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DIAGNOSTIC ET ANALYSE DE L'ENVIRONNEMENT ACOUSTIQUE DES CONFIGURATIONS URBAINES SAHARIENNES. CAS DE BISKRA.

Présenté par :
Okba BENAMEUR

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Devant le jury composé de :

Noureddine Belghar	**Président**	**Professeur**	**Université de Biskra**
Noureddine Zemmouri	**Directeur**	**Professeur**	**Université de Biskra**
Abida Hamouda	**Examinateur**	**Professeur**	**Université de Batna**
Atef Ahriz	**Examinateur**	**MCA**	**Université de Tebessa**
Valerio Cutini	**Invité**	**Professeur**	**Université de Pise**

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University Mohamed Khider-Biskra — جامعة محمد خيضر بسكرة
Faculty of Science and Technology — كلية العلوم والتكنولوجيا
Department of architecture — **قسم الهندسة المعمارية**
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A Dissertation submitted in fulfilment of
the requirements for the degree of
Doctorate of Science in Architecture

DIAGNOSIS AND ANALYSIS OF THE ACOUSTIC ENVIRONMENT OF SAHARAN URBAN CONFIGURATIONS. BISKRA CASE

Presented by:
Okba BENAMEUR

Publicly defended on: January,09,2023

In front of a jury composed of:

Noureddine Belghar	**President**	**Professor**	**University of Biskra**
Noureddine Zemmouri	**Supervisor**	**Professor**	**University of Biskra**
Abida Hamouda	**Examiner**	**Professor**	**University of Batna**
Atef Ahriz	**Examiner**	**MCA**	**University of Tebessa**
Valerio Cutini	**Guest**	**Professor**	**University of Pisa**

Abstract

Noise pollution affects a significant portion of the world's population, including Saharan inhabitants. The proliferating expansion of cities and traffic loads convey the primary reasons exacerbating the adverse effects of noise on the environment and people's quality of life. Thus, developing countries and Saharan settlements experience a lack of acoustic data and a tremendous gap in standards and operating procedures necessary for urban planning. The present study intends to examine the acoustic environment of Biskra city's urban layouts and relies mainly on multidisciplinary methodological approaches dealing with the objective and subjective aspects. Firstly, the space syntax theory for the urban morphology analysis focuses on the angular segment analysis, which provides a detailed diagnosis of the foreground and the background properties. The potential of the "to-movement" and "through-movement" keys provides an insightful exploration of mechanical and pedestrian movements on a local and global scale. Therefore, distinct metric radii were involved: 400 m, 800 m, 1200 m, 1600 m, 2000m, 2400 m, and 3200 m. Secondly, the experimental approach incorporates the assessment of the acoustic environment by performing 240 stations of measurements using a calibrated sound level meter. The monitored stations, which record 600 Level equivalent continuous sound weighted A (LeqA) values, are mostly installed close to residential areas and the edges of major highways, thoroughfares, and pedestrian axis. The modeling process involves different interpolation models provided by Geographic Information System (QGIS and SAGA GIS), namely: Inverse Distance Weighted (Gaussian, Exponential, Quadratic) and Kriging (Ordinary, Universal). Finally, a subjective approach involves developing a survey that addresses three distinct axes: Perceived affective quality, sonic mind mapping, and soundscape preferences. The findings highlight the noisy character of Biskra, despite the effectiveness of the IDW modeling. They demonstrate a moderate to a high positive correlation between global and local scales of syntactic measures, implying that these spatial variables may partially explain the urban acoustic patterns. This thorough investigation acts as a staging ground for bringing up this issue with city planners and decision-makers to create a practical action plan for a sustainable development strategy.

Keywords: Urban acoustic, GIS, Interpolation Models, Space Syntax, Biskra.

