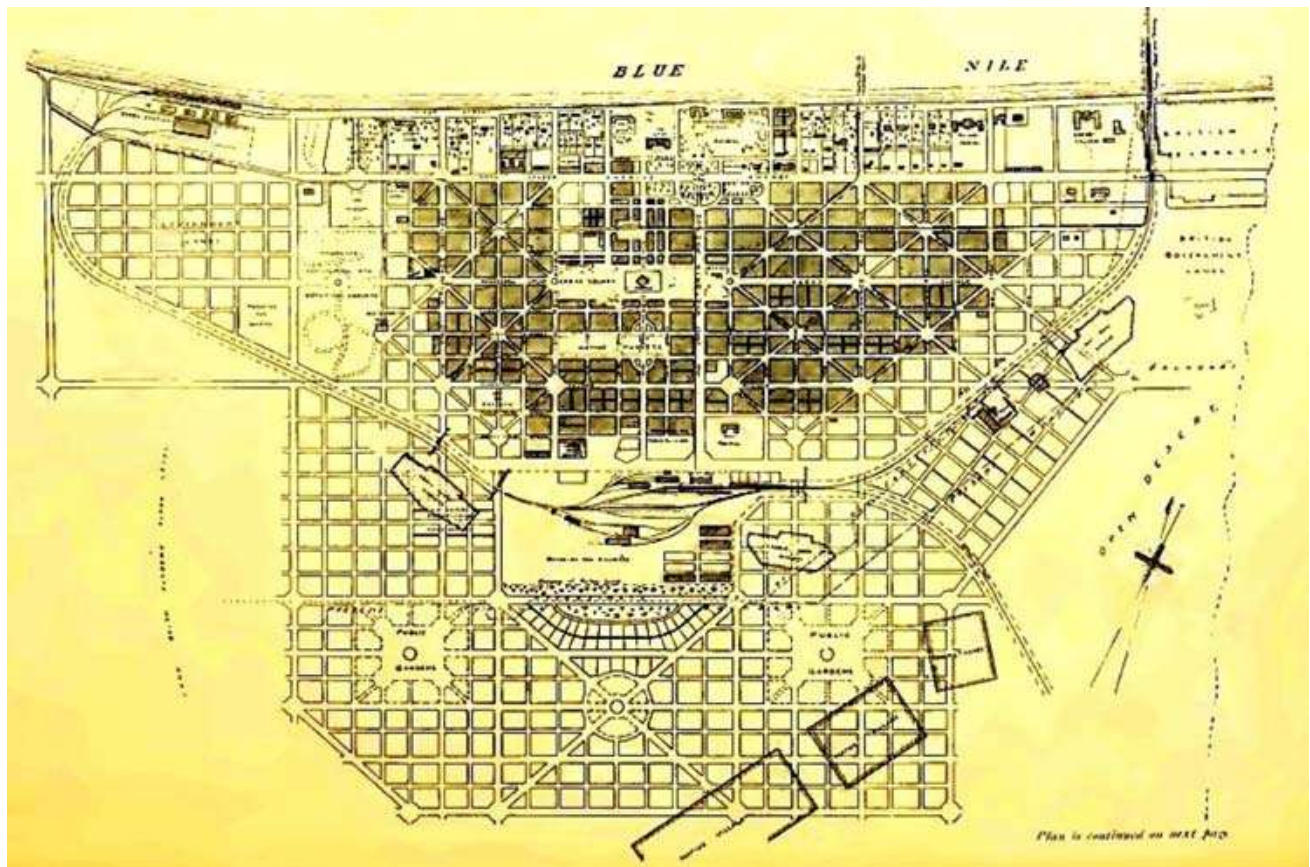


Figure 5 McLean's 1912 Plan for Khartoum (Source: Hamid and Bahreldin 2013).

Doxiadis 1960 and MEFIT 1975

Habitat (2009) Doxiadis, in 1960, was invited to prepare a comprehensive plan for Khartoum after independence in 1956. Doxiadis's plan share some of the McLean approaches. Nevertheless, land

allocation became a central government matter. According to Hafazalla (2006), the rapid influx of migrants to Khartoum drove the city's expansion to the south, and squatter settlements preched the urban boundary to a point where the administration sought the need for a new plan. The plans of Doxiadis 1960 and MEFIT 1975 adopted an approach similar to Transit-Oriented Development [TOD] to cope with the growing city and allow for economic development. As shown in figure 6, Doxiadis took rigorous land use plans and a network of roads that link the outskirts to the urban center (Habitat 2009). Doxiadis plan targeted 700,000 inhabitants allocating 182 square kilometers. The plan sacrificed density and expanded the city.

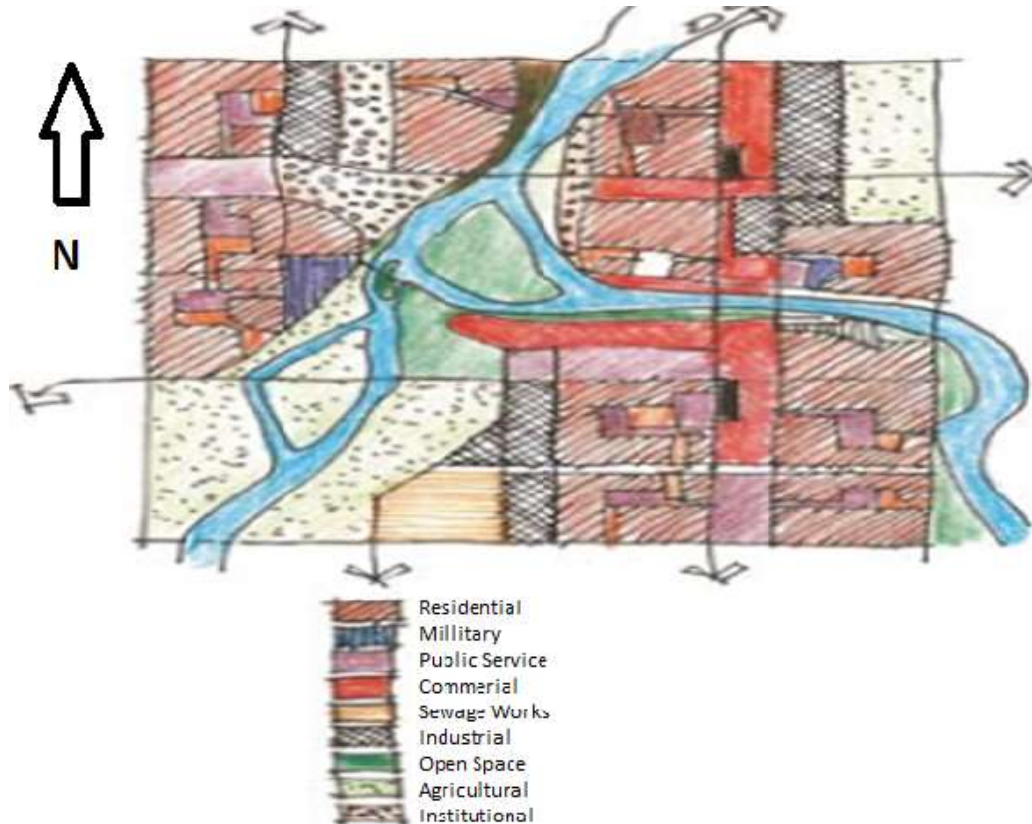


Figure 6 Doxiadis's 1960 Plan for Greater Khartoum (Source: Habitat 2009).

MEFIT 1975 plan increased the density to compensate for infrastructure cost, although it was out of budget (Habitat 2009). Hafazalla (2006) suggested that the MEFIT 1975 plan focused on urban design to beautify the city, and the administration did not approve it. As shown in figure 7, the plan partially adopted agricultural development as a beautification element and accommodated the predominantly agricultural society. Instead of shaping the expansion and distribution of critical functions, the MEFIT 1975 plan was ambitious compared to the economic status, and the plan became outdated quickly. It is essential to highlight (Hafazalla 2006) observed that housing was not highly considered in the Doxiadis 1960 plan, leaving MEFIT in 1975 with more issues to account for in their master plan. However, Doxiadis 1960 and MEFIT 1975 plans were agricultural development-oriented.

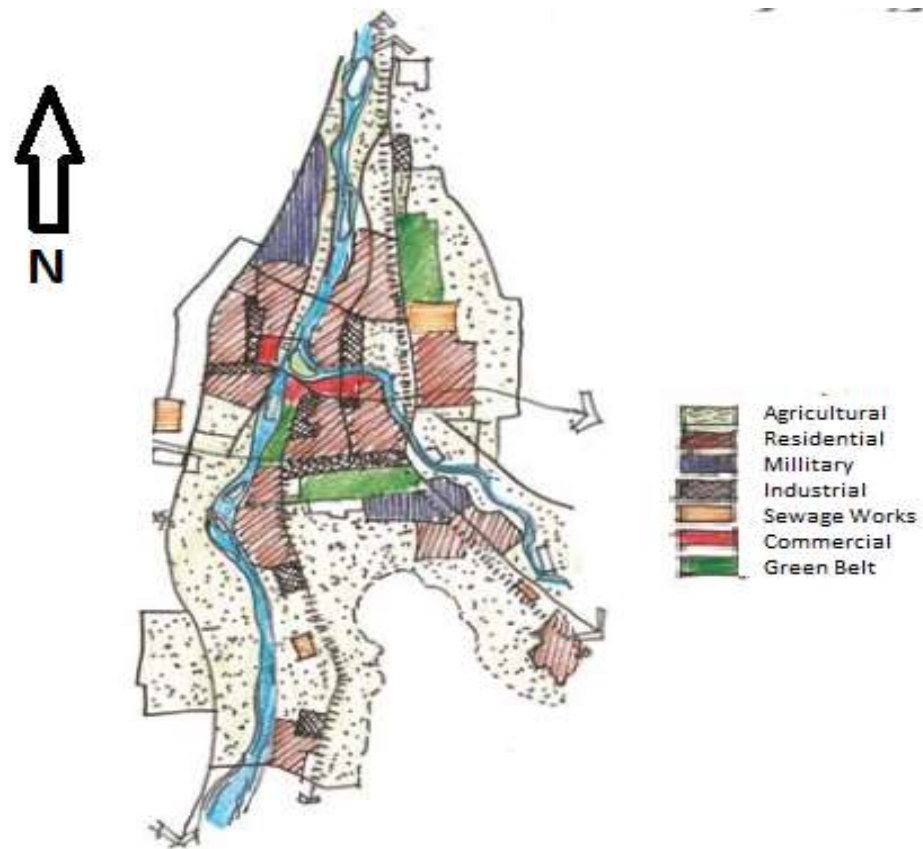


Figure 7 MEFIT's 1975 Plan for Greater Khartoum (Source: Habitat 2009).

The period from 1975 to 1990

In MEFIT's 1975 plan, the government introduced site-and-services to drive and direct housing supply which became dominant in the 1960s and became the primary housing supply approach. Doxiadis plan allocated differently sized plots for the housing classes with equal distribution of schools, markets, and local health clinics (Hafazalla 2006:114) cited his literature (Hafazalla 1984). Hafazalla, in his 1984 and 2006, mentioned the income group with the corresponding plot size in square meters '*the lowest income group 108 – 135, the low-income 135 – 252, the high – income 315 – 592, the highest-income 595 – 840*'.

The sprawl of squatter settlements around Khartoum was the product of several disorganized and intersected elements. These main obstacles that hampered the performance included a general weakness of planning institutions, lack of finance, and political instability. By 1985, Khartoum was surrounded by squatter settlements, as shown in figure 8, at the expense of agricultural lands. While the administration was unable to tackle the issue, this random settling reached 50% of urban at that time, which poses a challenge to governance and law rule (Habitat 2009).

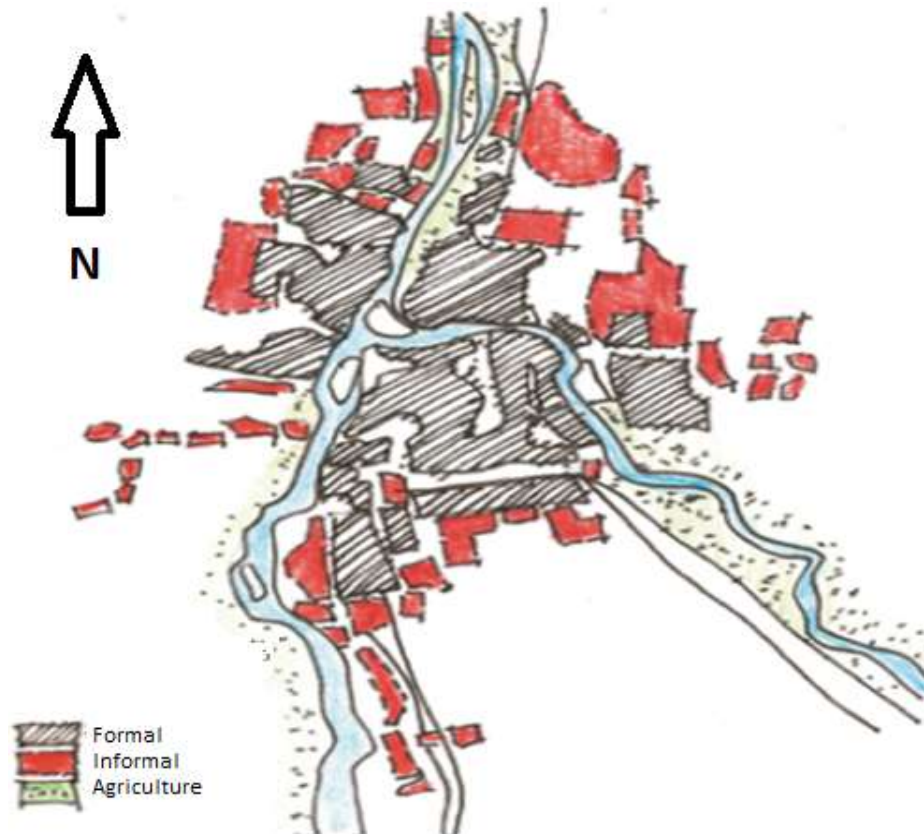


Figure 8 Squatter settlements around Khartoum in the 1980s (Source: HABITAT 2009).

Doxiadis and Mustafa 1990 – 2000

As established above, the Doxiadis 1960 plan was agricultural development-oriented and did not focus on housing. Doxiadis Associates and Abdelmonem Mustafa Partners Consultancy focused on Khartoum's leapfrog growth time rendered the squatter settlements in the 1980s (Hafazalla 2006; Habitat 2009). Hafazalla (2006) articulated that modeling population growth defined the plan's approach and considered the predicted development of Khartoum. The consequences of land consumption through site-and-services housing coupled with self-help housing and slum upgrading along with the urban city boundaries, both plans are shown in figure 9.

The site-and-services housing approach became popular in the 1970s to solve housing problems when major African cities with a high level of services attracted rural migrants and increased housing demand (Hafazalla 2006:73). Despite the relative economic stability during the 1970s compared to the present, the government's contribution to housing was limited. The limited contribution has led to the introduction of sites-and-services as the alternative approach (ibid). However, Hafazalla (2006) suggested that sites-and-services' appropriateness comes from the lack of more appropriate alternatives; this can be reflected in the principle of considering localizing services into the neighborhood. Patel et al., (2018) argue that since sites-and services housing is allocated to low-income groups, it should be supported with affordable transit to reduce household expenditures and enhance their socio-economic status.

Khartoum sites-and-services housing was incorporated into the national housing policy to respond to the growing slums and squatters around the city to upgrade mud and mud bricks houses near Khartoum's industrial areas' districts which were known as *Ad-Deum*. According to Hafazalla (2006), sites-and-services housing started when the demand for labor in Khartoum increased in the 1940s, but no services were provided, more in high-income neighborhoods. The upgrading process included the demolition of *Ad-Deum* and replaced by New *Deims* planned with shops and service to create local destination economies.

At that time, Hamdan (1960) criticized neighborhood upgrades and suggested no significant difference from the old *Deims*. However, sites-and-services neighborhoods did not receive as much development as the high-income neighborhoods such as Al-Amarat (The multi-storey concrete buildings) in terms of infrastructure, sewage, drainage, and telephone lines (Hafazalla 2006). The low-income housing policy aims to subsidize land at reasonable prices to low-income groups in the form of sites-and services by allowing households to build their homes through self-help to increase low-income housing affordability (ibid). The state ministry employed a set of control strategies by demolition, replanning, relocating, and incorporation. The state government applied the different approaches to different settings, from demolition to illegal settlements that block a neighborhood development or public roads, relocating solutions in seasonal flood ducts, and facing the same fate as its predecessors (Habitat 2009). Doxiadis Associates and Abdelmonem Mustafa Partners Consultancy adopted housing classification as a housing subdivision tool that corresponds to income levels forecasts (Hafazalla 2006).

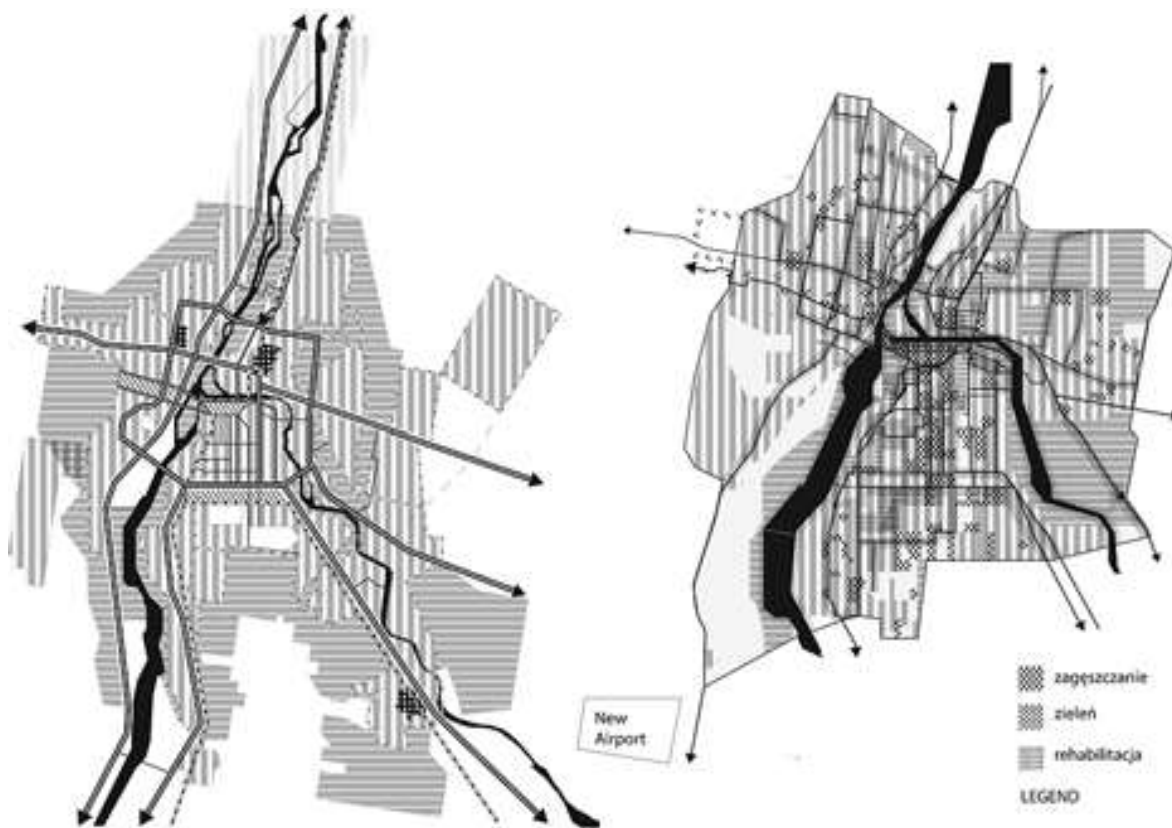


Figure 9 Doxiadis and Mustafa 1990 – 2000 (Source: Zuhail 2016).

The master plan 2000 – 2007

The latest master plan 2000-2007 aimed to deal with mobility using high roads and relocating settlements⁵ in flood ducts under re-planning schemes, as shown in figure 10. The re-planning scheme consists of housing-oriented strategies towards eradicating informal settlements, land price control, rent control, and the green belt to limit the squatter settlements (Habitat 2009). Suleiman (2007) argues that from 1990 to 2000-2007, plans employed strategies to relocate populations by demolition, which bought up the British colonization policy. The strategy implemented by the structural plan ignites conflicts social, political, and ethnic hurdles (Habitat 2009) attributes the strategies to political opposition reasons, in a similar way the colonial government excluded that Sudanese to the peripheries (Pantuliano et al., 2011).



Figure 10 The structural plan 2000-2007 (Source: Hamid and Bahreldin 2013).

The Structural plan 2007-2033

The Ministry of Physical Planning and Public Utilities designated the Italian firm MEFIT between 2007 and 2010 in collaboration with academic institutions in Sudan (Pantuliano et al., 2011). The plan mainly aimed to reintegrate the city's neighborhoods through a network of roads and transport systems and dissolve the ethnic structure and concentration, as shown in figure 11 (ibid). Easing traffic congestion in the city

⁵ The map in figure 10 is the only map available for Khartoum's structural plan 2000-2007.

center, replacing squatters with public housing, and relocating government and educational institutions to the city's outer parts were core objectives of the plan (Pantuliano et al., 2011).

Extending services to low-income neighborhoods, economic improvements, environmental concerns, and pollution were central to the plan's approach. Still, the plan failed to address the vulnerable (Pantuliano et al., 2011). There is no transparent approach to address housing affordability within this plan. However, service provision and roads to the peripheries were central to the plan. The Structural Plan 2007-2033 is the first plan to be officially endorsed at the executive and legislative level and enacted as a law in Sudan.

Pantuliano et al., (2011) Some projected projects are being implemented out of the master plan, and a wide range of conflicts in implementing the plan, such as land use schemes, road construction, and bridges that contradict other land uses. Pantuliano et al., (2011) stressed the MPUPP concerns to avoid demolition to regulate informal settlements. The government offers compensation to cover demolition but does not reflect the market value but developed conflict resolution to negotiate compensation with residents.

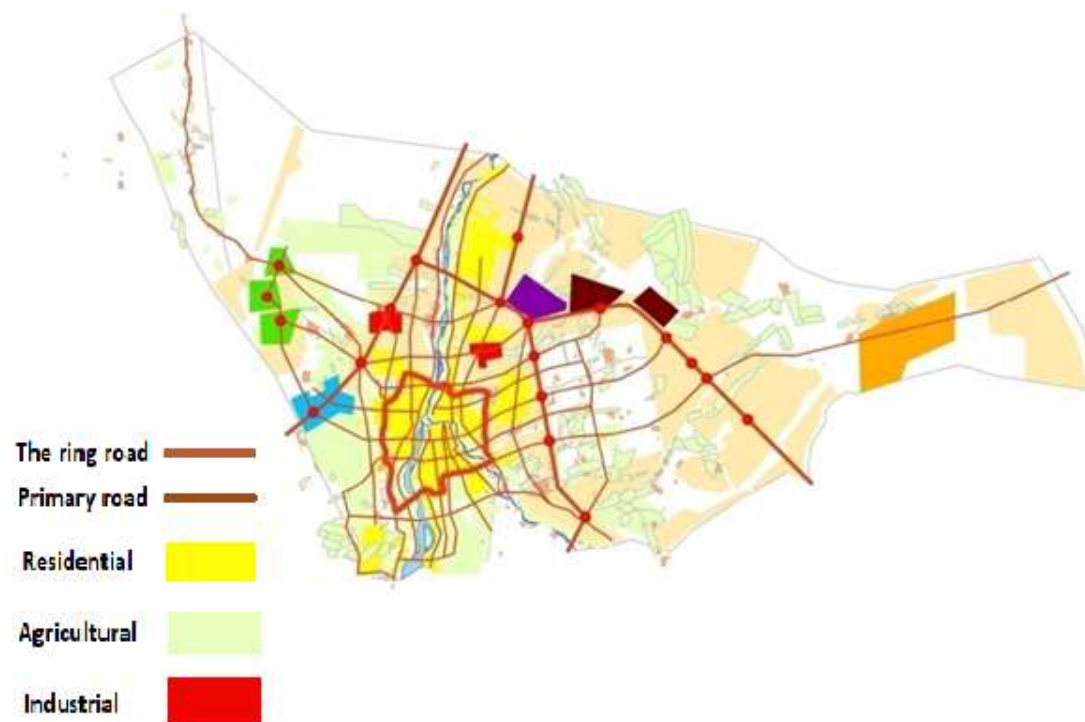


Figure 11 Khartoum Structural Plan 2007-2033 (Source: Ministry of Physical Planning and Development 2010).

Land prices and housing affordability

According to the African Development Bank, 36.1% of the Sudanese population is below the global poverty line. Feather and Meme (2019) reported that more than 80% of the Khartoum population are low-income. However, it is imperative to consider low-income households when addressing housing affordability; the

wages of Khartoum low-income households are well below GDP per capita (Sudan and UNICEF 2016; Feather and Meme 2019). With the limited options for adequate housing, Sudanese households have to meet their housing needs through informally and squatter settlements which can be recognized as a trend since the 1980s, as shown in figure (5).

Feather and Meme (2019:244) stated that *'Decent housing is not affordable for most Sudanese households'* the inflation in the Sudanese economy had further burdened housing affordability for the low-income. The cheapest house built by a formal contractor at 120 square meters had a cost of SD698,045.3 (US\$15,400) at 2019 exchange rate⁶, the mortgage structure was ten years with a 60% down payment at 14% interest rate, the monthly payment to meet the mortgage was SD13,054.4 (US\$287.98) (Feather and Meme 2019). The majority of the empty plots in Khartoum neighborhoods remained undeveloped, mainly due to the moratorium on property loans imposed by the Central Bank of Sudan, which was lifted in 2019 (Feather and Meme 2019). Another reason is the increasing costs of construction. These factors collectively have rendered more than 50% undeveloped plots across Khartoum's neighborhoods (ibid).

The housing market is segmented into three categories, the high-income segment with direct lump-sum payments. The middle-income professionals with consistent income and eligible for a mortgage prefer incremental housing, and the rest of the low-income households with low access to mortgage and finance (Feather and Meme 2019). There are 31 commercial banks in Sudan and six specialized banks, including banks from the United Arab Emirates, Qatar, Egypt, Lebanon, and Jordan, with less than 2% accounting from non-bank financial institutions. However, the government represents 41% ownership of the entire sector, and the Real Estate Commercial Bank [RECB] was founded in 1966 as the leading housing financing institution (Feather and Meme 2019).

The RECB provides housing finance to government employees and borrowers with stable and regular income and mortgages on a non-interest base, *'Murabaha'* with the loan agreement and conditions. The property should be new construction and be located in greater Khartoum (Feather and Meme 2019). The Central Bank of Sudan [CBoS] enacted a moratorium on property loans for government housing posed another challenge to financing the housing industry. Still, in 2019 the moratorium was lifted after five years from 2014 when the CBS seized real estate financing, including investment in land and housing development (ibid). Lifting the moratorium resulted in a recession on housing projects funded through real-estate and investment banks and shifted their investment out of the real estate market.