Résumé

La pollution sonore affecte une part considérable de la population mondiale, y compris les habitants Sahariens. L'expansion proliférante des villes et le trafic routier constituent les principales causes de la recrudescence des effets négatifs du bruit sur l'environnement et la qualité de vie de ces habitants. Par ailleurs, les pays développés et les agglomérations Sahariennes connaissent un manque de données acoustiques et une énorme lacune en matière des normes et des procédures nécessaires à la planification urbaine. La présente étude vise à examiner l'environnement acoustique des différents tissus urbains constituant la ville de Biskra, comme elle s'appuie principalement sur des approches méthodologiques multidisciplinaires traitant la dimension objective, voire subjective. Premièrement, la théorie de la Syntaxe Spatiale visant à analyser la morphologie urbaine. En se focalisant sur l'analyse des segments angulaires qui permet un diagnostic détaillé des propriétés de l'avant-plan et de l'arrière-plan. Le potentiel des deux concepts de « à-mouvement » et « à travers-mouvement » permet une exploration perspicace des mouvements mécaniques et piétonniers à l'échelle locale et globale. Par conséquent, plusieurs rayons métriques ont été utilisés : 400 m, 800 m, 1200 m, 1600 m, 2000 m, 2400 m et 3200 m. Ensuite, une approche expérimentale, consistant à évaluer l'environnement acoustique en effectuant 240 stations de mesures à l'aide d'un sonomètre étalonné. Ces stations, enregistrant chacune 600 valeurs de niveau sonore équivalent continu pondéré A (LeqA), sont pour la plupart installées à proximité des zones résidentielles et des bords des principales autoroutes, voies de circulation et axes piétonniers. Les données obtenues ont été modélisées à l'aide de différents modèles d'interpolation fournis par le système d'information géographique (QGIS et SAGA GIS), notamment : Distance Inverse Pondérée (Gaussienne, Exponentielle, Quadratique K2) et Krigeage (Ordinaire, Universel). Finalement, l'approche subjective consiste à élaborer un sondage abordant trois axes distincts : la qualité affective perçue, la carte mentale sonore et les préférences en matière de paysage sonore. Les résultats mettent en évidence le caractère bruyant de Biskra, tout en soulignant l'efficacité du model IDW. Ils démontrent aussi une corrélation positive moyenne à forte des mesures syntaxiques à l'échelle globale et locale, impliquant une explication partielle des configurations urbaines et acoustiques par ces variables spatiales. Cette étude approfondie constitue un point de départ pour soulever cette question auprès des planificateurs et décideurs de la ville afin de créer un plan d'action pratique pour une stratégie de développement durable.

Mots clés : Acoustique urbaine, SIG, Modèles d'interpolation, Syntaxe Spatiale, Biskra.

ملخص

يعاني العديد من سكان العالم من مشكل التلوث الضوضائي بما في ذلك قاطنوا المناطق الصحراوية. غالبًا ما يعتبر توسع المدن ووفرة وسائل النقل سببا رئيسيا في تفاقم الآثار الجانبية للضوضاء على المحيط من ناحية ورفاهية السكان من ناحية أخرى . علاوة على ذلك ، تشهد المدن النامية وكذا التجمعات الصحراوية ندرة في البيانات الصوتية وفشلا ذريعا في اتباع المعايير والإجراءات المطلوبة أثناء عملية التخطيط الحضري. تهدف هذه الدراسة إلى تحليل وفحص البيئة الصوتية لمختلف الأنسجة العمرانية المكونة لمدينة بسكرة وتعتمد بشكل أساسي على عدة مقاربات منهجية تتناول الجانبين الموضوعي والذاتي. أولاً ، نظرية التركيب الفراغي بغرض تحليل التشكل الحضري للمدينة ، مع التركيز على تحليل المقطع الزاوي (Angular Segment Analysis) الذي يسمح بتشخيص مفصل لخصائص المدينة (الأمامية والخلفية)، بالإضافة إلى قدرته في التعامل مع الحركة الميكانيكية وحركة المشاة على المستوى المحلي للأحياء وعلى المستوى العام للمدينة عبر إمكانات "إلى الحركة" و "خلال الحركة" باستخدام عدة أنصاف أقطار متريّة: 400 م ، 800 م ، 1200 م ، 1600 م ، 2000 م ، 2400 م و 3200 م. مرورا بالمنهج التجريبي ، والذي يمكن تلخيصه في تقييم البيئة الصوتية من خلال إجراء 240 محطة من القياسات باستخدام مقياس مستوى الصوت المعاير. يتم تثبيت هذه المحطات ، التي تسجل كل منها 600 من قيم مستوى الصوت المستمر الموزون A ، بالقرب من المناطق السكنية وأطراف الطرق السريعة الرئيسية والشوارع ومحاور المشاة. ناهيك عن نمذجة البيانات المحصلة استنادا على دراسة مقارنة لنماذج الاستيفاء المختلفة التي يوفرها نظام المعلومات الجغرافي (QGIS, SAGA GIS) ، من بينها: معكوس المسافة الموزونة (Inverse Distance Weighting, Gaussian, Exponential, K2)، وتقنيات كريغ (Ordinary, Universal Kriging). كما تضمن النهج الذاتي والأخير انشاء استطلاع يتناول ثلاثة محاور أساسية: الجودة العاطفية المتصورة، الخرائط الذهنية وكذا التفضيلات الصوتية. أبرزت النتائج عموما الطابع الصاخب لمدينة بسكرة، مأكدة على فعالية نمذجة البيانات بواسطة معكوس المسافة الموزونة (IDW K2). هذا وأظهرت ارتباطًا إيجابيًا متوسط إلى مرتفع بين المقاييس الفراغية من جهة والمقاييس الصوتية من جهة أخرى، مع تسجيل بعض الاختلافات بحسب طبيعة الأنسجة العمرانية المكونة للمنطقة . مما يشير إلى أن هذه المتغيرات المكانية قد تكون قادرة على شرح الظاهرة الصوتية بشكل جزئي. يعتبر هذا التحقيق الشامل بمثابة نقطة انطلاق لطرح هذه القضية مع مخططي المدن وصناع القرار من أجل إنشاء خطة عمل عملية تندرج كاستراتيجية للتنمية المستدامة.

الكلمات المفتاحية: المحيط الصوتي، نظام المعلومات الجغرافية، نماذج الاستيفاء، التركيب الفراغي، بسكرة.

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Table of contents

List of figures

List of tables

List of Abbreviations

ANOVA: Statistical analysis of variance

ASA: Angular segment analysis

BEM: Boundary element method

DG: Discontinuous Galerkin

DWM: Digital waveguide mesh

END: Environmental noise directive

ESM: Equivalent source method

FDTD: Finite-differences times-domain

FEM: Finite element method

IDW: Inverse distance weighting

LBM: Lattice Boltzmann method

Lday: Level equivalent sound during the day time

Lden: Level equivalent sound pressure during Day, Evening and Night time

Leq: Level equivalent sound pressure

Lnight: Level equivalent sound during the night time

Lp: Sound Level Pressure

NACH: Normalized angular choice

NAIN: Normalized angular integration

OK: Ordinary Kriging

PCA: Principal component analysis

PE: Parabolic equation

PSTD: Pseudo-spectral time-domain

QGIS: Quantum Geographic Information System

SS: Space Syntax theory

UK: Universal Kriging

WGW: Waveguide Web

WHO: World health organization

"All men's miseries derive from not being able to sit in a quiet room alone."

Blaise Pascal.

CHAPTER 1:

INTRODUCTION

Chapter 1: Introduction

1.1. Research Background

The soundscape is an interactive approach engaging innumerable city actors, comprising acousticians, architects, developers, local authorities, consultants, local action committees, and residents. Generally, this innovative concept is a paradigm shift in environmental acoustics that embodies a multidisciplinary complexity, notably acoustics and aesthetics, economics, social concerns, environment, sustainability, security, transportation, and mobility.

Therefore, a soundscape field differs from the environmental studies on sound management. It aims to comprehend the significations and connections between several parameters, including sound, inhabitants, spatial configuration, and noise attenuation. Since the 1960s, this topic has made the subject of considerable discussion. Thus, researchers' interest is constantly increasing since the World Health Organization's (WHO) reports indicate multiple adverse effects. Besides, a significant population proportion is potentially susceptible to acoustic annoyance (Clark & Paunovic, 2018).

During the COVID-19 pandemic, Díaz et al. (2021) affirmed that noise pollution remains a significant factor affecting the prevalence and severity of the viral infection in Madrid, Spain.

According to the previous empirical evidence, noise pollution represents one of the environmental stressors that negatively affect human health on a psychological and physiological level. These effects entail annoyance, cardiovascular system and metabolic diseases, sleep disturbances, hearing loss and tinnitus, birth outcomes, and cognitive impairments (Basner et al., 2015; Basner & McGuire, 2018; Guski et al., 2017; Ma et al., 2018). Moreover, sound sensitivity might be affected by both internal and external factors. These include the characteristics of the examined site (slope), the types of noise sources (aircraft, railways, heavy vehicular traffic, combination of multiple sources), and the acoustic insulation performance of buildings. Hence, several surveys in Asia have demonstrated the relevance of façade acoustic insulation, where residents felt less affected by external noise despite living in air-conditioned residences (Guski et al., 2017).

For European regions, the Environmental Noise Directive (END) of 2002 mandates a standard framework for Member States to use in their encounter against noise pollution from built-up areas, airports, and transportation infrastructure. The two principal goals were to create noise exposure maps and implement environmental noise prevention plans (PPBE), which represent several action plans for preventing and reducing environmental noise, initially based on these maps.

In 2020, The last update of this report provided an overview of inequalities and vulnerability to environmental noise exposure and alarmed its adverse effects on wildlife.

Such procedures in most African and Saharan regions still lack a substantial data set. Accordingly, the failure to perform strategic acoustic mapping and action plans by nations and cities will prevent an accurate diagnosis and management of environmental noise problems.

Generally, this environmental issue is due to the global mobility demand on the one hand and urban expansion on the other. In this regard, the lion's share of studies has focused on both facets and, more specifically, on investigating spatial and acoustic attributes for reducing and monitoring noise emissions.