The construction sector experienced positive growth between 1983 to 2005 due to national development projects for infrastructure around the city. The construction industry became the largest share in the Sudanese economy after South Sudan's independence in 2011 (Feather and Meme 2019). Despite the construction sector's growth, the housing deficit remains at 2.5 million units in Khartoum. The government established the National Fund for Housing and Reconstruction [NFHR] in 2008 to provide low-cost housing unities for the low-income (ibid). Despite the 736SP million (16.2USD\$ million) to fund housing, the NFHR could not mobilize construction funds due to the high cost of building materials, importing fees and local fees on building materials inflated costs submitted to the banks, which is

⁶ 1 USD = 45.33~ SD (2019 Exchange rate).

conceived as a lending risk. According to Feather and Meme (2019), the affordable housing market is divided into three categories based on income level:

- A. The high-income households could pay for lump-sum purchases.
- B. The upper-middle-income with regular income-eligible for but mortgages prefer incremental construction due to housing finance fees (most of the units are incomplete).
- C. The low-income who can access microloans.

It is essential to mention that 80% of households are low-income and below the Gross Domestic Product (GDP) per capita, have limited housing options, and 50% of Khartoum residents live in informal settlements, leaving most low-income households seeking their housing needs through informality.

Conclusion

In this chapter, we reviewed the research method and the context of the study area. The methods represent the application of econometric modeling using spatial regression to test the determinants of residential land prices and housing affordability. And use spatial interpolation to derive a continuous surface for housing affordability to make sense of the spatial pattern of housing affordability with distance from the CBD. The literature suggests that econometric modeling is essential to understand the spatial dynamics of residential land prices and property prices within the urban form's complexity.

Chapter Four: The preliminary findings: Discussing the determinants of residential land prices and housing affordability in the context of Khartoum expansion

This chapter is divided into two main sections. The first section is divided into two sub-sections: fieldwork and data collection, consisting of data preparation and descriptive statistics. The second sub-section deals with preparing the residential land prices models, housing affordability, calculating the housing affordability index, and using the interpolation to generate the continuous surface for housing affordability and present the findings.

The second section of this chapter consists of two sub-sections. The first sub-section presents the analysis derived from the OLS, GWR regression models, and the HAI findings' spatial interpolation compared to the literature. The final sub-section concludes with a summary of the findings and analysis presented and leads to the report's conclusion.

Fieldwork and data collection

There are two types of data necessary for this research: numerical data in estimates of sampled plot prices and construction cost from 18 neighborhoods in greater Khartoum. The sample is representative of the study area. There are more than 40 neighborhoods in Khartoum. The neighborhoods were selected randomly to represent the study area. The plot prices samples were collected from real estate agents through maps with points indicating the required estimates' locations representing the neighborhoods. The estimations are included in the attribute of the neighborhood's spatial representation. Residential land size measure in square meter and length of the plot façade measured in meters are extracted from satellite imagery and included in the neighborhoods' attribute table.

The second type of data is open-source geographical data obtained from OpenStreetMap represented in point, lines, and polygons, depending on the feature to be represented. For instance, roads are represented as line features, hospitals, and schools as points, the CBD as polygon feature. The estimations were entered into the point feature class's attribute tables to represent the samples geographically and used for the regression analysis and derivation of the Housing Affordability Index [HAI].

The construction cost estimations were provided by contractors based on the neighborhood class⁷ and construction standard designated for each neighborhood class. Average plot prices and construction costs are used to calculate the average housing cost for each neighborhood. The construction cost is calculated by multiplying the plots' maximum build-up area by the estimated construction cost per square meter to derive the total housing cost and then derive the HAI. HAI is calculated for each neighborhood from the attribute table. For the detailed attribute tables, look at (appendix A and B). (Appendix A) shows an attribute table of a neighborhood. The rows represent the samples, and columns represent each sample's data, the price per square meter, size, plot price, maximum built-up area, construction cost, and the HAI.

⁷ Neighborhood class in this case is similar to the land classes designated by the Land Registration Act 1925 to regulate neighborhood by income.

(Appendix B) shows the neighborhoods attribute table containing the averages for the dependent and explanatory variables. The variables' abbreviations are provided in (Appendix C) for ArcMap 10.5 does not allow long names for the attributes.

It is essential to understand the link between the numerical and geographical data, the land prices, construction costs. The calculated HAI and the distances are entered into the neighborhoods' attribute table as explanatory variables for regression analysis of residential land prices and the HAI and present the findings in a spatial context.

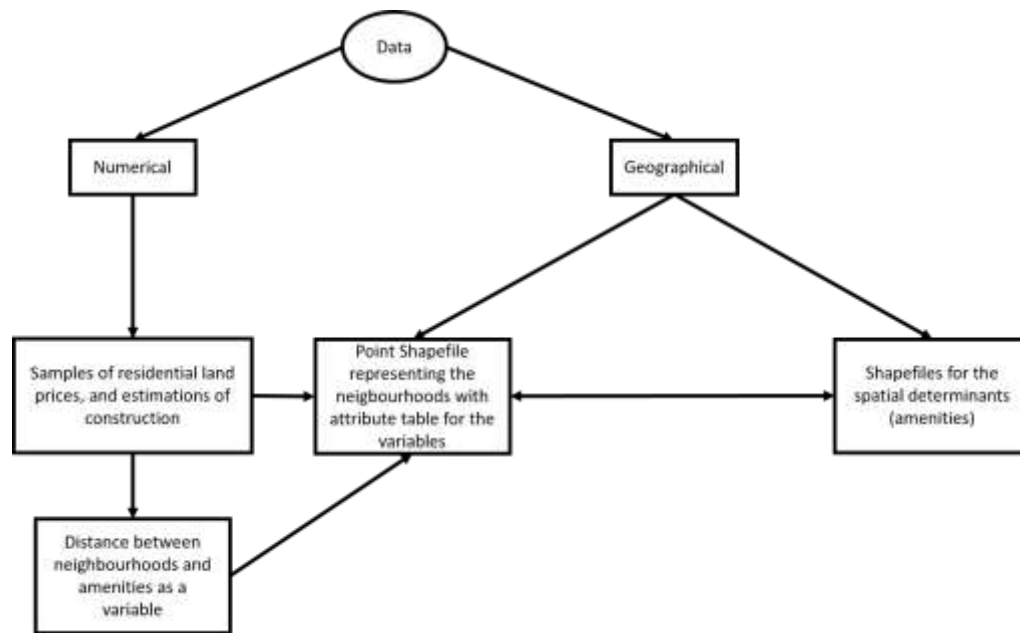


Figure 12 Data description (Source: Author's Own 2021).

Figure 12 illustrates the data structure and how the different data types relate to one another. The arrows show the direction of the data levels, numerical and geographical data. The numerical data has two components, and the first contains land price samples, construction costs, and the calculated HAI. Land prices and the HAI are the dependent variables for the regression analysis. The second component of the numerical data residential land characteristics and the distances between neighborhoods and amenities measured in meters using the ArcMap distance tool. These characteristics and distances are the explanatory variables to model residential land prices and the HAI.

The geographical data also has two components, and the first is the point feature class with an attribute table to represent the neighborhoods. The attribute table includes the dependent and the explanatory variables. The second component of the geographical data is feature classes representing the amenities and calculating their distances to the neighborhoods. These distances are entered into the attribute table of the neighborhoods for the regression models. The arrow linking the amenities to the then neighborhoods represent the distance relationship used to explain the residential land prices and the neighborhoods' HAI.

Data preparation

Data preparation is the first step in spatial statistical analysis and starts with data entry of the samples collected into the geographical data points' attributes. Descriptive statistics for samples are presented in the section below. The construction cost and total housing cost are calculated using the attribute field calculator in ArcMap 10.5 from the plot area to derive housing affordability.

Plot characteristics are derived from the satellite base map by measuring the plot area and the length of the plot's façade. As designated in the neighborhood class description, the built-up area should not exceed 2/3 of the neighborhood classes' plot area. Construction cost is calculated by multiplying the built-up area by the contractors' estimated average construction cost per square meter, as shown in table 1.

Residential land Class	Minimum plot area (in square meter)	Minimum standard of building materials	Maximum built-up area	Medium construction cost according to contractors
Class 1	550+	Permanent load-bearing (burnt bricks, cement bricks, concrete)	2/3 of the plot area	USD\$ 500 per square meter (for a single storey)
Class 2	350-400	Bricks, cement, mortar, <i>gishra</i> (a mix of cement and fine sand to cover the outer façade, inner façade with mud bricks)	2/3 of the plot area	Between USD\$ 300 and USD\$ 400 per square meter (per storey)
Class 3	200	<i>Gishra</i> , <i>galoose</i> (Mud)	2/3 of the plot area	Less than \$100

Table 1 shows the housing classes and building specifications (Source: Pantuliano et al., 2011).

The bar chart in figure 13 highlights the average residential land prices, construction cost, and total housing cost; residential land prices are costly compared to the construction cost. The majority of the housing cost is the price of land. The ratio of land price to construction cost shows that land is costly compared to the construction cost. Elzobier (2009) article suggests that Khartoum's residential land is more expensive than the USA, Egypt, among other countries. Hence, it is vital to investigate the spatial determinants of residential land prices across the sampled neighborhoods.

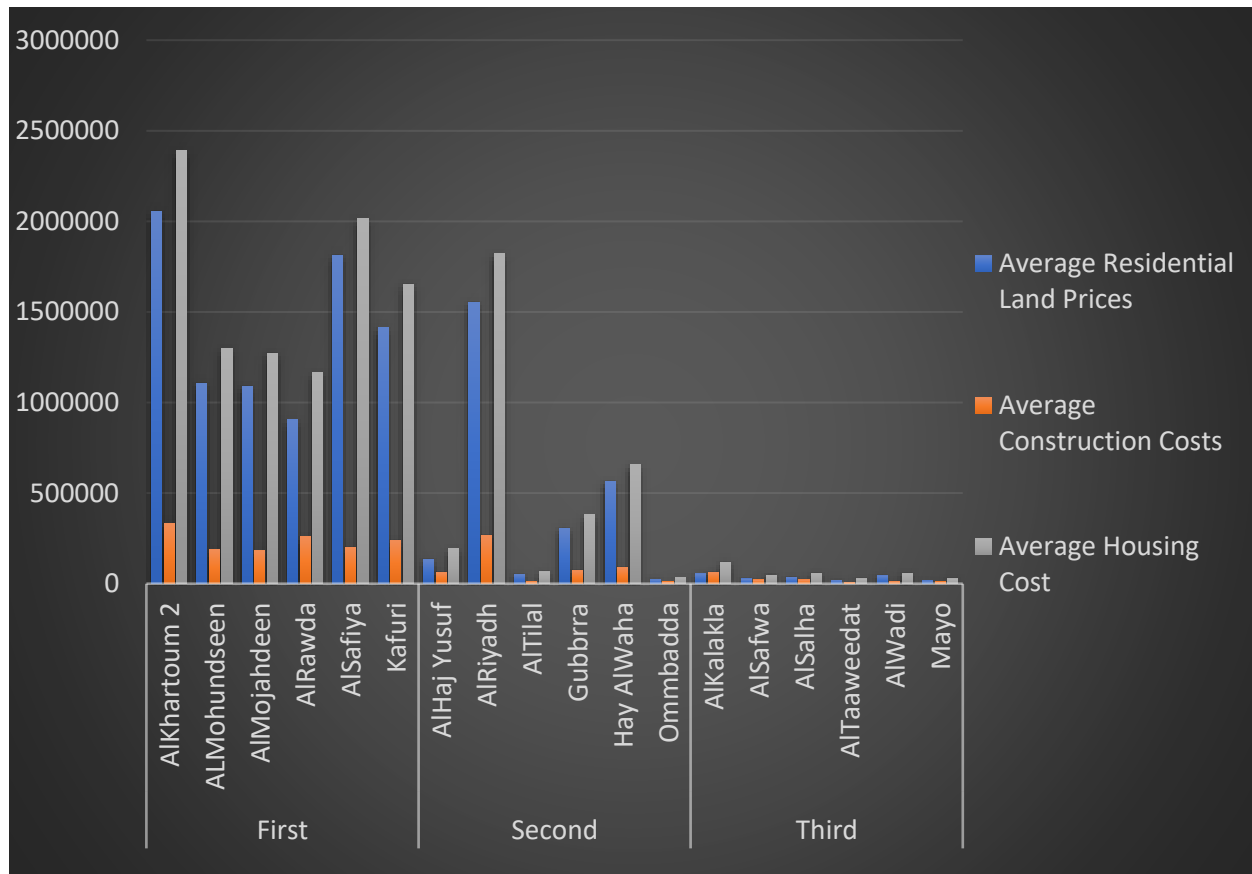


Figure 13 Average residential land price, Construction Cost, and the total housing cost (Source: Author's Own 2020).

Descriptive statistics

The total number of the samples collected is 822 samples from 18 neighborhoods in greater Khartoum, with an average of 45 samples for each neighborhood; estimations used are collected in June 2020, and prices change due to the market change in fiscal policy in 2021. The estimations are residential land prices in US Dollars per square meter; the average residential land prices per neighborhood are used to model and derive the HAI. According to the realtors, the first-class plot price difference may range from 10 to 35 dollars, second-class neighborhoods. The error ranges between 15 to 30 dollars and third-class neighborhoods between 10 to 20 dollars per square meter, as detailed in Table 2. The descriptive statistics for the explanatory variables are presented in Table 3.

Neighborhood Name	Neighborhood Class	Number of Samples	Plot Price Samples				
			Maximum	Minimum	Mean	Standard Deviation	Sample Error
Kafuri	First	73	2112180	231000	1412695	351752	10 to 35 USD\$ per square meter (22,000.0 USD\$ for an average sized residential plot)
Al Khartoum 2	First	58	5362000	622200	1758262	1025147	
Al Rawda	First	35	1843750	413100	904961	338430	
Al Mohundseen	First	48	2234250	403760	1107498	268246	
Al Mojahdeen	First	32	2012620	515000	1090398	296471	
Al Safiya	First	45	478800	756000	184122	715308	
Gubbrra	Second	29	670625	154350	306792	97449	15 to 30 USD\$ per square meter (13,750.0 USD\$ for an average sized residential plot)
Al Riyadh	Second	80	391680	632320	1553944	559248	
Al-Haj Yusuf	Second	77	180400	84000	131233	24753	
Al Tilal	Second	44	98842	24500	52380	18378	
Hay Al Waha	Second	53	880000	294000	567021	129708	
Ombadda	Second	31	79200	4160	23590	15084	
Al Kalakala	Third	40	119850	26400	54451	19439	10 to 20 USD\$ per square meter (7,000.0 USD\$ for an average-sized residential plot)
Al Wadi	Third	44	76875	21000	4425	10182	
Al Safwa	Third	30	35150	17160	26529	4795	
Al Sallha	Third	34	75758	21752	35874	11719	
Al Taaweedat	Third	32	36960	13650	19327	5371	
Mayo	Third	37	32640	8160	16523	5533	

Table 2 Descriptive statistics for the Sampled residential land prices (Source: Author's Own 2020).

The descriptive statistics for residential land prices show that first-class neighborhoods are the most expensive neighborhoods ranging between 1,090,398.0 to 1,107,498.0 USD\$ and error⁸ is estimated between 22,000.0 USD\$ to 25,000 for an averaged size plot. *Al-Khartoum 2* is the most expensive neighborhood within the sample. The average residential land price of an average-sized land (996 square meters) is 894,589.66USD\$. An average-sized residential land (435.33 square meters) in second-class neighborhoods costs an average of 439,160 USD\$. The most expensive second-class neighborhood is Al-Riyadh neighborhood, with an average residential land price of 1,553,944USD\$ for an average residential

⁸ Error estimate in table 2 are given in US dollars per square meter of land, but presented as an error for averaged size residential land.

land size of 801 square meters. In the third-class neighborhoods, an average-sized residential land costs 26,188.16USD\$ for an average plot size of 200 square meters, the most expensive third-class neighborhood is Al Kalakala, where an average-sized plot of 385 square meters costs an average of 54,451USD\$.

Variable	Maximum	Minimum	Mean	Standard Deviation
Average Distance to Schools (In meters)	7263	257	1336.05	1657.26
Average Distance to Secondary Roads (In meters)	949	125	371.44	22193398
Average Distance to Hospitals (In meters)	9431	282	2195.16	2330.79
Average Distance to Markets (In meters)	7974	351	1209.16	1657.11
Average Distance to Mosques (In meters)	1253	139	337. 44	236.59
Average Distance to Police Stations (In meters)	5000	320	1254.66	1389.44
Average Distance to Primary Roads (In meters)	1141	62	273.22	237.52
Average Distance to Industrial Corridor (In meters)	19894	624	7036.61	5909.95
Average distance to the Airport (Khartoum International Airport) (In meters)	27311	803	10808.77	6973.91
Average Distance to Commercial Corridors (In meters)	21399	804	8641.66	5450.45
Average Distance to Government Institutions (In meters)	24521	804	11366.27	6398.61
Average Land Size (In square meters)	996	228	521	221.55
Average Length of the plot's Façade (In meters)	87	14	37.11	16.55

Table 3 Descriptive Statistics for the explanatory variables (Source: Author's Own 2020).

Derivation of housing affordability index and the interpolation analysis

For the research, the housing affordability index is calculated for the different housing classes using average housing cost and average income⁹, a mortgage of 10 years, and a 14% profit of the total housing cost to secure finance based on the *Murabaha* principle (Feather and Meme 2019). The resulting index value represents the household income sufficiency percentage to afford the housing unit (Jewkes and Delgadillo 2010). The HAI value of 100 indicates that a medium-income household can afford the housing mortgage, and index values of less than 100 indicate a typical household cannot afford the housing mortgage (ibid).

⁹ The average income used in this case is the GDP per capita in US dollars for the year 2019 calculated in Sudanese Pounds (772.11USD = 35,000SD) for 2019 exchange rate at 1 USD = 45.33– SD.

Housing affordability index findings

Based on the estimation of total housing cost derived from residential land prices and construction cost, the calculated HAI. Figure 14 shows the HAI for the sampled neighborhoods; affordability increases in the low-income class neighborhoods, a medium-income household can afford only two neighborhoods of second-class neighborhoods, and most of the third-class neighborhoods. Al Tilal and Ombadda neighborhoods are only second-class neighborhoods affordable to a medium-income household with indexes of 113.04 and 256.39; the rest of the second-class's neighborhoods are not affordable to medium-income households. However, the third-class neighborhoods are the most affordable neighborhoods to medium-income households. Although second-class neighborhoods are designated as affordable to medium-income households, the findings indicate they are too expensive to afford. The findings indicate that medium-income households can only afford part of the second-class and most third-class; the latter is designated for low-income households.

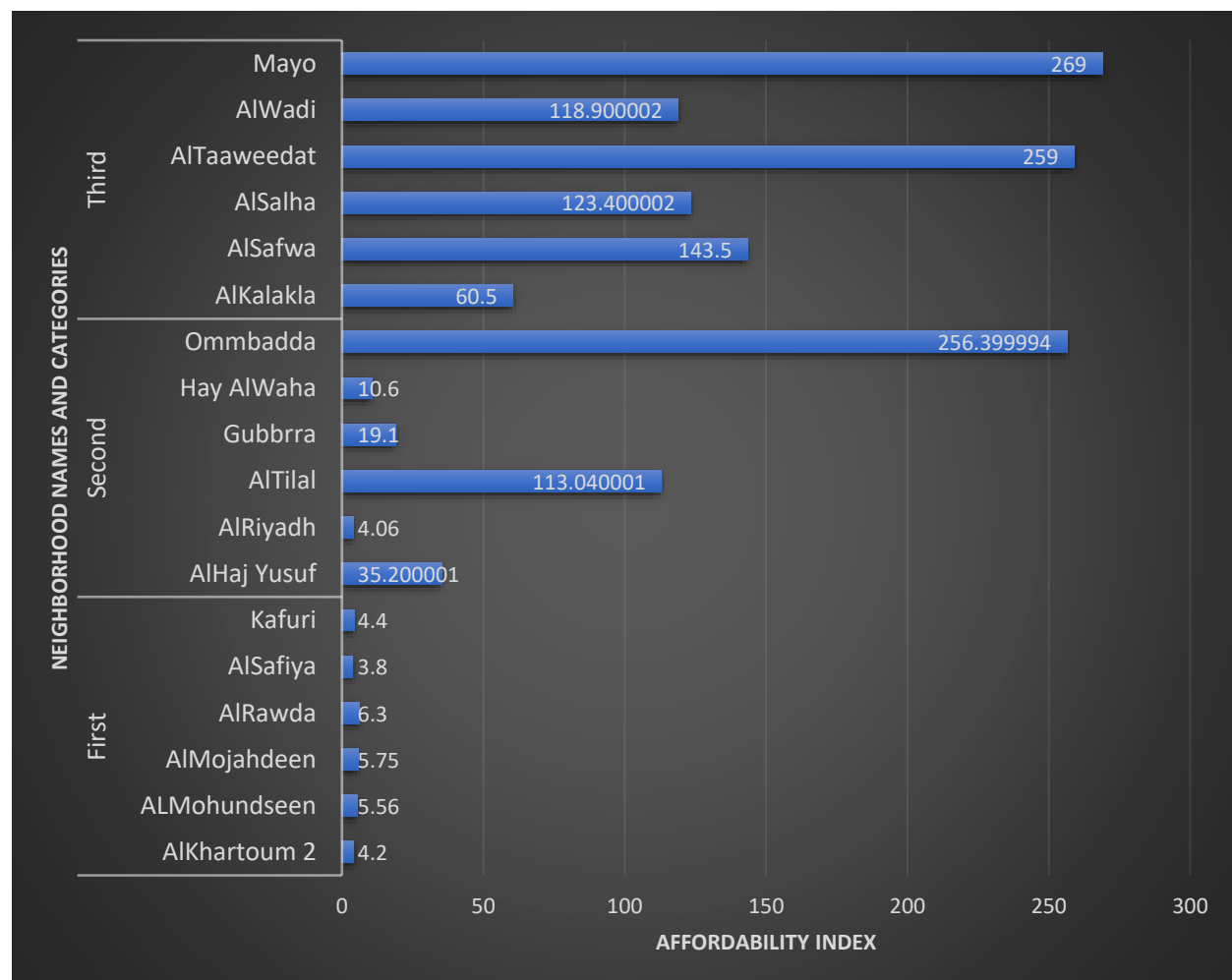


Figure 14 Housing affordability index per neighborhood (Source: Author's Own 2020).

The first-class neighborhoods are far from affordable to medium-income households with an average index of 2.02 which means the medium income covers only 2.02% of the mortgage, which is appropriate

for the designated housing standards. Based on the results, the medium-income household's ability to meet their housing need is skewed from the designated second housing class to the third housing class. The interpolation surface for the HAI in figure 15 shows the distance decay effect for housing affordability fading with the distance from the CBD outwards and moving away from the city center affordability increases.

The HAI calculation based on medium-income indicates that medium households cannot afford the majority of the second-class neighborhoods. But low-income neighborhoods are highly affordable to medium-income households. With medium-income households are left without affordable housing options, perhaps the low-income neighborhoods. In this case, the state housing affordability investigated could have implications on the accessibility of low-income households to meet their housing needs and increase housing prices due to the additional housing demand by medium-income households.

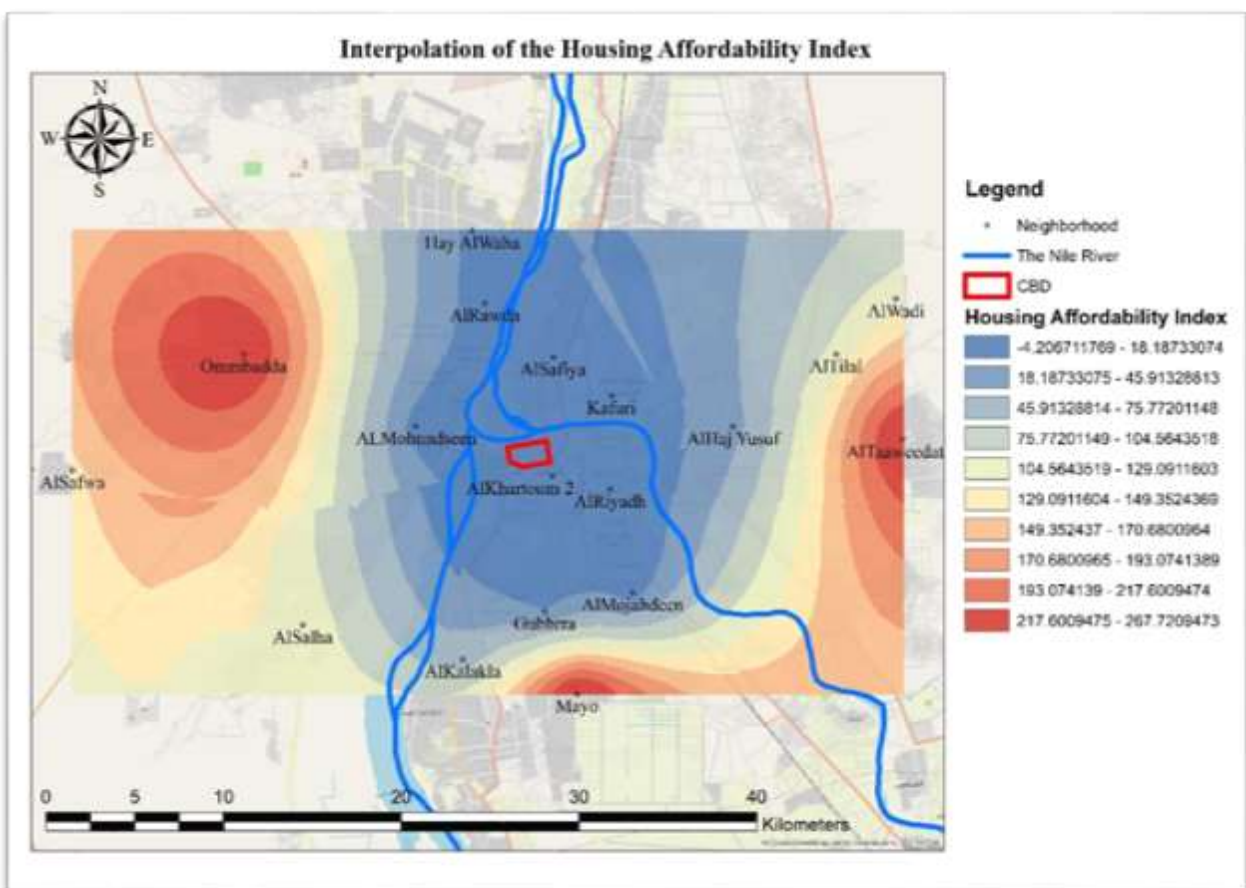


Figure 15 Interpolation surface for housing affordability of Khartoum (Source: Author's Own 2020).

The following section presents the regression analysis model to explore the factors affecting plot prices, followed by a section looking at the spatial variations in housing affordability.

Regression analysis

Finding a properly specified model depends on examining how the explanatory variables affect plot prices and housing affordability and derive spatial variations. The first step is finding the significant variables using exploratory regression in ArcMap, which evaluates all possible combinations of variables for properly specified OLS models that best explain the dependent variable. Exploratory regression OLS regression and spatial autocorrelation to avoid model bias and test the residuals for clustering in value or location. Exploratory regression tries every combination of the explanatory variables based on the specified model criterion shown in (Appendix D).

The second step is finding a properly specified OLS model using the significant variables of the passing exploratory regression models to explain the variation and how the explanatory variables influence residential land prices and housing affordability. It is essential to consider the OLS regression diagnostics shown in Table 4 below.

Diagnostic Name	Definition
AICc	Corrected Akaike's Information Criterion: second-order correction for small sample sizes.
AdjustedR ²	Adjusted R-Squared: R-Squared adjusted for model complexity (number of variables) related to the data.
F-Prob	Joint F-statistical Probability (p-value): The probability that none of the explanatory variables affects the dependent variable.
JB-Prob	Jarque-Bera Probability (p-value): The probability that the residuals are normally distributed.
Sigma2	Sigma-Squared: OLS estimate of the variance of the error term (residuals).

Table 4 OLS diagnostics.

The final step is exploring spatial variation the explanatory variables have on the plot prices and housing affordability by using GWR. The regression analysis results in ArcMap are presented in the form of reports and maps inside the software. Model diagnostics are also presented as part of the report for model tests and validation.

The third step derives the spatial variations in residential land prices and housing affordability using the GWR model; GWR creates a model with a local measure for each variable's relationship to the dependent variable and generates coefficients explanatory variables. The following sections deal with the GWR models and details how the variables affect the plot prices. The two adequately specified OLS models' variables can be examined for local variation and coefficient variance using GWR across the study area. When interpreting GWR results, it is crucial to consider the different GWR diagnostics shown in Table 5 below to determine which GWR model is best to explain the variations. The diagnostics include standard errors for coefficients and residuals, the effective number, a trade-off between the fitted values' variance and the bias in the coefficients, and the AICc measure for model performance.

Diagnostic	Definition
Bandwidth	The number of neighbors used to calibrate the local estimations.
Residual Squares	The sum of the squared residuals in the models.
Effective Number	A measure of variable bias is calculated based on variable variance and the coefficients.
Sigma	The estimation of standard deviation for the residuals.
AICc	A measure of model performance derived from Sigma value.
R^2	A holistic measure of the model goodness is measured from the sum of the squared dependent variable value (denominator). Additional variables influence the R-squared value.
Adjusted R^2	A normalized R-squared values by using the denominator degrees of freedom.
Dependent Field	The variable under investigation.
Explanatory Field	Explanatory variables.

Table 5 GWR diagnostics.

AICc is a measure of model performance that comes with the GWR results to compare multiple GWR models. When subtracting AICc two values of some models, if the difference is more than 3, the lower AICc is the best fit for OLS. The final diagnostic is the adjusted R^2 which is a normalized multiple R^2 to ensure model validity.

The models' validity is measured by how well the model assumptions are achieved. In the spatial analysis, the statistical procedures are robust, which means only extreme violations of the model assumptions reduce confidence in the model. In each of the regression models explained below, the model diagnostics are referred to within the analysis.

Figure 16 dissects the regression procedure for plot prices and housing affordability. The first step is exploratory regression. The second step is the OLS regression model, and the third is the GWR model.

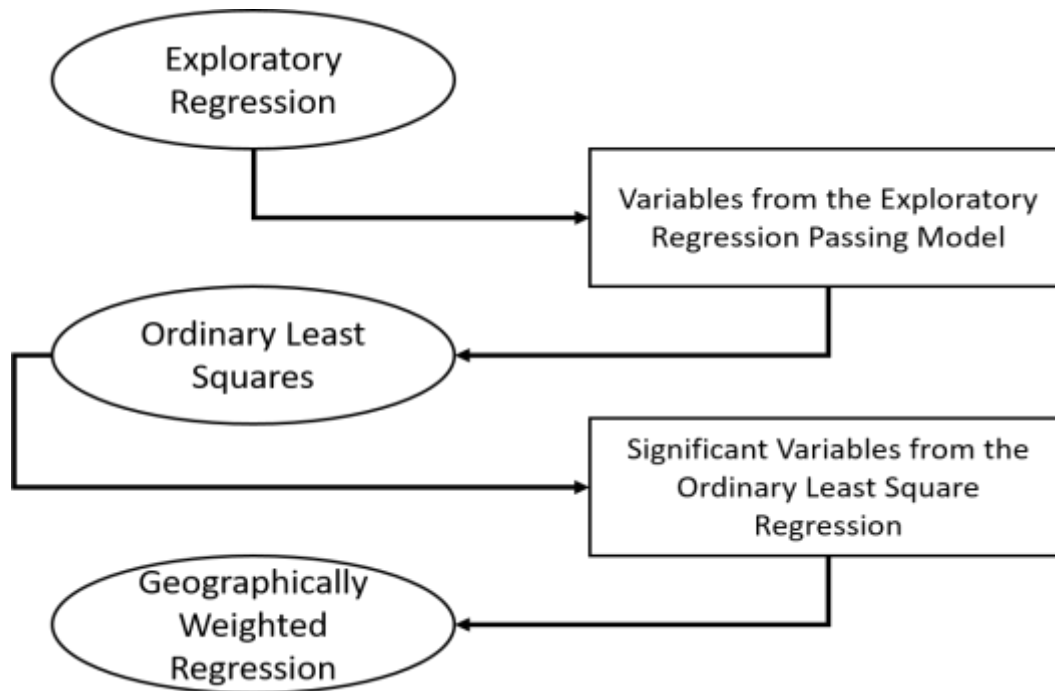


Figure 16 shows the spatial analysis and regression procedure (Source: Author's Own 2020).

Regression analysis of residential land prices

This section discusses the regression analysis results based on the spatial analysis procedure. As shown in figure 16—the exploratory regression results shown two specified OLS models used to derive the OLS and GWR models. The chapter then concludes by contrasting the findings from this research to the literature and summary.

Exploratory regression

The exploratory regression for modeling plot price has two passing models (Model 1 and Model 2) shown in figure 17 against the default model assumptions. The first has an adjusted $R^2 = 0.83$ with a VIF value of 2.13 for the variables, average distance to secondary roads, the average distance to the CBD, and the average plot façade length. The second passing model has an adjusted R^2 of 0.78 with a VIF of 1.93 for the variables, average distance to secondary roads, the average distance to police stations, and the average distance to the CBD, all the variables in both models are measured in meters.

Choose 3 of 8 Summary									
Highest Adjusted R-Squared Results									
AdjR2	AICc	JB	K(BP)	VIF	SA	Model			
0.83	514.28	0.70	0.78	2.13	0.49	-AVGSECRO**	-DISCBD***	+AVERFACADE***	
0.80	517.77	0.74	0.31	2.04	0.31	-AVGHOS	-DISCBD***	+AVERFACADE**	
0.80	517.87	0.43	0.67	2.98	0.88	-CLASSREP	-DISCBD*	+AVERFACADE**	
Passing Models									
AdjR2	AICc	JB	K(BP)	VIF	SA	Model			
0.834831	514.275443	0.699440	0.784027	2.130201	0.487819	-AVGSECRO**	-DISCBD***	+AVERFACADE***	
0.785186	519.005880	0.525891	0.360653	1.938270	0.286157	-AVGSECRO**	+AVGPOLICE**	-DISCBD***	

Figure 17 Exploratory regression summary of results for residential land prices (Source: Author's Own 2020).

Residential Land Prices $\int$ AVGDISECROD + AVGDISCBD + AVGFACADE (Model 1)

Residential Land Prices $\int$ AVRDISSECROD + AVGDISPOL + AVGDISCBD (Model 2)

Where:

AVGDISECROD: Average Distance to Secondary Roads

AVGDISCBD: Average Distance to the CBD

AVGFACADE: Average Length of the Plot Façade

AVGDISPOL: Average Distance to Police Stations

The exploratory regression results indicate the likelihood of explaining plot prices with two different models and a set of variables. The significance and impact of the variables are the same for the two models, as shown in Table 6 below:

Variable	Percentage of Significance	Percentage of Positive Significance	Percentage of Negative Significance	VIF
The average length of the plot's façade in Meters	100%	100%	0%	2.71
Average distance to the CBD in Meters	77%	0%	100%	5.95
Average distance to secondary roads in Meters	14.14%	0%	100%	2.29
Average distance to police stations in Meters	9.09%	31.31%	68.69%	3.18

Table 6 Summary of exploratory regression variable significance for plot prices (Source: Author's Own 2020).

The variables with the highest significance, positive or negative, in the model are the variables that are consistent and most likely to construct a valid OLS model. The percentage significance¹⁰ referred to when the variable was statistically significant in the regression trials, positive and negative significance show how the variable was consistent in the models, and stable variables will have a consistent negative or positive significance. Table 6 above shows that the plot area was 100% significant and had a consistent relationship to prices, which indicates the plot area is a good predictor of prices. Still, CBD distance is 77% significant in explaining plot prices, and 100% had a negative relationship to prices. The secondary roads variable is 14.14% significant, and 100% of the regression trials recorded a negative relationship to prices. The police station's distance was 9.09% in explaining plot prices, and 31.31% had a positive relationship to price and 68.69% negative relationship to prices.

Ordinary Least Squares

Depending on the passing model from the exploratory regression, two models can explain plot prices. The two models' variables are used in the OLS model to derive the relationship types and coefficients. The input variables for the OLS models are the variables from the exploratory regression passing models. However, plot prices are explained in two OLS models adopted from the exploratory regression. An asterisk follows the OLS diagnostic looks at the models' significant variables. Data redundancy is measured by VIF value, randomness measure by the Jarge-Bera statistic, and the model performance measured with the adjusted R^2 values. The OLS results contain the information on the model diagnostics explained in Table 4.

¹⁰ Exploratory regression is a combination of OLS models using different set of variables. The variable significance refers to number of times the variable was statistically significant in the models and the consistency of the variable impact on the model.

OLS for the first set of variables

The first model explains plot prices by using the three variables: average distance to secondary roads, the CBD, and the plot's facade's length average, from exploratory regression to the first passing model. The variables explained 83% of the variations in plot prices ($R^2=0.83$) in figure 18. The negative value coefficient (-771.487201) for the average distance to secondary roads indicates a decrease in plot price by 771.48 USD\$ for every 1-meter increase in distance. The CBD distance, a negative value coefficient (-47.377675), indicates a decrease in plot price by 47.37USD\$ to every 1-meter increase in the distance. However, the length of the plot's façade has a positive coefficient (18983.477213), demonstrates an increase in plot price by 1898.347 USD\$ for every increase in the length of a plot facade by 1 meter. Figure 18 shows the model diagnostics, and figure 19 summarizes the OLS model results:

OLS Diagnostics			
Input Features:	Neighborhoods Center Po	Dependent Variable:	AVERAGE_PR
Number of Observations:	18	Akaike's Information Criterion (AICc) [d]:	514.275443
Multiple R-Squared [d]:	0.863979	Adjusted R-Squared [d]:	0.834831
Joint F-Statistic [e]:	29.641659	Prob(>F), (3,14) degrees of freedom:	0.000003*
Joint Wald Statistic [e]:	132.626796	Prob(>chi-squared), (3) degrees of freedom:	0.000000*
Koenker (BP) Statistic [f]:	1.071216	Prob(>chi-squared), (3) degrees of freedom:	0.784027
Jarque-Bera Statistic [g]:	0.714950	Prob(>chi-squared), (2) degrees of freedom:	0.699440

Figure 18 Shows the diagnostics for the first OLS model of land prices (Source: Author's Own 2020).

Summary of OLS Results - Model Variables								
Variable	Coefficient [a]	StdError	t-Statistic	Probability [b]	Robust_SE	Robust_t	Robust_Pr [b]	VIF [c]
Intercept	743840.57352	374878.88562	1.984216	0.067192	346365.62925	2.147559	0.049741*	-----
AVGSECRO	-771.487201	324.930152	-2.374317	0.032420*	167.274465	-4.612104	0.000405*	1.117831
DISCBD	-47.377675	15.557865	-3.045256	0.008731*	14.470142	-3.274168	0.005541*	2.130201
AVERFACADE	18983.477213	5846.669304	3.246887	0.005849*	4437.554392	4.277914	0.000768*	2.013245

Figure 19 OLS report for the first ER model of residential land prices (Source: Author's Own 2020).

OLS for the second set of variables

The second OLS model explained 78% of plot variations ($R^2=0.78$) in figure 20. This model's three variables are the average distance to secondary roads, the average distance to police stations, and the average distance to the CBD. The negative coefficient (-1181.776711) for the average distance to secondary roads indicates that plot prices decrease by 1181.77USD\$ for every 1-meter away from secondary roads. The average distance to the police station has a positive coefficient of (172.005366), showing an increase in plot price by 172USD\$ for every 1-meter closer to police stations. The average distance to the CBD has a

negative coefficient of (-99.852034), indicating a 2527.14USD\$ decrease in the plot's price for every 1-meter increase in the CBD distance. Figure 20 shows the second model diagnostics of the second model, figure 21 shows a summary of the second OLS model results:

OLS Diagnostics			
Input Features:	Neighborhoods Center Po	Dependent Variable:	AVERAGE_PR
Number of Observations:	18	Akaike's Information Criterion (AICc) [d]:	519.005880
Multiple R-Squared [d]:	0.823095	Adjusted R-Squared [d]:	0.785186
Joint F-Statistic [e]:	21.712801	Prob(>F), (3,14) degrees of freedom:	0.000016*
Joint Wald Statistic [e]:	96.447765	Prob(>chi-squared), (3) degrees of freedom:	0.000000*
Koenker (BP) Statistic [f]:	3.208010	Prob(>chi-squared), (3) degrees of freedom:	0.360653
Jarque-Bera Statistic [g]:	1.285324	Prob(>chi-squared), (2) degrees of freedom:	0.525891

Figure 20 Diagnostics for the second OLS model of residential land prices (Source: Author's Own 2020).

Summary of OLS Results - Model Variables								
Variable	Coefficient [a]	StdError	t-Statistic	Probability [b]	Robust_SE	Robust_t	Robust_Pr [b]	VIF [c]
Intercept	1981367.0040	192661.06220	10.284211	0.000000*	56139.95750	12.689686	0.000000*	-----
AVGSECRO	-1181.776711	414.310218	-2.852396	0.012787*	282.222144	-4.187399	0.000915*	1.397378
AVGPOLICE	172.005366	77.939777	2.206901	0.044518*	95.251792	1.805797	0.092494	1.938270
DISCBD	-99.852034	15.137950	-6.596140	0.000012*	11.911069	-8.383130	0.000001*	1.550677

Figure 21 OLS report for the second ER model of residential land prices (Source: Author's Own 2020).

The result of the first OLS model explains plot prices better with higher adjusted R^2 and higher Jarque-Bera as a measure of the degree of freedom, indicating that the residuals are normally distributed spatially and in value, but the GWR might indicate otherwise. However, as the OLS model is a suitable regression method to explore relationships, the results do not imply that explanatory variables will decrease with plot price changes. Still, changing proximity and plot characteristics will have the most effect on prices.

Geographical Weighted Regression

The GWR models are derived from the exploratory regression and the OLS model variables. The validity and confidence on the GRW depend on the model diagnostics, most notably the residuals and the difference between the models in AICc values. Table 7 below dissects the GRW models' diagnostics,

coefficients, standard residuals, and the local R-square (Appendix E and F) shows the summary of GWR models for residential land prices.

As mentioned above in the model diagnostics, the standardized residuals and the difference between AICc values are the most vital indicators of the best GWR model. The mean value and the standard deviation of the standardized residuals for the two GWR models are summarised in table 7 below. The second GWR model has a lower AICc value and therefore is better than the first model in explaining the spatial variations in residential land prices.

Diagnostic	Value		Meaning
Standardized Residuals in the first GWR model	Mean	Standard Deviation	The confidence level of the first model is higher.
	0.003966	0.991899	
Standardized Residuals in the second GWR model	Mean	Standard Deviation	The confidence level of the second model is lower.
	-0.001163	1.104606	
AICc	First Model	Second Model	The difference is 4.077595; the first model has a lower AICc value, making it the best GWR model.
	514.283437	518.361032	

Table 7 Summary of GWR models diagnostics (Source: Author's Own 2020).

The coefficients in GWR are given for every neighborhood explanatory variable; the average distance variables negatively affect plot prices, decreasing the distance from secondary roads and the CBD. In contrast, prices increase with the increase in the average length of the plot's facade. The local adjusted R^2 per neighborhood indicates the strength and type of the relationship between plot prices per neighborhood and the exploratory variables. On the one hand, the residuals measure the model over and under predictions. On the other hand, it is a measure of model bias. If the residuals are not normally distributed, then the model is biased. The residuals are the difference between the observed and the predicted values and are represented in the Jarque-Bera statistic. In the OLS model, the Jarque-Bera statistic is not significant, and the residuals are normally distributed, and the model is valid. The standardized residuals in the first GWR have a mean of 0.003966 and a standard deviation of 0.99, a good fit for the valid model criterion.

Visualization of Geographical Weighted Regression model for land prices

Figure 22 shows the strength of the relationship between plot prices, the average distance from secondary roads, the average distance from police stations, and the average length of each neighborhood's plot façade. The neighborhoods with the red and orange colors have the most robust relationship with the explanatory variables. Al Wadi and Al Taaweedat neighborhoods are the most affected by the explanatory variables, whereas Al Safwa, Sallha, and Ombbadda are the least affected. Value of the R^2 does not mean prices are higher or low, but what it means a change in the explanatory variables would have the most effect on land prices.

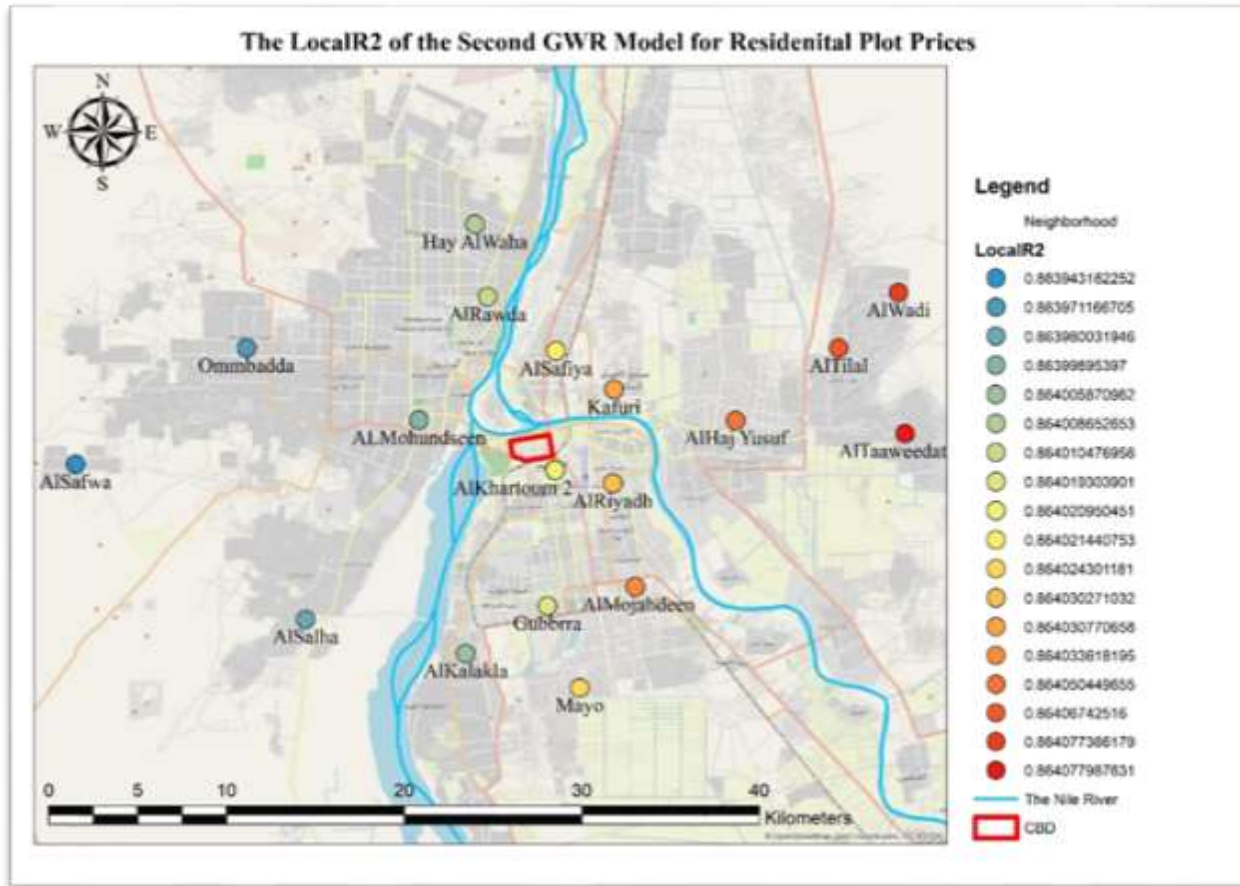


Figure 22 The map shows the local variations in R^2 values of the first GWR Model for plot prices (Source: Author's Own 2020).

The neighborhoods in figure 23 with the red and orange colors are affected mainly by the average distance to secondary roads. The negative coefficients indicate decreased plot prices for every 1-meter increase in average distance from the neighborhoods to secondary roads. The smaller the distance to secondary roads, the higher the prices. Plot prices in Al Safwa and Al Sallha neighborhoods are the most affected neighborhoods by average distance to secondary roads. On the contrary, Al Wadi and Al Taaweedat neighborhoods' plot prices are least affected by an average distance to secondary roads.

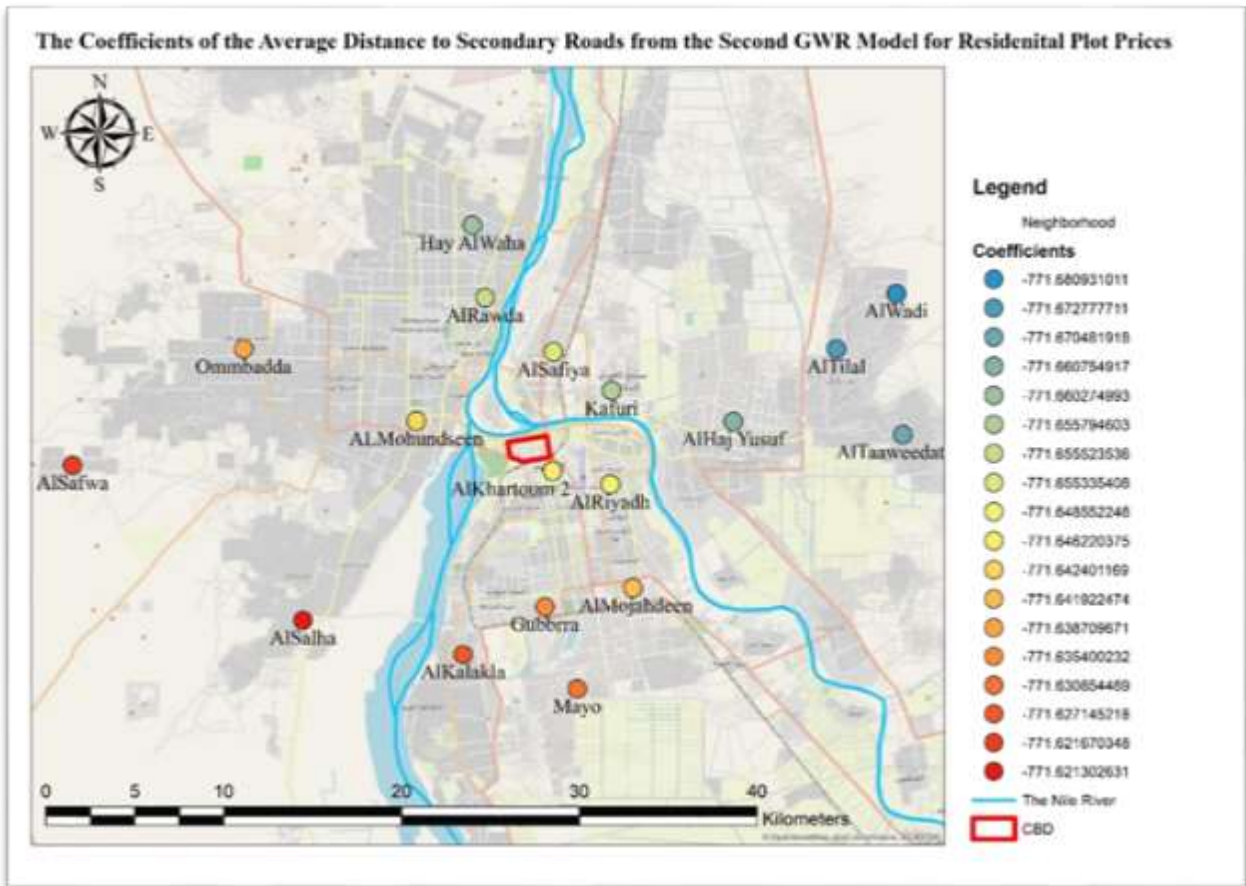


Figure 23 The map shows the coefficients of the average distance to secondary roads from the second GWR model for plot prices (Source: Author's Own 2020).

The neighborhoods shown in red and orange in figure 24 are affected mainly by the average distance to the CBD. The negative coefficients indicate decreased plot prices for every 1-meter increase in average distance from the neighborhoods to secondary roads. The smaller the distance to secondary roads, the higher the prices. Plot prices in Al Safwa and Al Sallha neighborhoods are the most affected neighborhoods by average distance to the CBD. The plot price in Al Wadi and Al Taaweedat neighborhoods is the least affected.

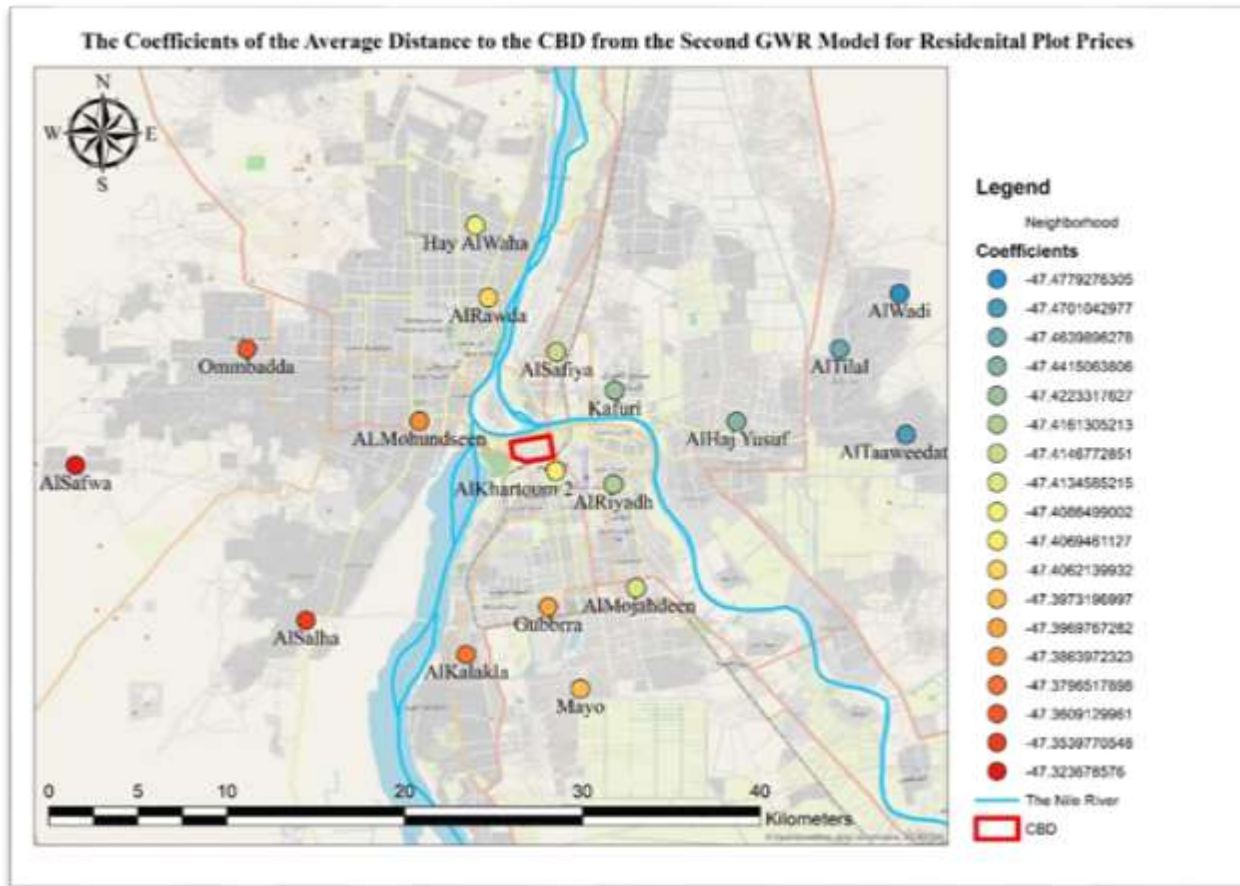


Figure 24 The map shows the coefficients of the average distance to the CBD from the GWR second model for plot prices (Source: Author's Own 2020).

Figure 25 neighborhoods are positively affected; Al Safwa, Sallha, and Al Kalakala neighborhoods are the most affected neighborhoods by the average length of plot façade. The coefficient represents the increase in plot price for every 1-meter increase in plot façade. Al Wadi, Al Tital, and Al Taaweedat neighborhoods in green are the least affected.

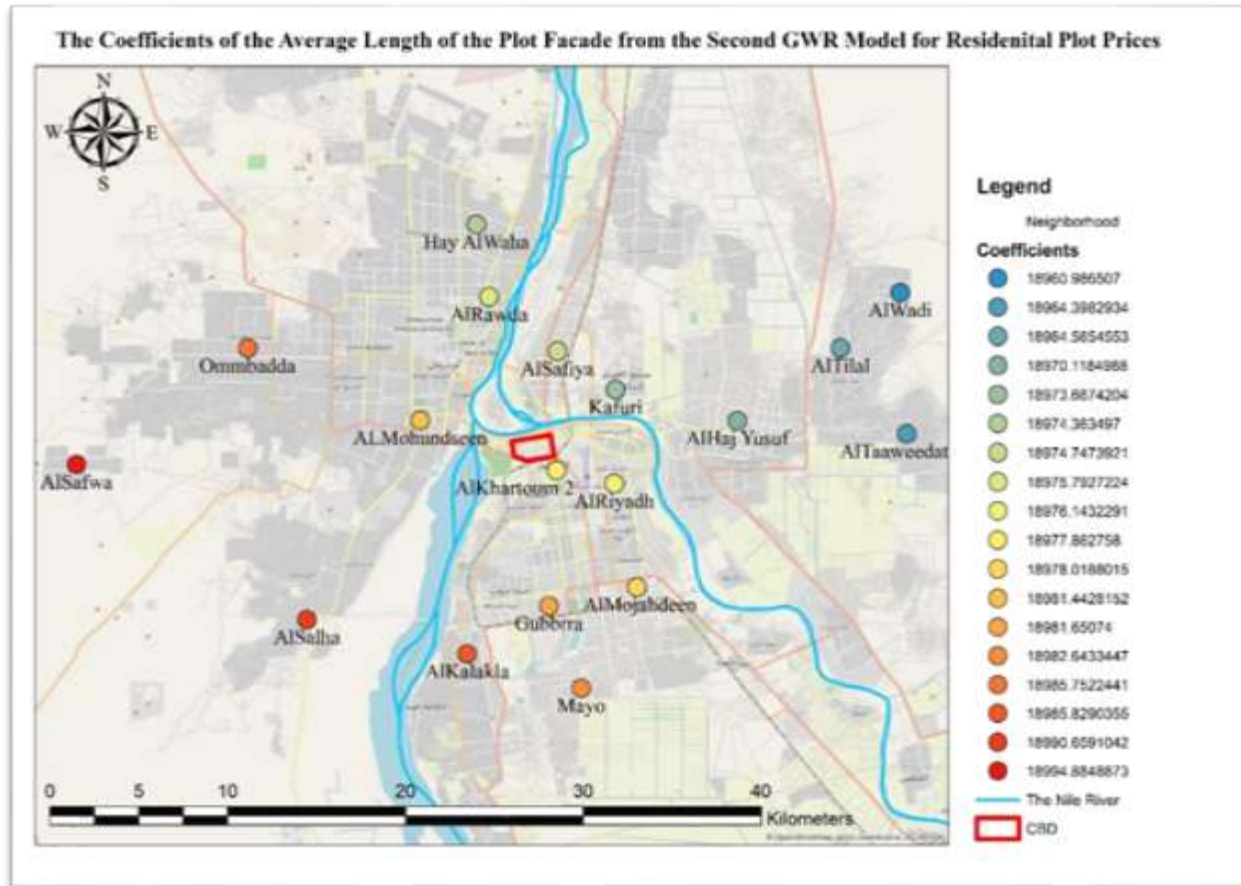


Figure 25 The map shows the coefficients of the average length of the plot façade from the second GWR model for plot prices (Source: Author's Own 2020).

Mapping the coefficients revealed that the explanatory variable's impact is more robust in neighborhoods located to the west and southwest of the CBD. The local R^2 map shows that the map neighborhoods are the most affected by the explanatory variables and have higher coefficients than the other neighborhoods.

Regression analysis of housing affordability

This section presents the results from the regression analysis based on the spatial analysis procedure. The exploratory regression results showed a properly specified OLS model for housing affordability to derive the OLS and GWR models.

Exploratory regression

This regression looks at the factors affecting housing affordability across the neighborhoods in Khartoum. Figure 26 shows the highest adjusted R^2 of a passing model is 0.71; the model's redundancy factor is 0.07. This model results from a combination of four explanatory variables: the neighborhood class, the average distances to schools, hospitals, and primary roads. Table 8 below summarize the model with variable significance and effect of housing affordability:

Variable	Percentage of Significance	Percentage Positive	Percentage Negative	VIF
Average Distance to Schools	75%	100.00%	0.00%	2.00
Neighborhood Class	56.20%	100.00%	0.00%	2.92
Distance from Hospitals	25%	25%	75%	5.57
Distance from Primary Roads	6.25%	37.50%	62.50%	4.77

Table 8 Summary of the Variable Significance for the exploratory regression of the HAI (Source: Author's Own 2020).

Choose 4 of 5 Summary

Highest Adjusted R-Squared Results

AdjR2 AICc JB K(BP) VIF SA Model

0.72 206.45 1.00 0.07 5.23 0.86 +CLASSREP*** +AVDISSCH*** -AVGHOS*** +AVGPRIROAD**

0.72 206.53 0.87 0.02 2.84 0.38 +CLASSREP* +AVDISSCH*** -AVGHOS** +DISCBD

0.62 211.90 0.20 0.12 4.99 0.73 +AVDISSCH** -AVGHOS +AVGPRIROAD +DISCBD***

Passing Models

AdjR2 AICc JB K(BP) VIF SA Model

0.719232 206.445801 0.999860 0.071979 5.228263 0.862941 +CLASSREP*** +AVDISSCH*** -AVGHOS*** +AVGPRIROAD**

Figure 26 Summary of Exploratory regression for HAI (Source: Author's Own 2020).

HAI ∫ NCLASS + AVGDISSCH + AVGDISHOS + AVGDISPRIROADS (Model 3)

Where:

NCLASS: Neighborhood Class

AVGDISSCH: Average Distance to Schools

AVGDISHOS: Average Distance to Hospitals

AVGDISPRIROADS: Average Distance to Primary Roads

The combination of explanatory variables that explain housing affordability across greater Khartoum in Table 8 above is the best candidate explanatory variable to model the housing affordability index using the OLS model. Percentage significance represents the times the variable was significant in explaining the housing affordability index. Percentage positive or negative signs indicate the effect of the explanatory variables on the affordability index.

Ordinary Least Squares

The OLS model explained 71% of the HAI variations, the adjusted $R^2=0.71$ as shown in figure 27. The Jarque-Bera statistic measure of randomness is 0.999860 which is a good measure of randomness; The OLS recognized the neighborhood's class, the average distances to schools, hospitals, and primary roads as explanatory variables to explain variations in HAI .However, from the coefficients in figure 28, the neighborhood class change is the most influential variable in determining housing affordability. As the neighborhood class changes from high-income to mid-and-low-income class, affordability increases by 90.72% for every class and decreases by the same amount in high-income neighborhoods. The average distance to schools is significant with a positive coefficient which increases affordability by (0.043069) but not as effective as neighborhood class. The average distance to primary roads is not as sufficient as the neighborhood class effect on HAI with a coefficient that increases in affordability by (0.161767) for every 1-meter increase in distance to primary roads. The average distance to Hospitals had a negative effect on HAI with a coefficient that decreases affordability by (-0.36181) for every 1-meter increase in distance to hospitals. However, the neighborhood class is the dominant determinant of the HAI.

OLS Diagnostics

Input Features:	Neighborhood	Dependent Variable:	AVERAGEHAI
Number of Observations:	18	Akaike's Information Criterion (AICc) [d]:	206.445801
Multiple R-Squared [d]:	0.785295	Adjusted R-Squared [d]:	0.719232
Joint F-Statistic [e]:	11.887045	Prob(>F), (4,13) degrees of freedom:	0.000277*
Joint Wald Statistic [e]:	118.548784	Prob(>chi-squared), (4) degrees of freedom:	0.000000*
Koenker (BP) Statistic [f]:	8.597759	Prob(>chi-squared), (4) degrees of freedom:	0.071979
Jarque-Bera Statistic [g]:	0.000280	Prob(>chi-squared), (2) degrees of freedom:	0.999860

Figure 27 OLS diagnostics for HAI model (Source: Author's Own 2020).

Summary of OLS Results - Model Variables

Variable	Coefficient [a]	StdError	t-Statistic	Probability [b]	Robust_SE	Robust_t	Robust_Pr [b]	VIF [c]
Intercept	-123.626300	34.577665	-3.575322	0.003391*	19.399065	-6.372797	0.000023*	-----
CLASSREP	90.729484	15.841676	5.727265	0.000069*	15.561472	5.830392	0.000058*	1.155286
AVDISSCH	0.043069	0.010064	4.279681	0.000899*	0.007089	6.075830	0.000038*	1.920781
AVGHOS	-0.036181	0.011806	-3.064775	0.009040*	0.009514	-3.803007	0.002198*	5.228263
AVGPRIROAD	0.161767	0.095199	1.699252	0.113065	0.067372	2.401098	0.032016*	3.530786

Figure 28 Results summary for OLS model for HAI (Source: Author's Own 2020).

Geographical Weighted Regression

The four variables from the OLS have produced a valid GWR model with diagnostics passing the confidence criterion, and the standard residuals have a mean value of 0.047262 and a standard deviation of 1.037889. The local R^2 explains the strength of neighborhood class's collective influence, the average distance to schools, hospitals, and primary roads on HAI for each neighborhood. The relationship coefficients are available in (appendix G), residuals and the local R^2 values, and table 9 shows the GWR model diagnostics for the HAI. The mean value and standard deviation for the standardized residuals indicate high confidence in the model.

Variable Name	Variable	Definition
Bandwidth	50476.82292	
ResidualSquares	27548.08447	
EffectiveNumber	6.09646	
Sigma	48.106929	
AICc	205.915441	
R^2	0.82546	
Adjusted R^2	0.750731	
Dependent Field	0	Average HAI
Explanatory Field	1	Neighborhood Class
Explanatory Field	2	Average distance to schools
Explanatory Field	3	Average distance to hospitals
Explanatory Field	4	Average distance to primary roads

Table 9 Summary of the GWR model diagnostics for the HAI (Source: Author's Own 2020).

Figure 29 show that the GWR model explained 78% of the local variation in HAI (Adjusted R^2 0.78) using the explanatory variables. However, the neighborhood class is the most influential variable in the model (Appendix G). For instance, on average, affordability changes by 90.72 between the different neighborhood classes examined; for instance, affordability increases by 90.72% when looking at lower-income neighborhoods.

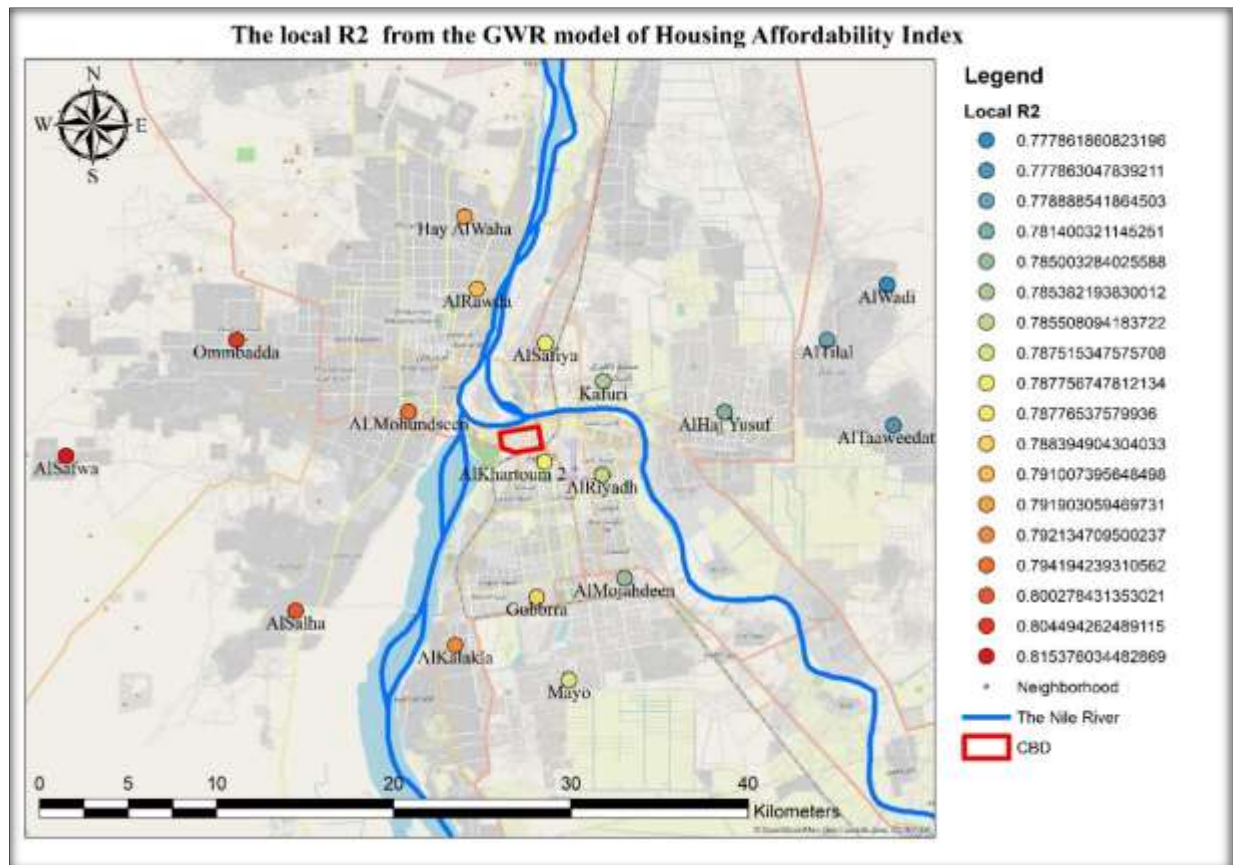


Figure 29 The map shows the local variations in R^2 values of the GWR model for the HAI (Source: Author's own 2020).

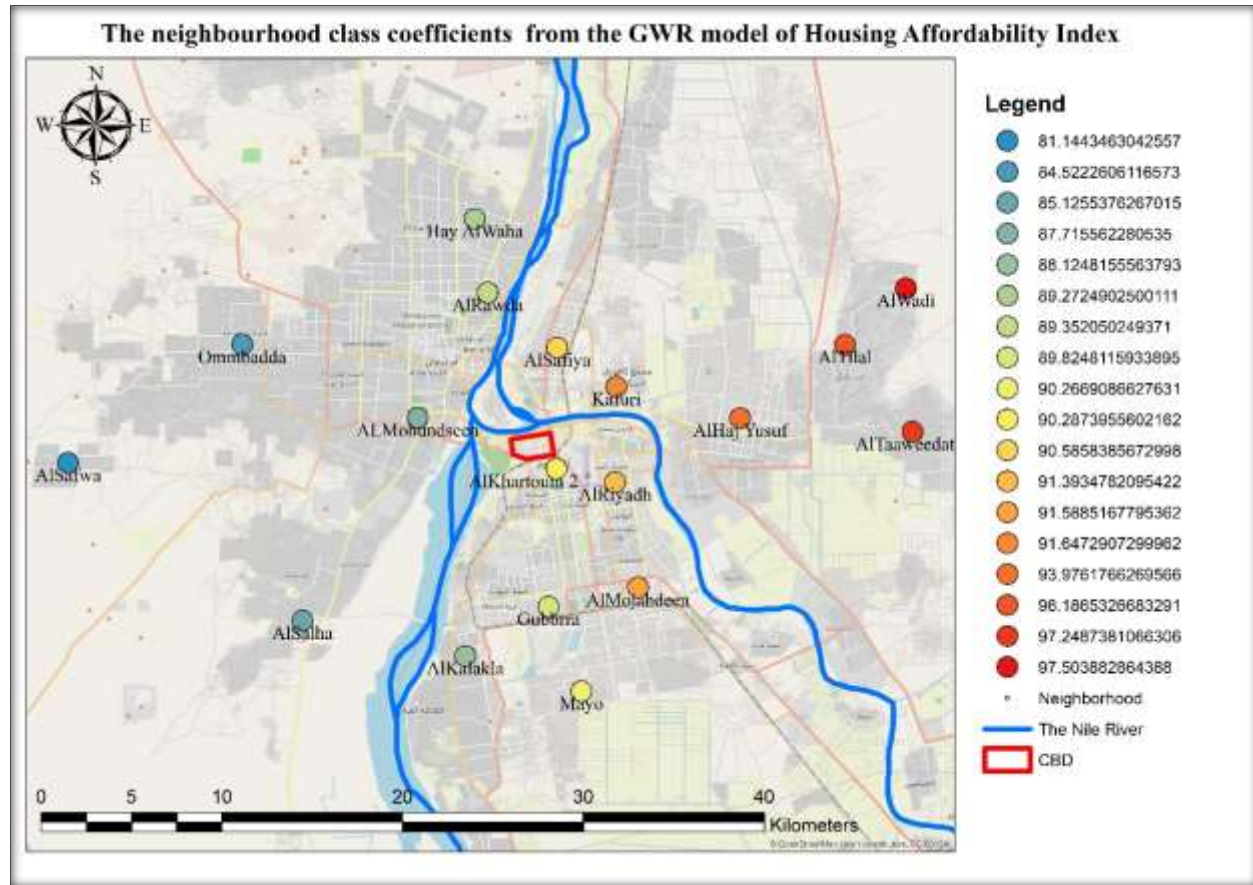


Figure 30 The map shows the neighborhood class's coefficients From the GWR model for housing affordability (Source: Author's Own 2020).

Figure 30 illustrates the spatial variations of how the neighborhood class is impacting each neighborhood differently. The coefficient values on the map legend show that AlWadi, AlTilal, and ATaaweedat are the most affected neighborhoods with neighborhood class, where the coefficients range between 97.24 to 97.50. AlSafwa, Ombbadda, and AlSalha are the least affected neighborhoods affected by neighborhood's class, where the coefficients range between 81.14 to 84.52. The coefficient corresponds to a change from a neighborhood's class to another, and changing the neighborhood's class in the neighborhoods with higher coefficients would have the most effect on affordability. The map shows that the impact of neighborhood class on housing affordability is skewed to the eastern part of the city. However, the reason behind this pattern has not been investigated.

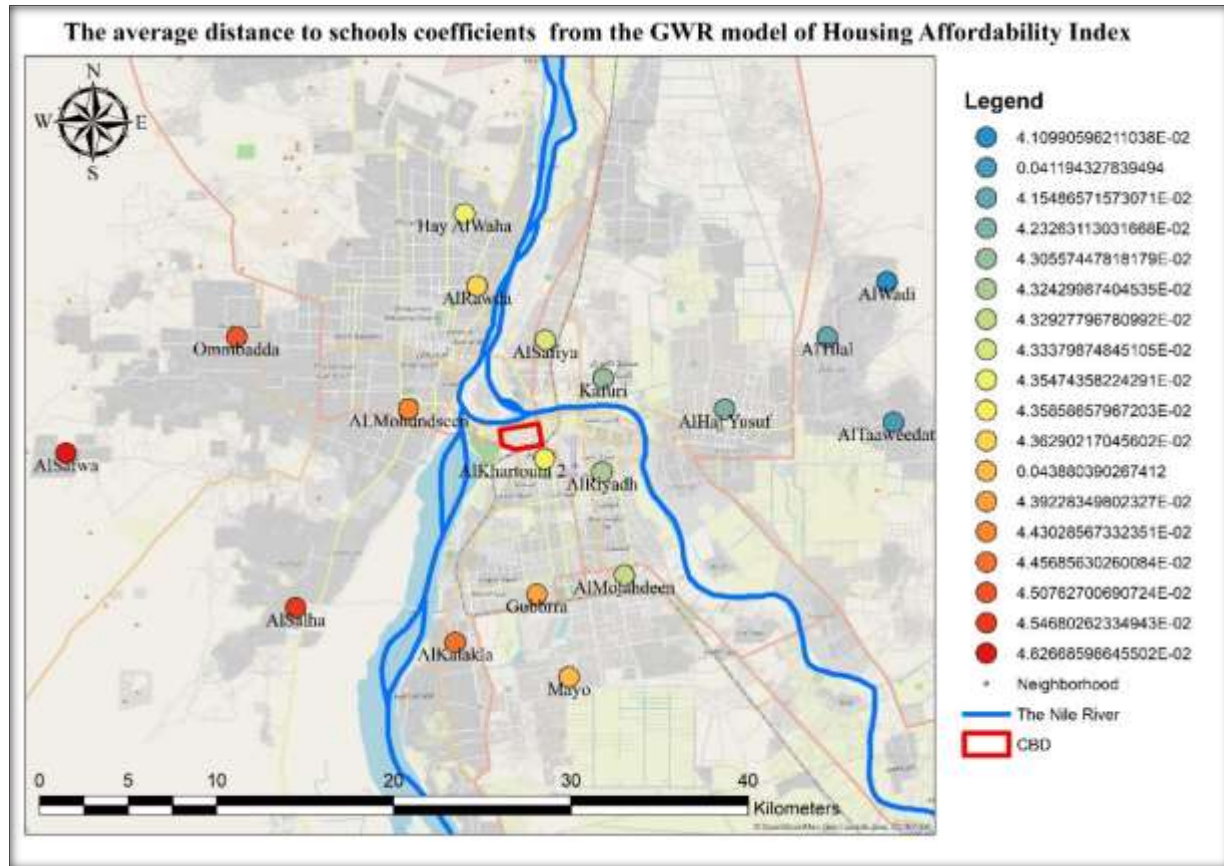


Figure 31 The map shows the coefficients for the average distance to schools of the GWR model for housing affordability (Source: Author's Own 2020).

As shown in figure 31, the average distance to schools' coefficient indicates a positive impact on HAI, whereby affordability increases on average by (0.040671) for every 1-meter increase in distance to the neighborhood. AlSafwa, AlSalha, and Ombbadda are the most affected neighborhoods, while AlWadi, AlTaaweedat, and AlTilal are the least affected neighborhoods by the average distance to schools, as a determinant of housing affordability.

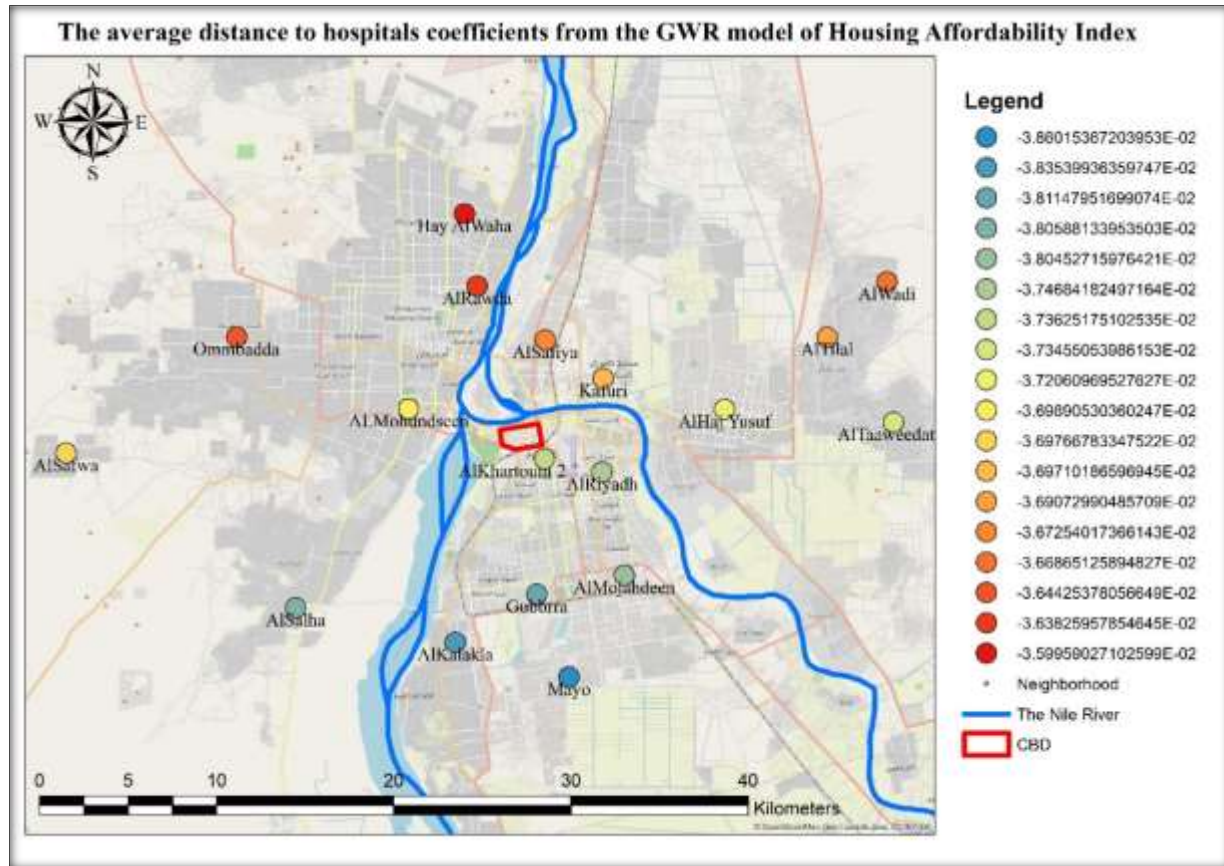


Figure 32 The map shows the coefficients of the average distance to hospitals from the GWR model for housing affordability (Source: Author's Own 2020).

As shown in figure 32, the average distance to hospitals coefficient indicates a negative impact on HAI, whereby affordability decreases on average by (-0.037257) for every 1-meter increase in distance to the neighborhood. Hay AlWaha, Ombbadda, and AlRawda are the most affected neighborhoods by distance to hospitals, while Mayo, AlKalakla, and AlSalha are the least affected neighborhoods by the average distance to hospitals as a determinant of housing affordability.

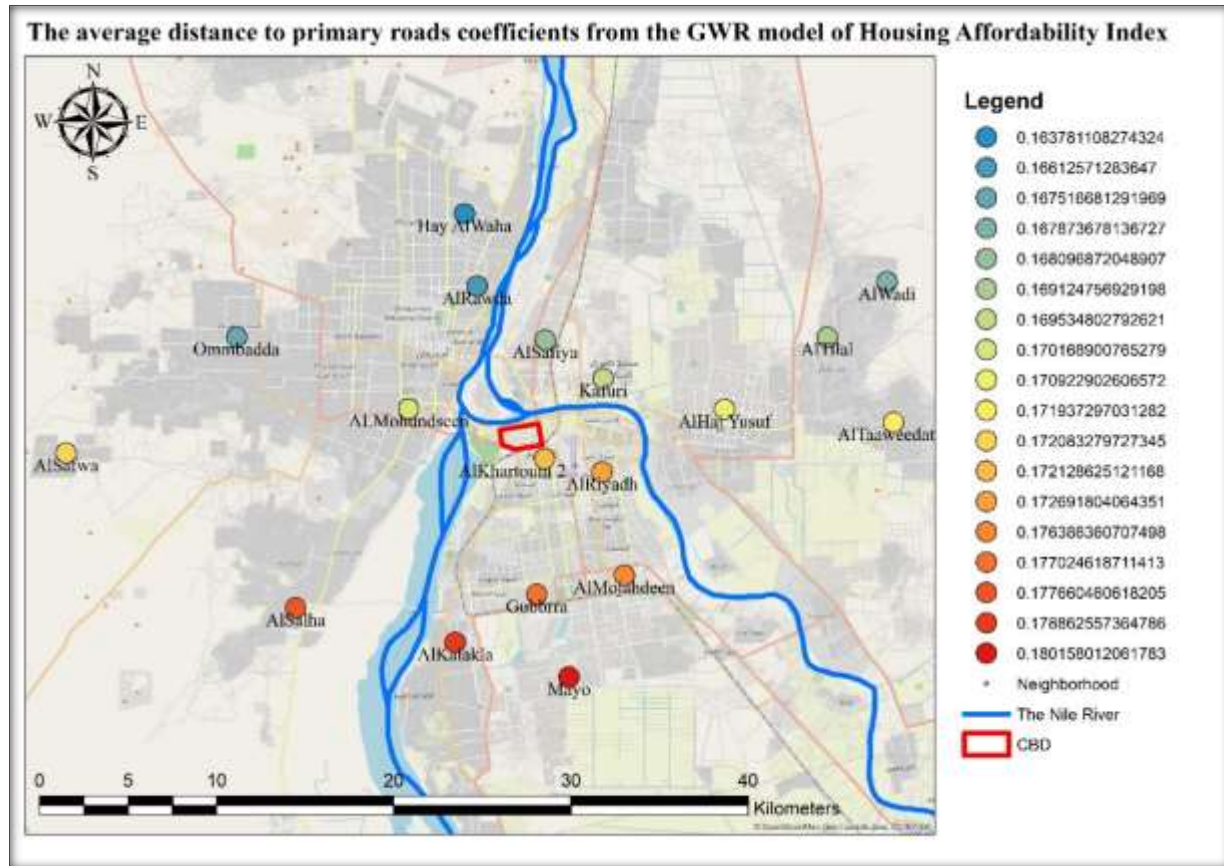


Figure 33 The map shows the coefficients for the average distance to primary roads of the GWR model for housing affordability (Source: Author's Own 2020).

As shown in figure 33, the average distance to primary roads affects HAI positively, whereby affordability increases by (0.141845) for every 1-meter increase in distance from primary roads to the neighborhood. Mayo, AlKalakla, and AlSalha are the most affected neighborhoods, while Hay Alwaha, AlRawda, and Ombbadda are the least affected with an average distance to primary roads, as a determinant of housing affordability.

GWR results indicate that housing affordability dominantly is a function of neighborhood class; most of the medium and low-income neighborhoods are affordable to medium-income households. Although, most of the second-class neighborhoods are not affordable to medium-income households. The shift in medium-income housing affordability from second-class housing to the third class reveals an alarming change in equity and housing access. Medium income is not sufficient to afford medium-income housing, leaving the medium-income households favoring third-class housing and increasing the competition between the medium and low-income households to meet their house needs.

Discussion of the findings

The analysis section links the literature to the findings presented in the previous section by highlighting similarities and differences and articulating the case study's uniqueness compared to the literature in terms of methodology, modeling parameters, and how the findings support or differ from the literature.

Similarities and differences

This research is distinctively modeling two dependent variables, residential land prices and the housing affordability index, to measure housing affordability compared to the literature. And to understand the spatial determinants of residential land prices and housing affordability and how housing affordability indirectly impacts Khartoum's physical expansion.

Modeling methods

This research has utilized methods frequently used in the literature to test the dependent variables residential land prices and housing affordability. This research looks at weighting the impact of the independent variables on each neighborhood within the study area that goes through a delict procedure to avoid spatial-autocorrelation and heterogeneity through spatial modeling. As we have shown on the spatial analysis and regression procedure diagram, the modeling starts with defining the significant variables using exploratory regression. The next step uses these variables to derive the OLS model from indicating the significant variables in the model, which is then used to derive the spatial differences between neighborhoods and map the weighting of variables using GWR.

To make sense of the change in affordability through space, the IDW interpolation illustrates the change in housing affordability with the CBD highlighted as a reference area and suggests a trend in which housing affordability shapes the city.

Modeling residential land prices

Modeling residential land prices spatially, OLS, and GWR models yielded significant variables from two distinct models affecting residential land prices differently. The first model that explained 83% of residential land prices indicated that distance to secondary roads and the CBD decrease prices. In contrast, the average length of the residential land significantly increases prices. The second model explained 78% of residential land prices using average distance to secondary roads, police stations, and the CBD.

The impact of the average distance to mobility networks and the CBD for this research supports the findings by (Mikelbank 2004; Du and Mulley 2006; Ping and Hui 2010; Du and Mulley 2012; Koramaz and Dokmeci 2012; Cai et al., 2019; Li et al., 2016) considered looking at commuting cost as an indicator of transportation and found that heterogeneity in prices due to other factors influencing the model. However, the case study of Huang et al., (2010) showed that the average distance to transportation is less significant than another variable specific to that case study. In the case of Khartoum, the explanatory variables proved significant in determining residential land prices, and the explanatory variables affect Khartoum differently compared to the literature. The increase in distance to mobility networks have shown a positive impact on residential land prices

The unique variable to model is the average length of the plot façade, a measurement in meters of the length, width, or both for attached or detached residential lands. In OLS and GWR models, the average length of the plot façade is a significant determinant of plot prices, whereby prices increase with the increase in this variable. The average length of the plot's façade as a variable is unique to this research and has not been investigated before, and it was significant in determining residential land prices positively where prices increase with longer facades. This finding suggests residential land prices depend on the local context and their determinants differ from one place to another.

The state of housing affordability

As established in the literature review, there are no case studies on modeling the spatial determinants of housing affordability, hence this research is unique. The housing affordability index derived from the data is based on using the medium-income to derive the different housing class index. The results show that a medium-income household cannot afford the first-class neighborhoods, which convenient. However, the designated housing second-class for medium-income households is not affordable. The case for third-class neighborhoods designated for most low-income households in the class of the only neighborhood affordable to the medium-income households. The situation that medium-income households competing for affordable housing in low-income neighborhoods might push the low-income households that are located further away from the CBD and the city center for cheaper land, leading to expanding Khartoum boundary, and increase the possibility of informal settlements.

Modeling housing affordability with regression and interpolation

The OLS and GWR models reveal that housing affordability of the neighborhoods is a function of four variables. The neighborhood class is the most significant variable in the model, followed by the average distance to schools, hospitals, and primary roads. The coefficients for the neighborhoods have the highest value than the distance variables with less weight in determining housing affordability. Downgrading or upgrading a housing class will decrease or increase the HAI by points 90.72, which increases competition over housing in cheaper areas. It is liable that a medium-income household would buy more than a house if there is a neighborhood with a housing affordability index value that is over 200. Their income is sufficient to own two housing units, which allows for speculating on properties and further increasing prices neighborhood.

The interpolation surface of housing affordability shows that affordability increases with the CBD distance, the least affordable neighborhoods to medium-income households than neighborhoods on outer Khartoum city, where the low-income neighborhoods are located. However, these neighborhoods are designated for low-income households, which became a competition between the low-and-high income households to meet their housing needs. As a result, this dynamic might lead to pushing the physical boundary of Khartoum city in the quest for housing and accommodate the growing population.

Analysis summary

In exploring spatial relationships, OLS is a global regression model to draw a general understanding of the data by averaging the coefficients and the regression's goodness measure. Exploratory regression is the best first step in finding an adequately specified OLS model. However, the variables from exploratory regression passing models are the variables that would have a properly specified model.

On the one hand, comparing the OLS and GWR results at modeling plot prices, the first OLS model explained 83% of plot price variations. In contrast, the GWR, on average, explained 86% of the spatial variation based on the three explanatory variables (the average distance to secondary roads, the CBD, and the average length of the plot's façade), a significant impact on the model.

On the other hand, the second OLS model explained 78% of the variations in plot prices. On average, the GWR model explained 83% of the variations based on three explanatory variables (average distance from secondary roads, police stations, and the CBD).

The GWR diagnostics indicates to the best-fit model has the lowest AICc value. However, the second GWR model is the best in explaining the spatial variation in plot prices across the study area. The variables' average distance to secondary roads and the CBD are mutual in both GWR models but had a different coefficient in each of the models due to introducing the third variable to each model. This change in the coefficients is explained in figures (34 & 35) below. In comparing the two GWR coefficients, it is found that the average length of the plot's façade has the most effect on the model compared to the rest of the variables. It is essential to consider this change in coefficients when using various variables and how replacing a variable could influence the model and affect the coefficients' interpretation. The literature suggests that transportation, central business district, and services influence land prices significantly. Still, no case study has more than one model to highlights this difference caused by replacing a variable.

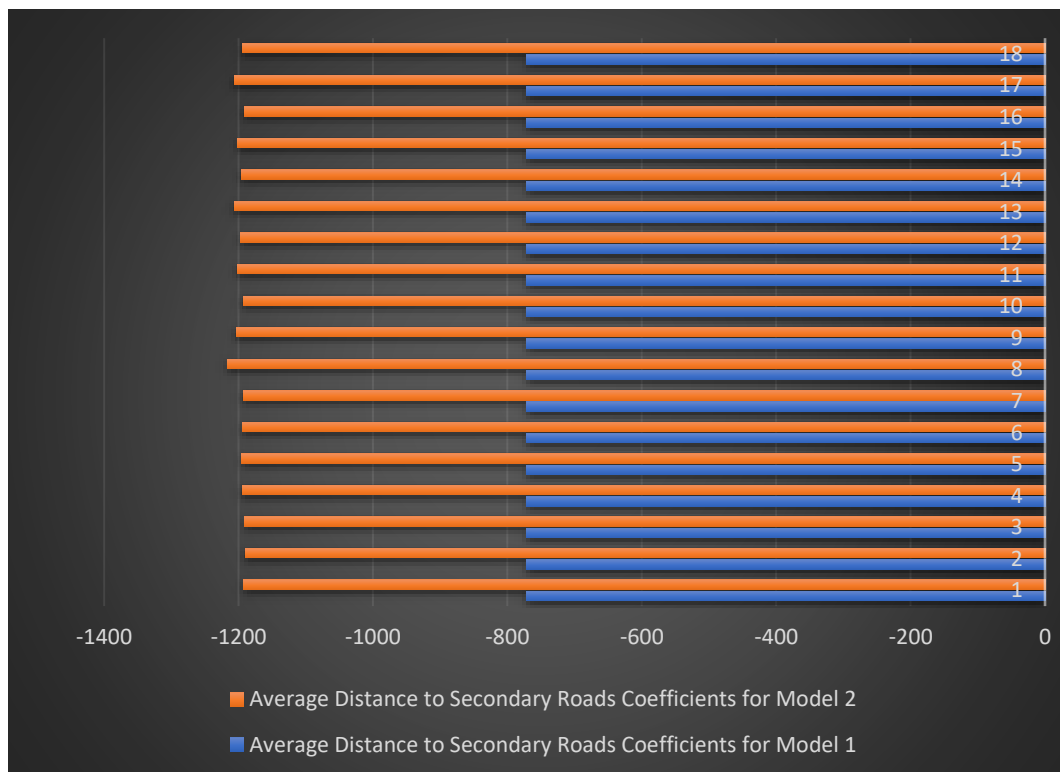


Figure 34 shows the difference in coefficients for the average distance to secondary roads for Plot Prices GWR models (Source: Author's Own 2020).

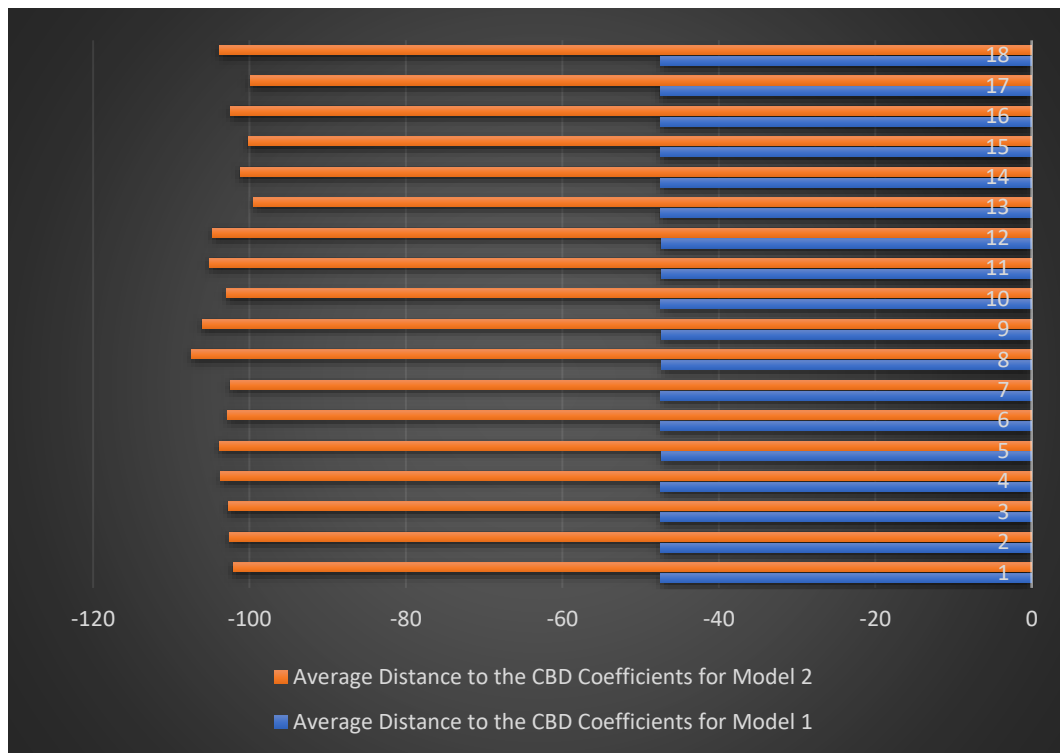


Figure 35 The figure shows the difference in coefficients for the average distance to the CBD for plot prices GWR models (Source: Author's Own 2020).

Comparing the OLS and GWR models in exploring HAI variables indicates that GWR has a more substantial model in explaining HAI. The OLS model explained 75% of the variations in affordability. The GWR explained 75% of the variations; both models had four explanatory variables: the neighborhood class, the average distances to schools, hospitals, and primary roads.

The OLS and GWR models are based on the variables adopted from the exploratory regression that indicate the candidate variables explaining the dependent variables. Plot prices are a function of three variables average distance to secondary roads, the CBD, and the average length of the plot's façade. The total housing cost was not significant to the small margin model between housing cost and plot prices.

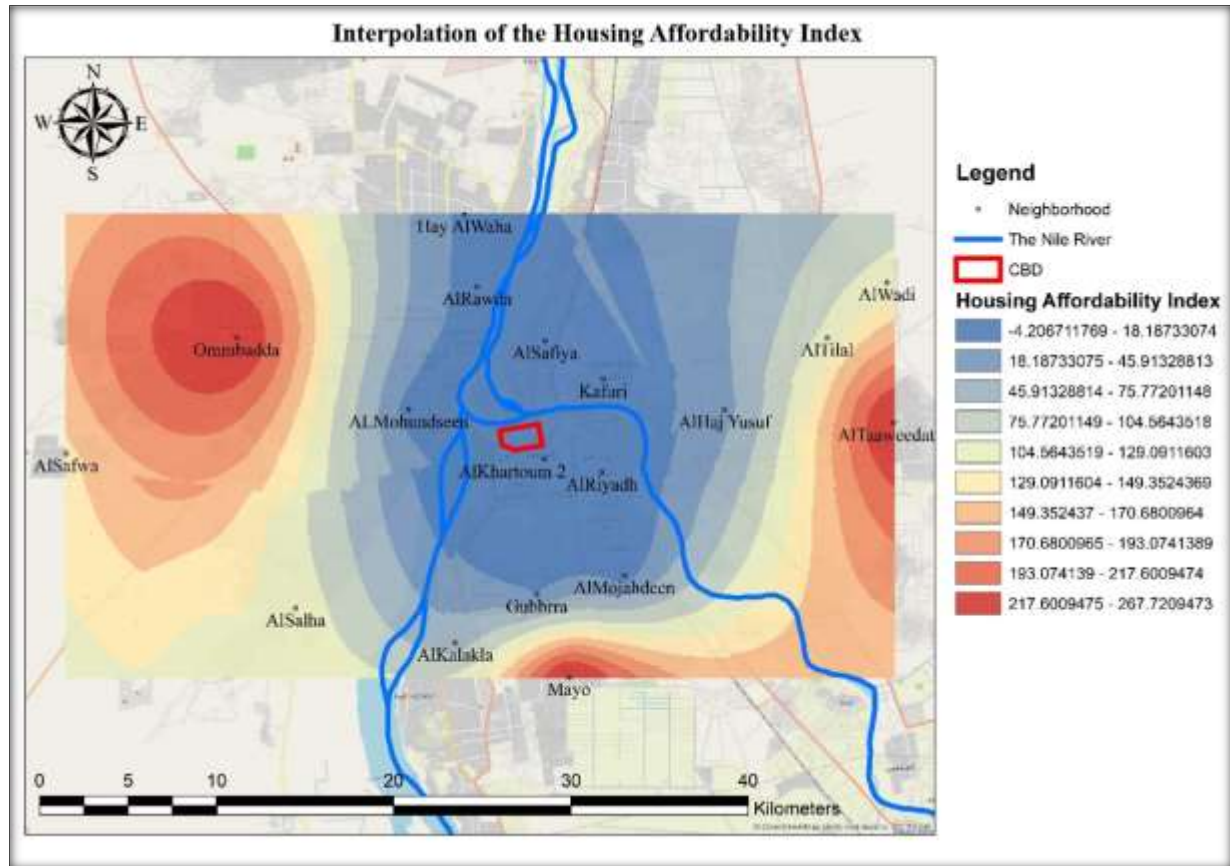


Figure 36 Housing affordability surface of greater Khartoum (Source: Author's Own 2020).

From Figure 36 above, housing affordability increases with distance from the CBD to the outer of greater Khartoum. The areas with an affordability value of more than 100 are the areas that a medium-income household would afford. The variables that explain housing affordability are different from those that explain plot prices which has no significant difference with the total housing cost as established in figure 37 or a significance in explaining housing affordability.

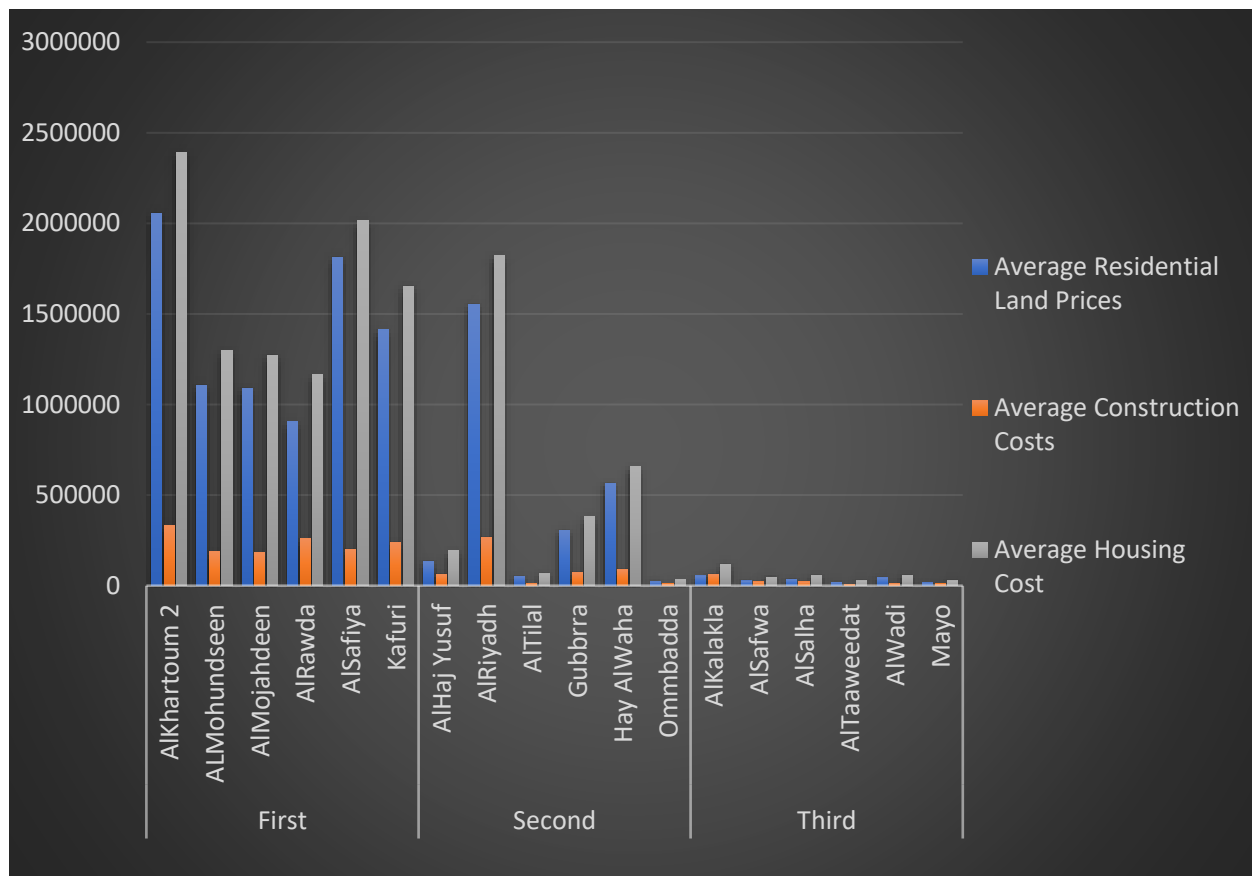


Figure 37 Average residential land price, construction cost, and the total housing cost (Source: Author's Own 2020).

It is essential to mention that the interpolation surface depends on the number of interpolation values used. Therefore, the northern part of the interpolation surface is not entirely reliable in conceptualizing the affordability index. The number of samples does not cover that area and introduces interpolation points to enhance the interpolation surface.

However, the model that explained housing affordability is dominantly a function of neighborhood class. Nevertheless, the medium-income households cannot meet their housing needs in the designated medium-income housing class unless they move to the low-income class and further from the CBD. From figure 36, the map shows the affordability gradient in greater Khartoum. The closer the neighborhood to the city center, the less affordable it is for medium-income households; by moving away from the city center, the chance to afford a house increase. As a result, affordability can be a substantial factor in Khartoum's physical expansion by pushing affordability further from the city center. The convention that urban expansion is inevitable makes sense in the case of greater Khartoum. The trade-off is how to realize equitable access to affordable housing and service simultaneously with cities' physical growth.

Conclusion

This chapter presented the data and findings yielded using two regression techniques to examine the determinants of residential land prices and housing affordability in Khartoum City. OLS model generated

accurate global models for land prices and housing affordability; GWR was accurate in explaining the spatial differences in residential land prices and housing affordability.

The medium-income household housing affordability in the study area shows that a medium-income household cannot afford a medium-income housing neighborhood. Low-income neighborhoods are affordable to a medium-income household—however, this increases competition over housing between the medium-and-low-income households to attain their housing need.

The regression revealed that residential land prices could be explained using two different models with different variables. The first OLS model shows that the average distance to secondary roads, the CBD, and the average length of the plot façade explains 83% of the residential land prices. The second model explained 78% of the prices using the average distance to secondary roads, police stations, and the CBD. However, the GWR models derived using the same variables from the two OLS models reveal that the second model explains the local variations in residential land prices and explained 83% of the local variations. The takeaway from analyzing the residential land prices using regression is that the model will depend on the variables used to derive the relationship and the findings' accuracy.

The OLS model of housing affordability explained 71% of the variations using four variables. The neighborhood class prevailed the other variables explaining housing affordability by having the highest coefficient in the model. The GWR model also explained an average of 78% of the local variations in housing affordability. The interpolation surface of the HAI reveals that housing affordability increase with the distance from the CBD. Although the regression models included the average distance to the CBD as a variable, it was not part of the model's explanatory variables. The takeaway from explaining housing affordability in this research is that it can be explained differently depending on the analysis method and technique. With the affordable neighborhoods located in the outer city, this pushes the low-income further away to attain their housing need.

The next chapter concludes the research report by presenting the objectives, research questions, and findings tied to the literature. It highlights the study's limitations and suggests recommendations to acknowledge the expanding Khartoum, spatially normalize land prices and housing affordability, and use the spatial modeling techniques to inform future planning.

Chapter Five: Conclusion and recommendations

This chapter concludes the research work in four sections. The first section summarizes the key findings that answer the research sub-questions that examine the factors affecting plot prices, housing affordability, and the change in housing affordability index across the study area in the second section. The second section looks at the main research question. It illustrates the effect of housing affordability on the physical expansion of greater Khartoum and the implications on the low-income housing class. The third section articulates the limitation of this research in fieldwork and data collection and the restrictions imposed by the Covid-19 pandemic. The fourth section provides recommendations regarding the methodology and data and suggests further work to investigate some of the areas that have not been researched in this particular study.

Summary of the key findings

The main objective is divided into three sub-objectives that respond to the research sub-questions. Three sub-questions emerged, the first two sub-questions deal with modelling the spatial determinants of residential land prices and the HAI for the sampled neighborhoods. The third sub-question explore the difference in explaining housing affordability using regression analysis as oppose to spatial interpolation in relation to the physical expansion in Khartoum's context with different approaches.

The broad issue of housing affordability in Khartoum can be explained to the effects of expensive land and construction. On one side from a spatial context, proximity to the city center and neighborhood class are the main factors increasing land prices and decreased housing affordability, leading the majority of low-income households to move out of the city center to attain their housing needs. On the other side, the city is morphing into low-density development that pushes the city as evidenced from the literature and the findings. The spatial determinants of both residential land prices and housing affordability leads to the conclusion that Khartoum's expensive areas are concentrated around the city center, and affordable neighborhoods are expanding the city.

The general pattern of models and findings in terms of explaining residential land prices and housing affordability support the literature on modelling land prices, property values, and housing prices. The significance of this research lies in combining OLS which globally explains residential land prices and housing affordability with GWR to provide local explanation associated with each individual neighborhood. The OLS and GWR findings explained 78% and 83% of residential land prices consecutively, 77% and 90% of the variations in housing affordability.

Housing affordability and the city expansion

This research's prime objective is to illustrate how housing affordability in Khartoum's sampled neighborhoods provides grounds for looking at Khartoum city's physical expansion using regression analysis and interpolating the HAI sampled neighborhoods. The main research question contextualizes this research's first objective as follows "*How housing affordability affect the physical expansion of Khartoum city?*". The main finding is double-faced and suggests that from the housing market and provision perspective, medium-income households cannot afford the medium-income neighborhoods

and can only afford the low-income neighborhoods. Khartoum's affordable neighborhoods are located on Khartoum's peripheries and stretching the city outwards from the spatial pattern perspective.

However, the HAI's spatial interpolation shows a gradient effect, and housing affordability increases with distance from the city center. The neighborhoods further away from the city center, such as Al Safwa, Mayo, and Al Taaweelat, tend to be affordable than Al Khartoum 2, Kafuri, and Al Mohundseen, which are proximate to the center. This finding suggests that housing affordability can play a significant role in Khartoum's evolution because physical expansion derived the need for affordable housing by pushing the medium and low-income households to the peripheries.

The determinants of residential land prices

The first sub-objective deals with exploring residential land prices' determinants using the plot's characteristics, the average distances to central amenities, primary and secondary mobility networks, and local services. This objective is contextualized in the first sub-question, stating, "*How the residential land's characteristics, distance to the central amenities, main mobility networks, and local services affect plot price and housing affordability?*". The regression models have explained residential land prices in two models with different explanatory variables regarding this sub-question. The first model explained 83% of the variation in residential land prices using the average distance to secondary roads, the CBD, and the average length on the plot's façade as the residential land price determinants. The neighborhoods closer to secondary roads, the CBD, and the higher average length of the plot façade are more expensive. The second model explained 78% of the variation in residential land prices using the average distance to secondary roads, police stations, and the CBD, closer neighborhoods are more expensive. The distance variables influence residential plot prices differently. The average distance to secondary roads, police stations, and the CBD changes prices. Prices decrease by 1181.77 USD\$ for every 1-meter increase in the average distance to secondary roads. As for police stations, prices increase by 172 USD\$ for every 1-meter increase in distance, and prices decrease by 99.85 USD\$ for every 1-meter increase in distance from the CBD.

These findings suggest that residential land prices can be explained based on the variables used. Still, the average distance to secondary remained constant, and both models had close adjusted R^2 values in both models, which are the dominant determinants of residential land pricing. So, the density of secondary roads is significant determinant of prices by the effect of reducing the distance to secondary roads, and therefore increase prices.

The determinants of housing affordability

The second sub-objective looks at the determinants of housing affordability using the plot's characteristics, the average distances to central amenities, primary and secondary mobility networks, and local services. This objective is contextualized in the second sub-question, stating, "*How the residential land characteristics and price, distance to the central amenities, main mobility networks, and local services affect housing affordability?*". The OLS model explained 71% of the variations in housing affordability by using four variables, neighborhood class, the average distance to schools, hospitals and primary roads. The coefficients have shown significant variations where the neighborhood class had the highest coefficient value (90.72), indicating a difference in affordability by 90.72 in the neighborhood classes'

affordability index. The construction standard associated with neighborhood class is reason behind higher housing costs and lower affordability.

For instance, a third-class neighborhood such as Al Safwa has HAI value of 90.72 more than a second-class neighborhood such as Al-Haj Yusuf. Such finding helps make affordability predictions based on the neighborhood class. If there is a plan for a new third-class neighborhood in Khartoum, there is a 90.72% chance to be affordable for the medium-income household. However, the remaining distance variables have minimal influence on housing affordability compared to the neighborhood class. The average distance to schools, hospitals, and primary roads changes affordability by 0.0430669% (4.3%), -0.036181% (-3.6%), and 0.0161767% and (1.6%) for every-1 (100-meter) change in distance. The HAI regression model suggests that the neighborhood class mainly dominates housing affordability compared to the rest of the variables.

Housing affordability between regression analysis and spatial interpolation

The third sub-objective is about how affordability can be explained differently using different spatial analysis methods. This objective is contextualized in the third sub-question, stating, *"What are the implications of explaining housing affordability with the regression models and the spatial interpolation on Khartoum's evolution? How does the interpolation analysis and regression analysis explain housing affordability differently?"*. The spatial interpolation of the HAI shows a gradient effect. HAI value is increasing with distance from the city center (CBD). Neighborhoods that are further away from the city center, such as Al Safwa, Al Wadi, and Mayo, are the most affordable than the neighborhoods close to the CBD, such as Al Khartoum 2, Al Mohundseen, and Kafuri, which are the least affordable.

The regression models show that the neighborhood class determines housing affordability. When interpreting the visualized interpolation surface of HAI, it shows that affordability increases with the CBD distance but it is not a significant variable in the regression model. However, this difference in explaining housing affordability with the different methods used in this research reveals the dynamic nature of modeling housing affordability and housing pricing within the residential location choice and housing econometric modeling frameworks, which provides two perspectives.

The first is explaining housing affordability with the neighborhood class as the primary determinant of affordability reflects is a practical application of the economics of residential location choice, where the income level is the main determinant of choosing where to live. The second perspective reflects Khartoum city's evolution as the city developed around its core which contains the CBD which drove the value of land and determined the housing affordability. This evolution started with squatter settlements that evolved into formal housing and part of the current housing system but further away from the city center and designated for middle and low-income groups.

Limitations of the research

This section dive into the limitation of the research in terms of constraints faced during data collection and sampling, the analysis and results and how they fit with the research objectives and question, the previous literature specific to the research problem, and how the time frame, the word count has limited the scope of the analysis.

Data and sample

The real-estate agents indicated during the data collection that the estimations of plot prices are 80-90% accurate, and verified by three different real estate agencies, but the estimation increase and decreases as referred to in the fieldwork section in the previous chapter. For this study, the plot price samples were collected from the study area covering 18 neighborhoods representing Khartoum city with around 40 neighborhoods that spread across more than 1010km². However, the data sufficiently cover

The distance threshold between the sampled neighborhoods is 5km, which is around 25% coverage of the study area neighborhoods. In addition to the absence of official data on land prices, the collected sample randomly covers the neighborhoods surrounding the city center and outwards to the peripheries of Khartoum. More samples would have increased the model's accuracy and a deeper understanding of the residential land prices and housing affordability in Khartoum.

The unpredicted COVID-19 pandemic has further complicated the data collection process, which was done remotely to avoid direct contact with the respondents. During the lockdown in the study area, the market recessed which also affected access to more data for a more holistic representation of the study area. the research had to utilize the available data hence the set of limitations explained above.

Analysis results

The total number of samples collected is 820 samples from 18 neighborhoods assembled, all on one spatial dataset. The random distribution of data to perform the spatial analysis is not possible using even observation. Still, averaging the sample per neighborhood is convenient to avoid data clustering in value and space. It aligns with the research objective, which is a general understanding of the study area.

The analysis relies on the data accuracy and meeting the regression model criteria to increase the result's reliability. The results are reliable to generally understand the determinants of residential land price and housing affordability. Still, for detailed analysis, the estimations tend to cluster in space and value which makes regression analysis per bias and will not yield reliable models.

The models have explained 71% of the residential land prices and 83% of the housing affordability variations; adding more variables to the models would have helped a more in-depth explanation and more robust predictions, but the time frame of the study and travel restriction did not allow for using variables from the study area. Out of 13 explanatory variables highlighted in the conceptual framework, the regression diagnostics revealed some of these variables were highly redundant and removed from the analysis, hence the small number of the passing models' explanatory variables which are sufficient to explain the variations. The data and variables used for modeling are sufficient for prediction within the samples' spatial extent.

Many scholars have pointed to the limitations and weaknesses of housing affordability indices used in several housing systems worldwide but were not the sole focus of their work. In the USA, (Jewkes and Delgadillo 2010) reviewed the housing affordability indices and suggested that housing affordability indices in the USA cannot adapt housing affordability measures to individual households. In this research, housing affordability is used to make sense of Khartoum's physical expansion rather than market-based research which is beyond this research's purpose but the server the research designated aim which is the understanding the determinants of residential land prices and housing affordability and their relationship with Khartoum expansion.

Recommendations

The development in modeling spatial relationships and prediction has allowed us to understand relationships, provide insights to target the urban planning efforts spatially, make predictions based on a given set of data, and advise in policy and decision making. The research findings point to different land value issues, housing affordability, and how they affect the greater Khartoum's physical expansion. The spatial distribution of amenities as a determinant of residential land prices and guiding urban planning to give equal access to service and amenities.

Acknowledging the expanding city

Khartoum city is expanding as medium-income housing is not affordable for medium-income households to live closer to the CBD. However, it is essential to look at the spatial distribution of residential land price and housing affordability in the context of an expanding city. Another approach is to target land use practice, increase density, and adopt mixed-use to localize economic activities and services while adding affordable housing for the medium-income to reduce the competition with the low-income groups to attain affordable housing.

The mortgage structure can utilize to increase the medium-income households to mortgages by extending the time-frame and reducing the monthly mortgage payments over a longer time. Limit housing purchases in the low-income neighborhoods to the designated low-income households to reduce competition over housing which acts as a pull factor to get the low-income groups to the low-income neighborhoods.

The higher the distance from the CBD the cheaper it is to obtain land for housing and finding affordable housing further away from the CBD. However, with distance from the city center, transportation costs increase. Increasing the density of affordable housing for the low-and-medium-income households around the CBD tackle commuting issues as well as density and expansion.

Normalizing land prices and housing affordability spatially

As mentioned throughout the analysis and conclusion, the determinants of plot prices from the explanatory variables are the average distances to secondary roads, the CBD, primary and secondary roads. As for housing affordability, the regression results have shown that housing affordability is determined by the neighborhood's class, distance to schools, hospitals, and primary roads, while the interpolation surface shows that affordability increases with distance from the CBD. The spatial pattern of residential land price and housing affordability is not inclusive to the medium and low-income households. By understanding determinants of land prices and housing affordability, a more inclusive

approach to the spatial distribution of service and housing location can be developed from the models of this research.

Sprawl modeling and future planning

This research's main finding suggests the city is expanding due to the unaffordable housing for medium-income households. From the market perspective, the appropriate recommendation is to target the gap between income growth and housing cost through access to broader funding options for different income groups, building regulations, and purchase control measures to restrict access to housing based on income.

From a spatial pattern perspective, it is essential to consider equity in access to service to normalize the impact of proximity to service on land prices and housing affordability. Another aspect to consider is implementing density and mixed-use planning approaches to have a local destination economy and reduce transport costs considered by many scholars as housing affordability.

Land prices and housing affordability modeling require a large sum of data that might be too complex for OLS and GWR. More accurate prediction requires using different variables and advanced regression techniques. The Random Forest algorithm is embedded in ArcGIS Pro named Forest-Based Classification and Regression which is part of the spatial modeling tools for modeling complex data relationships used for regression, classification, and prediction. The random forest algorithm is based on Leo Breiman's algorithm used in machine learning for making predictions using categorical variables to generate regression models that are more accurate than OLS and GWR and provide a deeper understanding of residential land prices and housing affordability.

References

- Africa, S., Housing, S.A.D. of, 1994. White Paper: A New Housing Policy and Strategy for South Africa. Government Printer, South Africa. (Policy Document).
http://www.dhs.gov.za/sites/default/files/legislation/Policies_Housing_White_Paper.pdf. Accessed on April 7th, 2020.
- African Development Bank (ADB), 2018. Sudan Poverty Profile. Nairobi, Kenya. Internet:
https://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/Brief-Sudan_Poverty_Profile_2014-2015_-_Key_Findings.pdf. Accessed on August 4th, 2020.
- Ahmad, A.M., Sultan, A.E.-I.M., Abdalla, M.M., Malik, A.O., Said, M.A., Mukhtar, E.-S.M., El-Mufti, N.M., 2002. Low-cost housing projects in Khartoum with a special focus on housing patterns. *Habitat International* 26, 139–157. Internet: [https://doi.org/10.1016/S0197-3975\(01\)00037-6](https://doi.org/10.1016/S0197-3975(01)00037-6). Accessed on May 10th, 2020.
- Anacker, K.B., 2019. Introduction: housing affordability and affordable housing. Taylor & Francis. Interdate: <https://doi.org/10.1080/19491247.2018.1560544>. Accessed on March 13, th2020.
- Anselin, L., 1988. Model validation in spatial econometrics: a review and evaluation of alternative approaches. *International Regional Science Review* 11, 279–316. Internet: <https://doi.org/10.1177/016001768801100307>. Accessed April 5th, 2020.
- Anselin, L., Florax, R., Rey, S.J., 2013. Advances in spatial econometrics: methodology, tools, and applications. Springer Science & Business Media. Accessed April 10th, 2020.
- Anselin, L., Le Gallo, J., 2006. Interpolation of air quality measures in hedonic house price models: spatial aspects. *Spatial Economic Analysis* 1, 31–52. Internet: <https://doi.org/10.1080/17421770600661337>. Accessed on March 20th, 2020.
- Asici, M., Yilmaz, O., Hepsen, A., 2011. Housing affordability index calculation integrating income inequality in Turkey. *Empirical Economics Letters* 10, 359–367. Internet: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1999405. Accessed March 20th, 2020.
- Assembly, G., 2016. United Nations Conference on Housing and Sustainable Urban Development (Habitat III) regional report for Africa: transformational housing and sustainable urban development in Africa. Internet: <http://uploads.habitat3.org/hb3/regional-report-africa.pdf>. Accessed March 23rd, 2020.
- Austin, P.M., Gurrán, N., Whitehead, C.M., 2014. Planning and affordable housing in Australia, New Zealand, and England: common culture; different mechanisms. *Journal of housing and the built environment* 29, 455–472. Internet: <https://doi.org/10.1007/s10901-013-9356-3>. Accessed 14th June 2020.
- Babiker, B., 2003. Khartoum: past, present, and the prospects for the future. Internet: <http://dro.dur.ac.uk/89/1/Babiker.pdf>. Accessed on July 24th, 2020.

Bailey, T.C. and Gatrell, A.C., 1995. Interactive spatial data analysis (Vol. 413, No. 8). Essex: Longman Scientific & Technical. Internet: <http://www.personal.psu.edu/faculty/f/k/fkw/rsoc597/Introduction.pdf>. Accessed on August 6th, 2020.

Bieri, D.S., 2013. Housing affordability. Michalos, Alex C. (Ed.). Internet: <http://ssrn.com/abstract=2144558>. Accessed on March 23rd, 2020.

Bin, M., Jing-qiu, Z., Jin-feng, W., Wen-zhong, Z., Wei-qiu, H.A.O., 2005. Application of spatial analysis to the research of real estate: taking Beijing as a case. *地理研究* 24, 956–964. Internet: [10.11821/yj2005060015](http://dx.doi.org/10.11821/yj2005060015). Accessed on July 10th, 2020.

Bogdon, A.S. and Can, A., 1997. Indicators of local housing affordability: Comparative and spatial approaches. *Real Estate Economics*, 25(1), pp.43-80. Internet: <https://doi.org/10.1111/1540-6229.00707>. Accessed on July 20th, 2020.

Bohari, S.N., Saad, S.N.M., Marzukhi, F., Rahim, A. and Darim, A.D.A., 2015. Residential property valuation using GIS. In 2015 IEEE 11th International Colloquium on Signal Processing & Its Applications (CSPA) (pp. 131-134). IEEE. Internet: [10.1109/CSPA.2015.7225632](http://dx.doi.org/10.1109/CSPA.2015.7225632). Accessed on July 26th, 2020.

Boyle, A., Barrilleaux, C. and Scheller, D., 2014. Does walkability influence housing prices? *Social Science Quarterly*, 95(3), pp.852-867. Internet: <https://doi.org/10.1111/ssqu.12065>. Accessed on August 8th, 2020.

Briassoulis, H., Kavroudakis, D. and Soulakellis, N., 2019. Introduction: the practice of spatial analysis. In *The Practice of Spatial Analysis* (pp. 1-18). Springer, Cham. Internet: https://doi.org/10.1007/978-3-319-89806-3_1. Accessed on August 5th, 2020.

Brookes, I., O'Neill, M., 2017. *Collins English Dictionary*. Collins. Internet: <https://www.collinsdictionary.com/dictionary/english/research>. Accessed on July 25th, 2020.

Brueckner, J.K., 1987. The structure of urban equilibria: A unified treatment of the Muth-Mills model. *Handbook of regional and urban economics* 2, 821–845. Internet: [https://doi.org/10.1016/S1574-0080\(87\)80006-8](https://doi.org/10.1016/S1574-0080(87)80006-8). Accessed on April 5th, 2020.

Bruegmann, Robert., 2015. Urban Sprawl, in: Wright, J.D. (Ed.), *International Encyclopedia of the Social & Behavioral Sciences (Second Edition)*. Elsevier, Oxford, pp. 934–939. <https://doi.org/10.1016/B978-0-08-097086-8.74061-X>

Burgess, E.W., 2008. The growth of the city: an introduction to a research project. In *Urban Ecology* (pp. 71-78). Springer, Boston, MA. Internet: https://doi.org/10.1007/978-0-387-73412-5_5. Accessed on March 15th, 2020.

Cai, Z., 2017. Analyzing Measurements of Housing Affordability (Doctoral dissertation). Internet: <http://hdl.handle.net/1773/40314>. Accessed on April 3rd, 2020.

Câmara, G., Monteiro, A.M., Fucks, S.D., Carvalho, M.S., 2004. Spatial analysis and GIS: a primer. Image Processing Division, *National Institute for Space Research (INPE)*, Brasil. Internet:

https://bhattadevuniversity.ac.in/docs/studyMaterial/Jyotismoy_Bora_Geography/Dr.%20Jyotishmoy%20Bora_Geography_PG%20IV%20Sem_Spatial%20Analysis%20and%20GIS%20%20A%20Primer.pdf.

Cao, K., Diao, M., Wu, B., 2019. A big data-based geographically weighted regression model for public housing prices: A case study in Singapore. *Annals of the American Association of Geographers* 109, 173–186. Internet: <https://doi.org/10.1080/24694452.2018.1470925>.

Cavana, R., Delahaye, B., Sekeran, U., 2001. Applied business research: Qualitative and quantitative methods. John Wiley & Sons. ISBN- 0471341266.

Chauvin, J.P., Glaeser, E., Ma, Y., Tobio, K., 2017. What is different about urbanization in rich and poor countries? Cities in Brazil, China, India, and the United States. *Journal of Urban Economics* 98, 17–49. Internet: <https://doi.org/10.1016/j.jue.2016.05.003>. Accessed on August 10th, 2020.

Chen, J., Deng, L., 2014. Financing affordable housing through compulsory saving: The two-decade experience of housing provident fund in China. *Housing studies* 29, 937–958. <https://doi.org/10.1080/02673037.2014.923088>. Accessed on September 2nd, 2020.

Cheng, I.-H., Raina, S., Xiong, W., 2014. Wall Street and the housing bubble. *American Economic Review* 104, 2797–2829. Internet: [10.1257/aer.104.9.2797](https://doi.org/10.1257/aer.104.9.2797). Accessed on June 1th 2020.

Childs, C., 2004. Interpolating surfaces in ArcGIS spatial analyst. ArcUser, July-September 3235, 32–35. Internet: <https://community.esri.com/ccqpr47374/attachments/ccqpr47374/arcgis-spatial-analyst-questions/6861/2/interpolating-1.pdf>. Accessed on March 14th, 2021.

Choplin, A., Franck, A., 2010. A glimpse of Dubai in Khartoum and Nouakchott: prestige urban projects on the margins of the Arab world. *Built Environment* 36, 192–205. Internet: <https://doi.org/10.2148/benv.36.2.192>. Accessed on March 5th, 2020.

De Geoffroy, A., 2005. IDPs and urban planning in Khartoum. *Forced Migration Review* 24, 38–39. Internet: <https://www.fmreview.org/sites/fmr/files/FMRdownloads/en/sudan/degeoffroy.pdf>. Accessed on March 17th, 2020.

De Waal, A., 2008. Darfur, the Court, and Khartoum: The politics of state non-cooperation. *Courting conflict* 29–35.

Delhaas, R., 2006. Forgotten and Marginalized: Displaced Persons in Khartoum: One Year after the Peace Agreement'. *Interchurch Organization for Development Co-operation (ICCO)* 4.

Dorokh, E. and Torluccio, G., 2011. Housing affordability and methodological principles: An application. *International Research Journal of Finance and Economics*, (79), p.64. Internet: https://www.researchgate.net/profile/Alena_Dorakh/publication/328225066_SSRN-id2005895pdf/data/5bbf60a192851c88fd6506ae/SSRN-id2005895.pdf. Accessed on April 2nd, 2020.

Du, H. and Mulley, C., 2006. Relationship between transport accessibility and land value: Local model approach with geographically weighted regression. *Transportation Research Record*, 1977(1), pp.197–205. Internet: <https://doi.org/10.1177/0361198106197700123>. Accessed on August 7th, 2020.

Du, H. and Mulley, C., 2012. Understanding spatial variations in the impact of accessibility on land value using geographically weighted regression. *Journal of Transport and Land Use*, 5(2), pp.46-59. Internet: <https://www.jstor.org/stable/26201690>. Accessed on August 7th, 2020.

Düzgün H., Kemeç S. 2008. Spatial and Geographically Weighted Regression. In: Shekhar S., Xiong H. (eds) *Encyclopedia of GIS*. Springer, Boston, MA. Internet: https://doi.org/10.1007/978-0-387-35973-1_1242. Accessed on August 6th, 2020.

Elagib, N.A., 2011. Evolution of urban heat island in Khartoum. *International Journal of Climatology* 31, 1377–1388. Internet: <https://doi.org/10.1002/joc.2159>. Accessed on April 22nd, 2020.

Elhadary, Y., Ali, S., 2017. A new trend in urban housing: Gated communities in Khartoum, Sudan. *American Journal of Sociological Research* 7, 45–55. Internet: https://d1wqtxts1xzle7.cloudfront.net/57530541/paper_27.pdf?1539065448=&response-content-disposition=inline%3B+filename%3DA_New_Trend_in_Urban_Housing_Gated_Community.pdf&Expires=1615907340&Signature=Ab8xeTSBp6u43cPpr-WWIZAiUnOF10PNk9~z2r9auoajdsmaXfMnzH1CcmQZGWkHAT5UusJ9FFfXD8cYu96kwnYZv6CT8AwrlE9Lh9oDubh7S1VNL3CFkAVbOYyuTLv11mBQtIZQPfegJqadOa4aEfHNckurlQ4jAeul7tr7OI4MYN8nk3ztNSMzp60GckaMH3R~QHYHurlTPRHM1CaSpL0brGeo9wUfWt1Aplv6PB~32uMcddBrdorT5bA1TDOtFWr73ydw6ZZnU8Qdxoqv5jmig-Zvf8DEgNKpAwl-L1o-PhwN7s4rtRGO48ZDsGsS3QN5y9HY8Vr9S1J2KnPw_&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA. Accessed on May 11th, 2020.

ELKHEIR, O., 2012. The urban environment of Khartoum: Proceedings of National Civic Forum (NCF), Rio+ 20 Civil Society Preparatory Process. Internet: https://d1wqtxts1xzle7.cloudfront.net/34238792/1_THE_URBAN_ENVIRONMENT_OF_KHARTOUM.pdf?1405739645=&response-content-disposition=inline%3B+filename%3DThe_Urban_Environment_of_Khartoum.pdf&Expires=1615906472&Signature=Yu8YmDHJuu1o4bQH0cH-u1~T-GF9hAxN4rO1z-iOmOpOgg3F8mwdJ49xHp6tIswbkBlivl3sRWyV~2mNMcfWtp4kXM5U4sHyPeofXMLuzb9bNttCyzK~R1c6o-0Q94vA2KELV-YMkl6GRhBHpwK40tnnSbeHd9HK0d7tuGOLPfmSb0WifLI-tlpD2Jg3wyynUucluNQW3TepCCdXaqWezyt7Lh~BfM~hKlFADRfb2WLuME3gA6wV7akoktR4TUWkrMYrOqbju3zE~vjezKAmH6vijSe7tteH8E73T9cWdunE1Vxzi0VI44JFTzzxQvm9hLHxx8LbWoXLavYijOsg_&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA. Accessed on April 15th, 2020.

Eltahir, M.M., 2005. Community participation in housing and urban development in poor urban communities, case study of Umbadda, Khartoum. Internet: <http://hdl.handle.net/2263/10377>. Accessed on April 12th, 2020.

Eltayeb, G.E., 2003. Khartoum, Sudan. *UN-HABITAT Case Studies*, London 2. Internet: https://www.ucl.ac.uk/dpu-projects/Global_Report/pdfs/khartoum_bw.pdf. Accessed on February 25th, 2020.

Elzobier, A., 2009. The madness of land and property values in Khartoum (2-2) - Sudan Tribune: Plural news and views on Sudan [WWW Document]. Internet: <https://sudantribune.com/The-madness-of-land-and-property,32403>. Accessed on February 25th, 2020.

Evans, A.W., 1973. *The economics of residential location*. Springer. Internet: https://doi.org/10.1007/978-1-349-01889-5_1. Accessed on May 15th, 2020.

Evans, A.W., 2008. *Economics and land use planning*. Wiley Online Library. Internet: [10.1002/9780470690895](https://doi.org/10.1002/9780470690895). Accessed on May 23rd, 2020.

Feather, C. and Meme, CK, 2019. Strengthening housing finance in emerging markets: the savings and credit cooperative organization (SACCO) model in Kenya. *Housing Studies*, 34(9), pp.1485-1520. Internet: <https://doi.org/10.1080/02673037.2019.1584663>. Accessed on April 21st, 2020.

Feng, X., Humphreys, B., 2018. Assessing the economic impact of sports facilities on residential property values: A spatial hedonic approach. *Journal of Sports Economics* 19, 188–210. Internet: <https://doi.org/10.1177/1527002515622318>. Accessed on July 22nd, 2020.

Fotheringham, A.S., Brunsdon, C. and Charlton, M., 2000. *Quantitative geography: perspectives on spatial data analysis*. Sage. Internet: https://books.google.co.za/books?hl=en&lr=&id=QuEladpO1oEC&oi=fnd&pg=PP1&ots=ZtJJAxWT-h&sig=T7EqSmrRI4CjXRQjKh6WRjTGg_w&redir_esc=y#v=onepage&q&f=false. Accessed on August 6th, 2020.

Fox, S., Goodfellow, T., 2016. *Cities and development*. Routledge.

Gabay, C., Ilcan, S., 2018. *The Politics of Destination in the 2030 Sustainable Development Goals: Leaving No-one Behind?* Routledge. ISBN-9780367587505.

Ghasri, M. and Rashidi, TH, 2019. Investigating the Internal Compromise Between Wife and Husband's Commute Time Changes in Residential Relocation. In *The Practice of Spatial Analysis* (pp. 325-339). Springer, Cham. Internet: https://doi.org/10.1007/978-3-319-89806-3_15. Accessed on August 7th, 2020.

Gilbert, A., 1984. Planning, invasions and land speculation: the role of the state in Venezuela. *Third World Planning Review* 6, 225.

Goodchild, M.F. and Longley, P.A., 1999. The future of GIS and spatial analysis. *Geographical information systems*, 1, pp.567-580. https://www.geos.ed.ac.uk/~gisteac/gis_book_abridged/files/ch40.pdf. Accessed on March 14th, 2020.

HABITAT III, U., 2016. United Nations Conference on Housing and Sustainable Urban Development. Policy Paper 9. ISBN Volume: 978-92-1-132755-7. Internet: <https://unhabitat.org/sites/default/files/download-manager-files/WCR-2016-WEB.pdf>. Accessed on May 20th, 2020.

Habitat, U.N., 2009. Urban sector studies and capacity building for Khartoum State. Nairobi: UN-HABITAT. ISBN Number: 978-92-1-132181-4. Internet: <https://unhabitat.org/sites/default/files/download-manager-files/Urban%20Sector%20Studies%20and%20Capacity%20Building%20for%20Khartoum%20State.pdf>. Accessed on March 13th, 2020.

Habitat, U.N., 2011. Affordable land and housing in Asia. Volume 2, 43. ISBN-9789211323696. Internet: https://unhabitat.org/sites/default/files/download-manager-files/3225_alt.pdf. Accessed on May 25th, 2020.

Habitat, U.N., 2015. Habitat III Policy Paper Framework. Internet: <http://uploads.habitat3.org/hb3/PU10-HABITAT-III-POLICY-PAPER.pdf>. Accessed on March 1st, 2020.

Hafazalla, A.A., 2006. *Housing policy and supply in Khartoum: the role of the public sector in the supply process* (Doctoral dissertation, Newcastle University). Internet: <http://hdl.handle.net/10443/1051>. Accessed on March 21st, 2020.

Haining, R.P., Haining, R., 2003. Spatial data analysis: theory and practice. Cambridge university press. Internet: <https://doi.org/10.1080/13658810310001638682>. Accessed on August 6th, 2020.

Hamdan, G., 1960. The Growth and Functional Structure of Khartoum. *The Geographic Review*.1: 21-40. Internet: <https://doi.org/10.2307/212333>. Accessed on April 5th, 2020.

Hamdan, G., 1960. The growth and functional structure of Khartoum. *Geographical Review* 50, 21–40. Internet: <https://doi.org/10.2307/212333>. Accessed on April 20th, 2020.

Hamid, G.M., Mohamed Elhassan, A.A., 2014. Incremental housing as an alternative housing policy: evidence from Greater Khartoum, Sudan. *International Journal of Housing Policy* 14, 181–195. Internet: <https://doi.org/10.1080/14616718.2014.908576>. Accessed on April 20th, 2020.

Hikichi, H., Ni, M.Y., Leung, G.M., 2020. Parental cohabitation and mental well-being amongst young adults in the world's densest population with least affordable housing: Evidence from the FAMILY cohort. *Journal of Affective Disorders* 274, 698–703. Internet: <https://doi.org/10.1016/j.jad.2020.05.060>. Accessed on July 11th, 2020.

Hjort, B., Widén, K., 2015. Introduction of sustainable, low-cost housing in Ethiopia—an innovation diffusion perspective. *Procedia Economics and Finance* 21, 454–460. Internet: [https://doi.org/10.1016/S2212-5671\(15\)00199-9](https://doi.org/10.1016/S2212-5671(15)00199-9). Accessed on July 5th, 2020.

Home, R. 1990. "British Colonial Town Planning in the Middle East: The Work of W. H. McLean." *Planning History* 12 (1): 4-9

Hu, S., Cheng, Q., Wang, L. and Xu, D., 2013. Modeling land price distribution using multifractal IDW interpolation and fractal filtering method. *Landscape and urban planning*, 110, pp.25-35. Internet: <https://doi.org/10.1016/j.landurbplan.2012.09.008>. Accessed on August 5th, 2020.

Hu, S., Yang, S., Li, W., Zhang, C. and Xu, F., 2016. Spatially non-stationary relationships between urban residential land price and impact factors in Wuhan city, China. *Applied Geography*, 68, pp.48-56. Internet: <https://doi.org/10.1016/j.apgeog.2016.01.006>. Accessed on July 23rd, 2020.

Huang, B., Wu, B., Barry, M., 2010. Geographically and temporally weighted regression for modeling Spatio-temporal variation in house prices. *International Journal of Geographical Information Science* 24, 383–401. <https://doi.org/10.1080/13658810802672469>. Accessed on September 5th, 2020.

Ibrahim, G.M., Saeed, T.A., El-Khouly, T., 2020. The transition of spatial organisation planning of pre- and post-colonial housing in Khartoum. *International Journal of Architectural Research*. Internet: <https://doi.org/10.1108/ARCH-04-2020-0075>. Accessed on May 14th, 2020.

Isard, W., 1956. Location and space-economy. Internet: <https://doi.org/10.1017/S0022050700089130>.

Kemeny, J., 2013. Housing and social theory. Routledge. ISBN 9781138972018.

King, R., Orloff, M., Virsilas, T., Pande, T., 2017. Confronting the urban housing crisis in the global south: adequate, secure, and affordable housing. *World Resources Institute*, Working Paper. Internet: <https://smartnet.niua.org/sites/default/files/resources/towards-more-equal-city-confronting-urban-housing-crisis-global-south.pdf>. Accessed on September 15th, 2020.

Koramaz, T.K. and Dokmeci, V., 2012. Spatial determinants of housing price values in Istanbul. *European Planning Studies*, 20(7), pp.1221-1237. Internet: <https://doi.org/10.1080/09654313.2012.673569>. Accessed on March 10th, 2020.

Kosareva, N. and A. Tumanov, 2008, Assessing Housing Affordability in Russia. *Problems of Economic Transition*, 50 (10), 6-29. Internet: https://www.tandfonline.com/doi/pdf/10.2753/PET1061-1991501001?casa_token=2qeP274sx5YAAAAA:ELxfoCYvrUPihu5k60mSeSGzpL0VhQFPY2PvEdGvVkf0q_eEj_JZFKZVauZUrGMN8lZd4B4Tz8Wjsw. Accessed on July 23rd, 2020.

Kostov, P., 2009. A spatial quantile regression hedonic model of agricultural land prices. *Spatial Economic Analysis*, 4(1), pp.53-72. Internet: <https://doi.org/10.1080/17421770802625957>. Accessed on August 8th, 2020.

Kuntz, M. and Helbich, M., 2014. Geostatistical mapping of real estate prices: an empirical comparison of Kriging and Cokriging. *International Journal of Geographical Information Science*, 28(9), pp.1904-1921. Internet: <https://doi.org/10.1080/13658816.2014.906041>. Accessed on August 6th, 2020.

Lam, N.S.-N., 1983. Spatial interpolation methods: a review. *The American Cartographer* 10, 129–150. Internet: <https://doi.org/10.1559/152304083783914958>. Accessed on March 14th, 2020.

Lee, B.H., Waddell, P., Wang, L., Pendyala, R.M., 2010. Reexamining the influence of work and nonwork accessibility on residential location choices with a microanalytic framework. *Environment and Planning* 42, 913–930. Internet: <https://doi.org/10.1068/a4291>. Accessed on October 10th, 2020.

Li, H., Wei, Y.D., Yu, Z., Tian, G., 2016. Amenity, accessibility and housing values in metropolitan USA: A study of Salt Lake County, Utah. *Cities* 59, 113–125. Internet: <https://doi.org/10.1016/j.cities.2016.07.001>. Accessed on October 13th, 2020.

Li, J., Heap, A.D., 2008. A review of spatial interpolation methods for environmental scientists. Internet: http://planet.botany.uwc.ac.za/NISL/BCB_BIM_honours/Course_Documents_2016/Spatial_Interpolation_statistics_methods.pdf. Accessed on June 11th, 2020.

- Li, J., Heap, A.D., 2011. A review of comparative studies of spatial interpolation methods in environmental sciences: Performance and impact factors. *Ecological Informatics* 6, 228–241. Internet: <https://doi.org/10.1016/j.ecoinf.2010.12.003>. Accessed on June 10th, 2020.
- Li, J., Heap, A.D., 2014. Spatial interpolation methods applied in the environmental sciences: A review. *Environmental Modelling & Software* 53, 173–189. <https://doi.org/10.1016/j.envsoft.2013.12.008>. Accessed on June 13th, 2020.
- Li, Z., Zhou, S.L., Zhang, H.F., Yao, X., and Wu, W., 2009. Exploring the factors impacting on the residential land price and measuring their marginal effects based on a geographically weighted regression model: a case study of Nanjing. *China Land Science*, 23(10), pp.20-25. Internet: http://en.cnki.com.cn/Article_en/CJFDTotal-ZTKX200910007.htm. Accessed on August 6th, 2020.
- Linneman, P. D. and I. F. Megbolugbe, 1992, Housing Affordability: Myth or Reality?. *Urban Studies*, 29 (3-4), 369-392. Internet: <https://journals.sagepub.com/doi/abs/10.1080/00420989220080491>. Accessed on July 20th, 2020.
- Locurcio, M., Morano, P., Tajani, F., Di Liddo, F., 2020. An innovative GIS-based territorial information tool for the evaluation of corporate properties: An application to the Italian context. *Sustainability* 12, 5836. Internet: <https://doi.org/10.3390/su12145836>. Accessed on November 5th, 2020.
- Loesch, A., 1940. *The economics of location* (trans. WH Woglom, WR Stolper, 1954). Yale University Press, New Haven.
- MacLean, W. H., 1910. The Planning of Khartoum and Omdurman. Town Planning Conference Proceedings. London. pp. 575-603.
- Manganelli, B., Pontrandolfi, P., Azzato, A. and Murgante, B., 2014. Using geographically weighted regression for housing market segmentation. *International Journal of Business Intelligence and Data Mining* 13, 9(2), pp.161-177. Internet: [10.1504/IJBIDM.2014.065100](https://doi.org/10.1504/IJBIDM.2014.065100). Accessed on August 6th, 2020.
- McAuslan, P., 1982. The urban land questions. *Habitat International* 6, 545–554. Internet: [https://doi.org/10.1016/0197-3975\(82\)90021-2](https://doi.org/10.1016/0197-3975(82)90021-2). Accessed on April 28th, 2020.
- Menon, A., Hodkinson, G., Galal, H., Reckford, J., Charles, A., 2019. Making affordable housing a reality in cities, Insight Report. Geneva: World Economic Forum. Internet: http://www3.weforum.org/docs/WEF_Making_Affordable_Housing_A_Reality_In_Cities_report.pdf. Accessed on March 24th, 2020.
- Mikelbank, B.A., 2004. Spatial analysis of the relationship between housing values and investments in transportation infrastructure. *The Annals of Regional Science*, 38(4), pp.705-726. Internet: <https://link.springer.com/content/pdf/10.1007/s00168-003-0187-0.pdf>. Accessed on August 4th, 2020.
- Miller, H.J., 2004. Tobler's first law and spatial analysis. *Annals of the Association of American Geographers*, 94(2), pp.284-289. Internet: https://www.jstor.org/stable/3693985?seq=1#metadata_info_tab_contents. Accessed on August 3rd, 2020.

Ministry of Physical Planning and Development, 2010. Khartoum Structural Plan, 2007-2032. Khartoum, Sudan.

Mirrlees, J.A., 1972. The optimum town. *The Swedish Journal of Economics* 114–135. Internet: <https://doi.org/10.2307/3439013>. Accessed on April 19th, 2020.

Mitas, L., Mitsova, H., 1999. Geographical information systems, *Principles and Technical Issues*.

Mohammed, E.A., Alawad, H.M., Zeinelabdein, K.A.E., Ali, A.G., 2015. Urban expansion and population growth in Omdurman city, Sudan using geospatial technologies and statistical approaches. *American Journal of Earth Sciences* 2, 1–7. Internet: https://www.researchgate.net/profile/Khalid-Elsayed-Zeinlabdein/publication/272563112_Urban_expansion_and_population_growth_in_Omdurman_city_Sudan_using_geospatial_technologies_and_statistical_approaches/links/5a0a12b30f7e9bb949f96d35/Urban-expansion-and-population-growth-in-Omdurman-city-Sudan-using-geospatial-technologies-and-statistical-approaches.pdf. Accessed on March 13th, 2020.

Montero, J. and Larraz, B., 2011. Interpolation methods for geographical data: Housing and commercial establishment markets. *Journal of Real Estate Research*, 33(2), pp.233-244. Internet: <https://www.tandfonline.com/doi/pdf/10.1080/10835547.2011.12091301?needAccess=true>. Accessed on March 14th, 2020.

Moreno, E.L., 2016. Urbanization and development: Emerging futures: world cities report 2016. UN-Habitat. ISBN: 978-92-1-132708-3. Internet: <https://unhabitat.org/sites/default/files/download-manager-files/WCR-2016-WEB.pdf>. Accessed on March 25th, 2020.

Mostafa, M.M., 2018. A spatial econometric analysis of residential land prices in Kuwait. *Regional Studies, Regional Science* 5, 290–311. Internet: <https://doi.org/10.1080/21681376.2018.1518154>. Accessed on November 3rd, 2020.

Mouratidis, K., 2019. Compact city, urban sprawl, and subjective well-being. *Cities* 92, 261–272.

Mulliner, E., Maliene, V., 2011. Criteria for sustainable housing affordability. Internet: <https://researchonline.ljmu.ac.uk/id/eprint/469>. Accessed on August 10th, 2020.

Namangaya, A. and Kiunsi, R., 2018. Assessing the influences of service provision on pace and short- and medium-term development patterns of residential housing in Dar es Salaam. *Geografisk Tidsskrift-Danish Journal of Geography*, 118(2), pp.151-159. Internet: <https://doi.org/10.1080/00167223.2018.1500490>. Accessed on May 14th, 2020.

Naoum, S., Tsanis, I.K., 2004. Ranking spatial interpolation techniques using a GIS-based DSS. *Global Nest* 6, 1–20. Internet: <https://doi.org/10.30955/gnj.000224>. Accessed on August 5th, 2020.

Nguyen, M.T., Basolo, V., Tiwari, A., 2013. Opposition to affordable housing in the USA: Debate framing and the responses of local actors. *Housing, Theory and Society* 30, 107–130. Internet: <https://doi.org/10.1080/14036096.2012.667833>. Accessed on October 4th, 2020.

Onour, I., 2017. Anatomy of Black Market for Dollars in Sudan. Available at SSRN 3048995. Internet: <https://ssrn.com/abstract=3048995> or <http://dx.doi.org/10.2139/ssrn.3048995>. Accessed on March 10th, 2020.

Outlook, A.E., 2020. Developing Africa's Workforce for the Future. African Development Bank Group: Abidjan, Côte d'Ivoire.

Pace, R.K., Barry, R., Sirmans, C.F., 1998. Spatial statistics and real estate. *The Journal of Real Estate Finance and Economics* 17, 5–13. Internet: <https://doi.org/10.1023/A:1007783811760>. Accessed on July 5th, 2020.

Pagliara, F., Preston, J., Simmonds, D., 2010. Residential location choice: models and applications. *Springer Science & Business Media*. ISBN 978-3-642-12788-5. Internet: <http://10.1007/978-3-642-12788-5>. Accessed on September 10th, 2020.

Pantuliano, S., Buchanan-Smith, M., Metcalfe, V., Pavanello, S. and Martin, E., 2011. City limits: urbanization and vulnerability in Sudan. Khartoum case study. HPG, London. Internet: <https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/6518.pdf>. Accessed on March 14th, 2020.

Patel, B., Byahut, S., Bhatha, B., 2018. Building regulations are a barrier to affordable housing in Indian cities: the case of Ahmedabad. *Journal of Housing and the Built Environment* 33, 175–195. Internet: <https://doi.org/10.1007/s10901-017-9552-7>. Accessed on June 5th, 2020.

Ping, L.V. and Hui, ZHEN, 2010. Affecting factors research of Beijing residential land price based on GWR model. *Economic Geography*, 3, pp.472-478. Internet: http://en.cnki.com.cn/Article_en/CJFDTotal-JJDL201003021.htm. Accessed on August 7th, 2020.

Planning History. 1990. Bulletin of the Planning History Group. United Kingdom. ISSN 0959-5805

Pohlmann, John T., and Dennis W. Leitner. 2003. A comparison of ordinary least squares and logistic regression (1). *The Ohio Journal of Science*, vol. 103, no. 5, p. 118. Internet: <http://hdl.handle.net/1811/23983>. Accessed August 7th, 2020.

Pomeroy, S., 2018. Discussion paper: Envisioning a modernized social and affordable housing sector in Canada. Internet: <https://ir.library.carleton.ca/pub/27732/Envisioning-a-strengthened-social-housing-sector-FINAL-Oct-2018.pdf>. Accessed on April 2nd, 2020.

Potoglou, D., Maoh, H., Wang, Y., Orford, S., 2019. The Impact of Public Transport Infrastructure on Residential Land Value: Using Spatial Analysis to Uncover Policy-Relevant Processes: *The Practice of Spatial Analysis*. Springer, pp. 275–293. Internet: https://doi.org/10.1007/978-3-319-89806-3_13. Accessed on August 4th, 2020.

Rajasekar, S., Philominathan, P., Chinnathambji, V., 2006. Research Methodology, 1–53. Internet: https://www.researchgate.net/publication/2174858_Research_Methodology. Accessed on June 5th, 2020.

Ratcliffe, J., Stubbs, M., Shepherd, M., 2004. Urban planning and real estate development. *Taylor & Francis*. ISBN 9780415450782.

Reibel, M., Bufalino, M.E., 2005. Street-weighted interpolation techniques for demographic count estimation in incompatible zone systems. *Environment and Planning A* 37, 127–139. Internet: <https://doi.org/10.1068/a36202>. Accessed on June 15th, 2020.

Renn, O. and Klinke, A., 2013 A Framework of Adaptive Risk Governance for Urban Planning. *Sustainability*, MDPI AG, 5(5), 2036–2059. Internet: <http://dx.doi.org/10.3390/su5052036>. Accessed on March 13th, 2020.

Richardson, H.W., Vipond, J., Furbey, R.A., 1974. Determinants of urban house prices. *Urban Studies* 11, 189–199. Internet: <https://doi.org/10.1080/00420987420080341>.

Ritchie, H., Roser, M., 2018. Urbanization. Our World in Data. Internet: <https://ourworldindata.org/urbanization>. Accessed on March 14th, 2021.

Rosenshein, L., Scott, L. and Pratt, M., 2011. Finding a Meaningful Model This Checklist Will Help You Evaluate Regression Models. ArcUser. ESRI, Redlands, CA, pp40-45. Internet: <https://www.esri.com/news/arcuser/0111/files/findmodel.pdf>. Accessed on November 11th, 2020.

Roy, A., 2009. Why India cannot plan its cities: Informality, insurgence, and the idiom of urbanization. *Planning theory* 8, 76–87. Internet: <https://doi.org/10.1177/1473095208099299>. Accessed on April 10th, 2020.

Ruonavaara, H., 2018. Theory of housing, from housing, about housing. *Housing, Theory and Society*, 35(2), pp.178-192. Internet: <https://doi.org/10.1080/14036096.2017.1347103>. Accessed on August 1st, 2020.

Saefuddin, A., Widyaningsih, Y., Ginting, A. and Mamat, M., 2012. Land price model considering spatial factors. Internet: <http://paper.sci.ui.ac.id/jspui/handle/2808.28/44>. Accessed on March 15th, 2020.

Saghir, J., Santoro, J., 2018. Urbanization in Sub-Saharan Africa, in: Meeting Challenges by Bridging Stakeholders. Washington, DC, USA: *Center for Strategic & International Studies*. JSTOR. Internet: https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/180411_Saghir_UrbanizationAfrica_Web.pdf. May 14th, 2020.

San Ong, T., 2013. Factors affecting the price of housing in Malaysia. *J. Emerg. Issues Econ. Finance. Bank* 1, 414–429. Internet: <http://psasir.upm.edu.my/id/eprint/28264>.

Schabenberger, O. and Gotway, C.A., 2017. Statistical methods for spatial data analysis. CRC press. Internet: https://books.google.com/books?hl=en&lr=&id=I2ONDgAAQBAJ&oi=fnd&pg=PP1&ots=HteKCCjvph&sig=_jpBDHAdaZsgpWfvaQkhsI75kpDk. Accessed on August 6th, 2020.

Scott, L.M., Janikas, M.V., 2010. *Spatial statistics in ArcGIS: Handbook of Applied Spatial Analysis*. Springer, pp. 27–41. Internet: https://doi.org/10.1007/978-3-642-03647-7_2. Accessed on November 10th, 2020.

Seto, K.C., Parnell, S., Elmqvist, T., 2013. A global outlook on urbanization. *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities*. Springer, Dordrecht, pp. 1–12. Internet: https://doi.org/10.1007/978-94-007-7088-1_1. Accessed on August 10th, 2020.

Shuttleworth, M., 2008. Definition of research. Experiment Resources. Internet: <https://pdfs.semanticscholar.org/81ae/fa0d269c8cefbae5cfcf5dd8949b2a019353.pdf>. Accessed August 9th, 2020.

Somekh, B., Burman, E., Delamont, S., Meyer, J., Payne, M., and Thorpe, R., 2005. Research communities in the social sciences. *Research methods in the social sciences*, pp.1-14. Internet: <http://www.sagepub.co.in/sage3g/sage-uk.war/managementresearch/Easterby-Smith%20Online%20Reading%20Links/Chapter%201/Somekh%20&%20Lewin%20Research%20Methods%20in%20the%20Social%20Sciences%20pp1-14.PDF>. Accessed on July 29th, 2020.

Staff, U.N.H.S.P., 2003. The challenge of slums: global report on human settlements, 2003. UN-HABITAT.

Steel, G., Abukashawa, S., Hussein, M.O., 2020. Urban Transformations and Land Governance in Peri-Urban Khartoum: The Case of Soba. *Tijdschrift voor economische en sociale geografie* 111, 45–59. Internet: <https://doi.org/10.1111/tesg.12372>. Accessed on May 1st 2020.

Stockemer, D., 2019. *A Short Introduction to Survey Research: Quantitative Methods for the Social Sciences*. Springer, pp. 23–35. Internet: https://doi.org/10.1007/978-3-319-99118-4_3.

Sudan, C.B.S., UNICEF, S., 2016. Multiple Indicator Cluster Survey 2014 of Sudan. Final Report. *Khartoum: United Nations Children's Fund and Central Bureau of Statistics*. Internet: https://www.un.org/ldc5/sites/www.un.org.ldc5/files/sudan_istanboul_ipoa.pdf. Accessed on April 4th, 2020.

Sudan, S., 2020. Sudan First State of Environment and Outlook Report 2020. Internet: <https://wedocs.unep.org/bitstream/handle/20.500.11822/33998/UNEN.pdf?sequence=1&isAllowed=y>. Accessed on November 12th, 2020.

Suhaida, M.S., Tawil, N.M., Hamzah, N., Che-Ani, A.I., Basri, H., Yuzainee, M.Y., 2011. Housing affordability: A conceptual overview for house price index. *Procedia Engineering* 20, 346–353. Internet: <https://doi.org/10.1016/j.proeng.2011.11.176>.

Suleiman, M., 2007. Will Khartoum Overcome NCP Monopoly and Become an Inclusive National Capital?.

Sulemana, I., Nketiah-Amponsah, E., Codjoe, E.A., Andoh, J.A.N., 2019. Urbanization and income inequality in Sub-Saharan Africa. *Sustainable Cities and Society* 48, 101544. <https://doi.org/10.1016/j.scs.2019.101544>. Accessed on May 26th, 2020.

Szczepańska, A., Gościński, D., Gerus-Gościńska, M., 2020. A GRID-Based Spatial Interpolation Method as a Tool Supporting Real Estate Market Analyses. *International Journal of Geo-Information* 9, 39. Internet: <https://doi.org/10.3390/ijgi9010039>. Accessed on May 15th, 2020.

Trojanek, R., Tanas, J., Raslanas, S. and Banaitis, A., 2017. The impact of aircraft noise on housing prices in Poznan. *Sustainability*, 9(11), p.2088. Internet: <https://doi.org/10.3390/su9112088>. Accessed on August 8th, 2020.

Turvey, R., 2017. *The economics of real property: an analysis of property values and patterns of use*. Routledge. ISBN 9781138102576.

United Nations, Department of Economic and Social Affairs, Population Division, 2019. World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). New York: United Nations. Internet: <https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf>. Accessed March 10th, 2020.

Van Doorn, L., Arnold, A., Rapoport, E., 2019. In the age of cities: The impact of urbanisation on house prices and affordability: *Hot Property*. Springer, Cham, pp. 3–13. Internet: https://doi.org/10.1007/978-3-030-11674-3_1. Accessed on June 10th, 2020.

Waters, N., 2016. Tobler's First Law of Geography. *International Encyclopedia of Geography: People, the Earth, Environment and Technology*, pp.1-15. Internet: [10.1002/9781118786352.wbieg1011](https://doi.org/10.1002/9781118786352.wbieg1011). Accessed on August 4th, 2020.

Weden, M.M., Peterson, C.E., Miles, J.N., Shih, R.A., 2015. Evaluating linearly interpolated intercensal estimates of demographic and socioeconomic characteristics of US counties and census tracts 2001–2009. *Population research and policy review* 34, 541–559. Internet: <https://doi.org/10.1007/s11113-015-9359-8>. Accessed on June 14th, 2020.

Xu, H., Wu, Q., Lei, H. and Li, S., 2012, July. Study on spatial interpolation method and its application. In 2012 International Conference on Audio, Language and Image Processing (pp. 1057-1061). IEEE. Internet: [10.1109/ICALIP.2012.6376772](https://doi.org/10.1109/ICALIP.2012.6376772). Accessed on August 5th, 2020.

Yates, J., 2016. Why does Australia have an affordable housing problem, and what can be done about it? *Australian Economic Review* 49, 328–339. Internet: <https://doi.org/10.1111/1467-8462.12174>. Accessed on September 1st, 2020.

Zdaniuk, B., 2014. Ordinary Least-Squares (OLS) Model. In: Michalos A.C. *Encyclopedia of Quality of Life and Well-Being Research*. Springer, Dordrecht. Internet: https://doi.org/10.1007/978-94-007-0753-5_2008. Accessed on August 7th, 2020.

Zhang, Y. and Xie, H., 2019. Interactive Relationship among Urban Expansion, Economic Development, and Population Growth since the Reform and Opening-up in China: An Analysis Based on a Vector Error Correction Model. *Land*, 8(10), p.153. Internet: <https://doi.org/10.3390/land8100153>. May 10th, 2020.

Zmölnig, J., Tomintz, M.N., Fotheringham, S.A., 2014. A spatial analysis of house prices in The Kingdom of Fife, Scotland. *GI_Forum* 125–134. Internet: [10.1553/giscience2014s125](https://doi.org/10.1553/giscience2014s125). Accessed on October 2nd, 2020.

Zuhal, E.A., 2016. Residential Density: Concept and Practice in Khartoum–Sudan. *Journal of Building and Road Research* 11. Internet: https://www.researchgate.net/profile/Zuhal-Awad/publication/334730271_Residential_Density_Concept_and_Practice_in_Khartoum_-_Sudan/links/5d3d7c4c299bf1995b5096ac/Residential-Density-Concept-and-Practice-in-Khartoum-Sudan.pdf. Accessed on April 23rd, 2020.

Appendix

	FID	Shape *	OBJECTID	Price	Size	Facade	Plot Price	BUILDUP	CONSTCOST	TOTCOST	PMT	GINCOME	MEDINCME	HAI	MORT	MORTPMT	GINCMORT	MORTHAI
	0	Point	1	2180	995	30	2147300	657	229950	2377250	13207	633936	7636	1	950900	5283	253584	3
	1	Point	2	2310	895	50	1397550	403	141850	1538800	8548	410304	7636	2	615440	3419	164112	5
	2	Point	3	2350	600	52	1588000	453	158550	1756650	9759	486432	7636	2	702620	3903	187344	4
	3	Point	4	2190	1025	25	2233000	609	230600	2471800	13732	659136	7636	1	990720	5493	263664	3
	4	Point	5	1820	2070	45	3767400	1305	483600	4259400	23613	1133424	7636	1	1700160	9445	453360	2
	5	Point	6	1930	895	55	1553650	537	187850	1741600	9676	464448	7636	2	696640	3870	185760	4
	6	Point	7	2180	2160	90	4708800	1448	504000	5212600	28960	1390080	7636	1	2685120	11584	556032	1
	7	Point	8	2180	780	25	1709400	525	182000	1882400	10458	521984	7636	2	752960	4183	200784	4
	8	Point	9	2330	600	45	1398800	405	140600	1538000	8544	410112	7636	2	615200	3418	164064	5
	9	Point	10	1860	770	55	1278200	513	179550	1457750	8099	388752	7636	2	583100	3239	155472	5
	10	Point	11	1750	590	45	875000	333	116550	991550	5595	264432	7636	3	396820	2203	105744	7
	11	Point	12	2800	950	60	1978000	633	221550	2187550	12209	596032	7636	1	879620	4883	234384	3
	12	Point	13	2160	1025	95	2203200	609	230600	2441200	13562	650976	7636	1	976480	5425	260400	3
	13	Point	14	2220	872	26	1935640	581	203350	2139190	11804	575432	7636	1	855676	4754	228192	3
	14	Point	15	2180	905	30	1972900	603	211950	2183950	12133	582384	7636	1	873560	4853	232944	3
	15	Point	16	2680	1535	35	3102800	1023	358550	3558650	19727	946896	7636	1	1420340	7891	378768	2
	16	Point	17	2180	980	75	2073600	648	224000	2297600	13764	612672	7636	1	819640	5108	245888	3
	17	Point	18	1740	690	50	1209600	480	161600	1361600	7584	363072	7636	2	544840	3026	145248	5
	18	Point	19	2020	715	25	1444300	477	166950	1811250	8951	429648	7636	2	644500	3581	171888	4
	19	Point	20	2230	1045	25	2339350	697	243950	2574300	14302	686496	7636	1	1029720	5721	274608	3
	20	Point	21	2640	865	25	1764800	577	201950	1866650	10925	524480	7636	1	786620	4370	209760	4
	21	Point	22	2605	618	48	1268800	407	142450	1411250	7840	376320	7636	2	564500	3136	150528	5
	22	Point	23	2240	548	45	1209600	395	126600	1335800	7420	356160	7636	2	534240	2965	142464	5
	23	Point	24	2170	995	30	2159150	683	232950	2391200	13264	637632	7636	1	856480	5314	255072	3
	24	Point	25	2280	750	63	1718000	508	175600	1885000	10472	582656	7636	2	754800	4189	201872	4
	25	Point	26	2180	350	35	758000	233	81550	837550	4653	223344	7636	3	335620	1861	89328	9
	26	Point	27	2220	655	25	1454100	437	152950	1607850	8928	428544	7636	2	642820	3571	171408	4
	27	Point	28	2870	915	65	1896120	611	213850	2109970	11722	562656	7636	1	843968	4689	225872	3
	28	Point	29	2200	630	51	1386000	428	147600	1533600	8517	408816	7636	2	613200	3407	163536	5
	29	Point	30	1750	845	55	1478750	563	197950	1975600	8310	446880	7636	2	670320	3724	178752	4
	30	Point	31	2180	628	45	1351600	413	144550	1496150	8312	398376	7636	2	590460	3325	158600	5
	31	Point	32	2180	1000	30	2180000	687	233450	2413450	13408	643584	7636	1	965380	5363	257424	3
	32	Point	33	2140	915	60	1858100	618	213500	2171600	12864	579072	7636	1	868640	4826	231648	3
	33	Point	34	2130	720	25	1533600	488	168800	1701600	9453	453744	7636	2	689640	3781	181488	4
	34	Point	35	2220	775	30	1729500	517	180950	1901450	10564	587072	7636	2	760580	4225	202800	4
	35	Point	36	2150	955	30	2053250	637	222950	2276200	12646	607088	7636	1	810480	5058	242794	3
	36	Point	37	2170	635	50	1377950	423	148850	1529800	8478	406944	7636	2	610400	3381	162768	5
	37	Point	38	2200	790	17	1659000	509	175600	1829600	10139	486672	7636	2	730000	4556	194688	4
	38	Point	39	2550	875	92	1996750	658	227500	2226250	12366	583064	7636	1	890500	4947	237456	3
	39	Point	40	2180	565	18	1237350	377	131950	1369300	7827	385136	7636	2	547720	3843	148864	5
	40	Point	41	2130	1290	75	2747700	885	301800	3048700	16937	812976	7636	1	1219480	6775	325200	2
	41	Point	42	2120	1000	90	2128000	687	233450	2353450	13675	627680	7636	1	841580	5230	251840	3
	42	Point	43	2180	475	40	1035500	317	110950	1146450	6389	385712	7636	2	458580	2548	122304	6
	43	Point	44	2145	490	40	858000	267	93450	951450	5286	253728	7636	3	380580	2114	101472	8
	44	Point	45	1980	895	60	1742400	587	205450	1947850	10821	519488	7636	1	779140	4329	207792	4

Appendix A: Attribute tables of a neighborhood sample.

Neighborhood_Points																	
Average_Pr	Class	Neighborho	AverageHAI	AVGDISSCH	AVGDISSSEC	AVGDISH	AVGDISMARK	AVGDISMOSQ	AVGDISPOLICE	AVGDISPRIOR	AVGDISINDC	AVGDISAIRPRQ	AVGDISCO	AVGDISC	AVGDISG	AVERSIZE	AVERFACADE
1412895	First	Khartoum	4.4	1574	487	1878	1435	381	1202	211	866	2997	2554	4529	2178	718	51
567921	Second	Hay AlWeha	10.6	1808	133	3094	868	292	396	205	4563	13240	7311	12339	6228	363	19
904961	First	AlRawda	6.3	1551	236	1570	609	286	511	285	2510	9225	3360	7955	6338	778	51
306792	Second	Gubba	19.1	556	772	2939	998	303	975	192	624	5948	8283	8279	2603	367	27
1107498	First	AlMahmudseen	5.56	362	164	1883	935	271	339	503	3454	8139	3406	5296	660	568	41
1090398	First	AlMogahdeen	5.75	877	429	282	1183	269	1128	91	3183	5164	8691	8691	4527	544	53
1553944	Second	AlRiyadh	4.06	529	219	488	1048	220	519	92	5398	873	3752	3772	1417	801	46
28529	Third	AlSahra	143.5	384	603	310	495	238	4766	257	19894	27311	21389	24521	20007	316	26
35874	Third	AlSahra	123.4	3365	949	9431	7947	1253	2527	1141	12442	16856	14824	14824	10233	659	39
2057026	First	AlKhartoum 2	4.2	961	153	477	438	354	328	82	4368	803	804	804	780	996	87
23590	Second	Omrabadda	256.4	7283	411	4944	1113	335	811	284	9208	18545	10915	15718	10966	309	24
54451	Third	AlKalaia	60.5	2427	427	4108	794	257	348	246	3653	10547	11318	11318	4936	385	29
44425	Third	AlWadi	118.9	349	139	4788	351	289	1377	447	16198	19254	14795	21249	18534	411	38
131233	Second	AlHaj Yusuf	35.2	270	301	489	584	218	451	145	7708	8136	4187	19507	7742	377	27
52380	Second	AlTali	113.04	373	505	478	634	139	5000	275	12604	14897	10470	17026	2939	375	32
1814122	First	AlSafya	3.8	318	125	1480	838	300	339	224	670	4881	2758	4717	4235	862	46
19327	Third	AlTawveedat	259	257	321	420	736	183	491	189	16904	17522	13653	19908	17259	228	14
18523	Third	Ways	269	1626	392	484	825	526	1086	229	2398	10228	13150	13150	6969	301	26

Appendix B: Neighbourhoods attribute tables with dependent and explanatory variables

Variable abbreviation	Variable	
Average_Pr	Average residential land price	Dependent Variables
AverageHAI	Average Housing Affordability Index	
AVGDISSCH	Average Distance to Schools	Explanatory Variables
AVGDISECROAD	Average Distance to Secondary Roads	
AVGDISHOS	Average Distance to Hospitals	
AVGDISMARKET	Average Distance to Markets	
AVGDISMOSQUE	Average Distance to Mosques	
AVGDISPOLICE	Average Distance to Police Stations	
AVGDISPRIROAD	Average Distance to Primary Roads	
AVGDISINDOR	Average Distance to Industrial Corridor	
AVGDISAIRPORT	Average Distance to Airport (Khartoum International Airport)	
AVGDISCOMCOR	Average Distance to Commercial Corridors	
AVGDISGOV	Average Distance to Government Institutions	
AVGSIZE	Average Land Size	
AVGFACADE	Average Length of the Plot's Facade	

Appendix C: Variables' abbreviations.

Search Criteria

Maximum Number of Explanatory Variables (optional)

1

Minimum Number of Explanatory Variables (optional)

1

Minimum Acceptable Adj. R Squared (optional)

0.3

Maximum Coefficient p-value Cutoff (optional)

0.05

Maximum VIF Value Cutoff (optional)

7.5

Minimum Acceptable Durbin Watson p-value (optional)

0.1

Minimum Acceptable Spatial Autocorrelation p-value (optional)

0.1

Appendix D: Exploratory regression model criterion

GWR_SecRod_CBD_Facade_PlotPrice																		
	ID	Shape*	Observed	Cond	LocalR2	Predicted	Intercept	C1_AVGSECR	C2_DISCBD	C3_AVERFAC	Residual	StdError	StdErr_Int	StdErrC1_A	StdErrC2_D	StdErrC3_A	StdResid	Source_ID
0	Point ZM	1412895	12.652664	0.864031	1183557.74734	744740.357852	-771.655795	-47.422332	18973.66742	229137.252864	268965.582309	374858.87257	324.91268	15.557038	5846.355615	0.851857		
1	Point ZM	567021	12.651236	0.864009	417537.347382	744639.588642	-771.660275	-47.40865	18974.363497	149493.652806	251428.723979	374858.829478	324.912708	15.557028	5846.355946	0.594537	1	
2	Point ZM	904961	12.651407	0.86401	1153068.79327	744530.493267	-771.655524	-47.496214	18975.792722	-248107.792266	273436.285407	374858.777164	324.912885	15.557028	5846.355273	-0.90739	2	
3	Point ZM	386792	12.652167	0.864019	268526.271678	744123.801069	-771.6354	-47.396977	18961.65074	36265.728322	222400.417651	374858.838023	324.912753	15.557034	5846.356214	0.172658	3	
4	Point ZM	1107468	12.658952	0.863969	1145288.38549	744085.079629	-771.642401	-47.386397	18981.442815	-37792.385489	266478.225854	374858.739183	324.912745	15.557031	5846.355413	-0.141822	4	
5	Point ZM	1080368	12.653009	0.864034	1007158.67358	744428.429845	-771.641922	-47.413459	18978.018801	83239.328425	270758.479735	374858.826616	324.912702	15.55704	5846.356803	0.30743	5	
6	Point ZM	1553944	12.652721	0.86403	1299615.17501	744557.283739	-771.640552	-47.416131	18976.143229	264328.824991	266761.213653	374858.856585	324.912674	15.557037	5846.355634	1.065855	6	
7	Point ZM	28529	12.647967	0.863943	-388895.015878	742949.796634	-771.62167	-47.323679	18994.884887	415424.015878	229427.525436	374858.548024	324.913546	15.557117	5846.38677	1.810698	7	
8	Point ZM	35874	12.648936	0.86398	49749.80828	743358.075273	-771.621303	-47.353977	18990.659104	-13875.88826	211371.454462	374858.806185	324.913148	15.557058	5846.359641	-0.965647	8	
9	Point ZM	2057025	12.652169	0.864021	2239383.3028	744406.295249	-771.64622	-47.436946	18977.862758	-182277.362801	183146.974118	374858.782121	324.912677	15.557032	5846.355127	-0.995252	9	
10	Point ZM	23590	12.649181	0.863971	137796.576484	743864.862784	-771.63871	-47.380913	18985.752244	-114200.578494	275632.631632	374858.957019	324.912947	15.557053	5846.358907	-0.414322	10	
11	Point ZM	54451	12.651463	0.864066	428642.788828	743781.356763	-771.627145	-47.379652	18985.829035	-374191.768828	278465.685134	374858.869827	324.912892	15.557038	5846.357281	-1.353454	11	
12	Point ZM	44425	12.655272	0.864077	199502.157255	745794.895677	-771.680931	-47.477928	18990.968507	-154077.157255	226265.932873	374859.90527	324.913179	15.557127	5846.365284	-0.800656	12	
13	Point ZM	131233	12.653831	0.86405	528508.463175	745053.358479	-771.660755	-47.441586	18970.118499	-395275.463175	271862.989162	374858.147382	324.912756	15.557061	5846.357987	-1.453951	13	
14	Point ZM	52380	12.654748	0.864067	154555.122243	745595.867821	-771.672778	-47.46389	18964.585455	-102175.122243	271827.280359	374858.587634	324.912871	15.557088	5846.361935	-0.375883	14	
15	Point ZM	1814122	12.65208	0.864021	1297362.75928	744636.328821	-771.655335	-47.414677	18974.747382	516759.248722	265617.910031	374858.804791	324.912874	15.557032	5846.355176	1.945498	15	
16	Point ZM	19327	12.655438	0.864078	-181683.57953	745545.905417	-771.670482	-47.470184	18964.386293	281028.57953	257948.082656	374859.79968	324.913016	15.557118	5846.364287	0.779303	16	
17	Point ZM	18523	12.652562	0.864024	311858.84512	744084.16716	-771.630854	-47.39732	18982.643345	-295335.84512	278754.286318	374858.944856	324.912802	15.557038	5846.357586	-1.067141	17	

Appendix E: The first GWR summary of results for the residential land prices.

GWR_Sectord_PoliceStation_CBD_PlotPrice																	
ID	Shape *	Observed	Cond	LocalR2	Predicted	Intercept	C1_AVGSECR	C2_AVGPOLI	C3_DISCBD	Residual	StdError	StdErr_Int	StdErrC1_A	StdErrC2_A	StdErrC3_D	StdResid	Source_ID
0	Point ZM	1412695	6.236143	0.829945	1263139.77826	2015536.87497	-1192.283051	182.381413	-102.082346	149555.221739	262222.642063	181229.179338	389.944108	73.607567	14.233779	0.529919	0
1	Point ZM	567021	6.29675	0.83353	655554.836045	2009945.75236	-1190.098906	175.261795	-102.561909	-68533.838045	276877.797261	181308.776882	389.834885	73.348728	14.284151	-0.319758	1
2	Point ZM	904961	6.293239	0.832794	1001881.82362	2010241.4271	-1191.212396	176.396881	-102.749625	-96920.823819	264553.665631	181173.484123	389.536895	73.308339	14.289167	-0.329043	2
3	Point ZM	306792	6.300162	0.8293	407523.210639	201166.93178	-1194.420211	181.111913	-103.652063	-100731.210936	238700.58345	181262.456648	390.12672	73.382807	14.273872	-0.421966	3
4	Point ZM	1107498	6.362578	0.83374	1327026.6039	2007207.63623	-1195.139067	191.899653	-103.889975	-219530.603905	286153.388351	181111.969687	389.914459	73.478973	14.330844	-0.767178	4
5	Point ZM	1090388	6.250291	0.827799	798799.411549	2015119.65894	-1194.121426	167.857212	-102.768323	261598.588952	296079.59624	181380.229382	390.202865	73.633275	14.256866	0.864886	5
6	Point ZM	1553944	6.24556	0.829106	1453313.96533	2014950.34358	-1192.157138	166.490338	-102.461183	108930.034674	283833.799526	181227.879564	389.836586	73.546477	14.239299	0.364539	6
7	Point ZM	26529	6.849615	0.84803	-201939.061628	2008676.18239	-1216.016773	244.261943	-107.39913	226468.061628	148852.519405	182182.211565	400.412232	78.85348	15.115565	1.534962	7
8	Point ZM	35874	6.537392	0.836867	-159223.006386	2003678.5549	-1203.51782	218.899683	-106.037024	195897.006386	214535.793888	181460.85005	383.748089	74.803284	14.544174	0.98391	8
9	Point ZM	2857036	6.272211	0.830195	1882725.6173	2012329.06453	-1192.979678	173.98526	-102.92913	254300.382697	285458.01997	181129.379763	389.599236	73.347934	14.24511	0.957968	9
10	Point ZM	23580	6.538131	0.839978	30857.58857	2002486.24975	-1202.285846	214.137056	-105.099959	-8467.58857	289010.38725	181517.191524	392.895483	75.105947	14.612883	-0.024042	10
11	Point ZM	54451	6.373826	0.831895	379794.525319	2007863.12575	-1196.711217	195.589857	-104.67739	-325343.525319	263894.006675	181325.988799	391.876257	73.558808	14.340254	-1.148811	11
12	Point ZM	44425	6.225789	0.83003	-79519.603824	2031625.32828	-1206.667918	124.857035	-99.488547	123844.603824	225598.741375	182778.547638	397.18838	76.437547	14.432358	0.549474	12
13	Point ZM	131233	6.208801	0.829481	864666.527662	2021515.73308	-1195.675578	147.473726	-101.288652	-533433.527662	294460.685777	181618.618748	391.534181	74.46423	14.275389	-1.611561	13
14	Point ZM	52380	6.209613	0.829123	378295.92658	2027769.7859	-1201.717969	132.45484	-100.133876	-325915.92658	135882.224073	182241.279445	394.531584	75.633346	14.381096	-2.389518	14
15	Point ZM	1814122	6.258884	0.831132	1438286.0487	2013019.26585	-1191.467252	168.893658	-102.465084	375825.951302	281545.52262	181156.43515	388.607289	73.388941	14.238774	1.334867	15
16	Point ZM	19327	6.216191	0.828802	-282780.328256	2038651.06142	-1206.712343	127.752465	-99.895678	302827.328256	239566.593143	182668.171934	395.593159	76.237949	14.426434	1.268724	16
17	Point ZM	16523	6.298222	0.827936	374580.237175	2011889.68841	-1194.674877	180.218673	-103.788644	-367977.237175	293753.799719	181475.395054	390.676773	73.48954	14.290447	-1.21983	17

Appendix F: The second GWR summary of results for the residential land prices.

GWR model for HA															
OBJECTID *	Shape *	Observed	Condition Number	Local R2	Predicted	Coefficient Intercept	Neighborhood	Coefficient #2 AVDISSCH	Coefficient #3 AVGHOS	Coefficient #4 AVGPERRROAD	Residual	Std. Residual	Source ID		
1	Point ZM	4.4	9.658824	0.783382	0.205135	-125.582188	91.647291	0.043058	-0.036971	0.169535	4.154885	0.068205	1		
2	Point ZM	10.6	9.136578	0.791583	22.298189	-122.79837	89.27249	0.043547	-0.036986	0.163781	-11.806189	-0.277744	2		
3	Point ZM	8.3	9.128462	0.791007	24.280348	-122.88547	89.38206	0.043628	-0.036983	0.166128	-17.980348	-0.413823	3		
4	Point ZM	19.1	9.088538	0.788366	2.823128	-124.816895	89.824812	0.043923	-0.036115	0.177825	17.078872	0.419168	4		
5	Point ZM	5.8	9.178724	0.794194	-1.795789	-121.493955	87.715982	0.043503	-0.036989	0.170189	7.395789	0.150287	5		
6	Point ZM	5.9	9.028296	0.788083	9.871685	-125.807112	91.888517	0.043283	-0.036945	0.176388	-3.321585	-0.075885	6		
7	Point ZM	4.9	9.048804	0.789508	77.838001	-125.402758	91.395478	0.043243	-0.037488	0.172892	-73.778001	-1.629828	7		
8	Point ZM	143.5	9.486789	0.818578	178.888328	-118.98382	81.144348	0.048287	-0.036977	0.172893	-35.398328	-1.84763	8		
9	Point ZM	123.400802	9.284793	0.800278	132.837847	-119.316591	85.125538	0.045468	-0.036859	0.17788	-9.493745	-0.23961	9		
10	Point ZM	4.2	9.085983	0.787795	8.777486	-124.24897	90.287396	0.043586	-0.037383	0.172129	3.422504	0.07805	10		
11	Point ZM	288.389894	9.300328	0.804484	232.319713	-118.115283	84.522281	0.045078	-0.036443	0.167517	24.088281	1.524404	11		
12	Point ZM	80.5	9.154345	0.792135	136.887587	-122.388825	88.124816	0.044589	-0.036354	0.178893	-78.051507	-1.521828	12		
13	Point ZM	118.900802	8.9792	0.777862	74.319567	-131.87988	97.503883	0.041099	-0.036887	0.167874	44.588435	1.384918	13		
14	Point ZM	35.200001	8.969588	0.7814	77.876541	-128.893955	93.975177	0.042328	-0.037285	0.170823	-42.676541	-0.943044	14		
15	Point ZM	113.940001	8.978188	0.778889	109.29593	-130.442404	96.18633	0.041545	-0.036907	0.168125	6.744971	0.159088	15		
16	Point ZM	3.8	9.089038	0.787757	-36.988824	-124.368755	90.86838	0.043338	-0.036725	0.168931	39.768824	0.913441	16		
17	Point ZM	289	8.938474	0.777883	173.682796	-131.896415	97.248738	0.041194	-0.037346	0.171937	85.307205	2.188251	17		
18	Point ZM	289	9.093506	0.787515	240.38821	-124.834672	90.288809	0.04388	-0.036802	0.180158	28.91078	0.818911	18		

Appendix G: The GWR summary of results for housing affordability.



**SCHOOL OF ARCHITECTURE AND PLANNING
HUMAN RESEARCH ETHICS COMMITTEE**

CLEARANCE CERTIFICATE
PROTOCOL NUMBER: SOAP049/06/2020

<u>PROJECT TITLE:</u>	Analytical study of Khartoum's sprawl, causes, trends, and prospects.
<u>INVESTIGATOR/S:</u>	Adam Ahmed (Student No: 2128422)
<u>SCHOOL:</u>	Architecture and Planning
<u>DEGREE PROGRAMME:</u>	Master of Urban Studies (MUS UM)
<u>DATE CONSIDERED:</u>	05 August 2020
<u>EXPIRY DATE:</u>	05 August 2021
<u>DECISION OF THE COMMITTEE:</u>	Approved

CHAIRPERSON
(Dr Brian Boshoff)

DATE: Signed under lockdown: 10.8.20

cc: Supervisor/s: Aly Karam

DECLARATION OF INVESTIGATORS

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to endure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee.

Signature

School of Architecture & Planning
University of the Witwatersrand
Private Bag 3 Wits 2050
Johannesburg South Africa
www.wits.ac.za

Date

T +27 11 717 7623
F +27 11 717 7649



Faculty of Engineering and the Built Environment

Private Bag 3, Wits 2050, South Africa * Telephone (011) 717 7007 * Fax: (011) 717 7009 * Email: febe.co@wits.ac.za



PLAGIARISM DECLARATION TO BE SIGNED BY ALL HIGHER DEGREE STUDENTS

SENATE PLAGIARISM POLICY: APPENDIX ONE

I Ahmed Adam (Student number: 2128422) am a student
registered for the degree of Master of Urban Studies in in the academic year 2020
the field of Urban Management

I hereby declare the following:

- I am aware that plagiarism (the use of someone else's work without their permission and/or without acknowledging the original source) is wrong.
- I confirm that the work submitted for assessment for the above degree is my own unaided work except where I have explicitly indicated otherwise.
- I have followed the required conventions in referencing the thoughts and ideas of others.
- I understand that the University of the Witwatersrand may take disciplinary action against me if there is a belief that this is not my own unaided work or that I have failed to acknowledge the source of the ideas or words in my writing.

Signature: _____

Date: March 29th 2021