Nevertheless, sound may also bring forth enjoyable experiences and joys. Based on this, some researchers have compared the acoustic environment to a musical composition produced by landscape architects and urban planners (Cain et al., 2008; Fang et al., 2021; Ismail, 2014).

1.2. Problem Statement

Conventionally, architects and urban planners robustly emphasize the functional rudiments of their spatial conceptions and urban layouts. Recently, they have become increasingly preoccupied with the thermal requirements to ensure the well-being of the inhabitants, more specifically, regarding the harsh hot, and arid climate. However, acoustic comfort and sound preferences are recurrently discarded and hardly considered during urban planning procedures.

Despite the lack of attention paid to this topic and the absence of adequate data, as in numerous countries, Algeria has a set of regulations since 1983 that act as a starting point for efficient acoustic management (Law N° 83-03, 1983). In 2003, new legislation aimed to lay out the roadmap for environmental preservation within the sustainable development frame (Law N° 03–10, 2003). These laws have detailed a range of valuable recommendations, despite their limited application throughout the planning process, especially in the Saharan regions where the impact of climate change remains the fundamental issue.

The Algerian Saharan city of Biskra is characterized by a well-structured economy that combines agricultural and commercial activity (Belguidoum, 2002). Over the last decades, the city appears to have experienced substantial urban sprawl far beyond its municipal boundaries. Landscape use increased from 6% to 32% during this period (Assoule & Alkama, 2020). This rate manifested the excessive extensions of peripheral settlements and the proliferation of informal habitats (Bouhata et al., 2016). Due to the lack of various analytic models that address this phenomenon, and the absence of spatial data, the alarming situation continues to escalate (Leghrib et al., 2021).

Correspondingly, the recent anarchic urban planning of this Saharan City, besides the convergence of multiple events and activities within adjacent areas, produces substantial densities of flows. Therefore, the noise issue currently persists near these residential clusters and conurbations. This ongoing problem has undesirable psychological repercussions on the residents, which affects their quality of life and well-being. This issue is further exacerbated by the failure to enforce the acoustic legislation suite, which comprises two laws previously mentioned, a decree and a normative document (DTR).

This latter highlights the main stratagems of acoustic isolation. Likewise, various conventional procedures are developing to reduce urban noise practices worldwide. These include using vegetated noise-canceling walls, a specific anti-noise asphalt for road surfaces, employing quiet tires for public transportation, and enhancing the acoustic insulation for residential and commercial buildings. In addition, quiet zones and green spaces, such as parks or nature reserves, are widely used and established in many cities and regions.

Besides, road transport remains the most impactful activity related to noise pollution. Therefore, sometimes we merely need to limit the distances covered by our cars. This logical solution leads to the basic concept that constituted the foundation of Space Syntax theory.

Several approaches have been developed for urban morphology explanation considering various aspects: historical, geographical, typological, and mathematical. Moreover, in the early 1980s, the space syntax was proposed by Hillier and Hanson, since then, the use of the quantitative spatial analysis methods in studies of architectural and urban space analysis has indeed expanded. The researchers' application of the spatial analysis methodology to urban settings yielded significant achievements. Correspondingly, spatial syntax theory could accurately predict movement patterns. This approach has become applicable to numerous topics, including complicated socio-economic patterns, human behavior prediction, criminality, and pedestrian and mechanical flow. Furthermore, the main advantage of this approach is its ability to display, on space graphs, a variety of spatial and intrinsic properties.

Within these perspectives, various inquiries are raised, ranging:

- What are the principal challenges for modeling noise and acoustic maps within a sustainable planning framework?
- How does urban planning affect the acoustic environment regarding social and economic implications?

1.3. Aims and Objectives

Intending to develop an engaging methodology for monitoring environmental noise, a comprehensive analysis covering multiple facets of physical acoustic and spatial configuration while ensuring data accessibility and availability is mandatory. Accordingly, the following objectives are defined:

- Examine the spatial configuration of the urban fabrics composing Biskra City, focusing on high-density morphologies, vehicular and pedestrian movement.
- Establish a strategic acoustic map to define the noise hotspot locations and the general acoustic environment of Biskra.
- Analyze the interconnectedness between the surrounding auditory environment and the current urban structure.
- Soundscape assessment, involving both perceived affective quality and sound preferences.

And finally, determine an action plan and provide recommendations for sustainable urban development.

1.4. Methodological Approaches

This research examines the relationship between the current urban form and its acoustic environment from an objective and subjective perspective.

The objective framework comprises two distinct components: firstly, spatial analysis and diagnosis of urban areas applying Space Syntax Theory and, more specifically, the Angular Segment Analysis method. Secondly, an experimental approach involves 240 stations of measurements within an acoustic profiling process via interpolation techniques.

This analytical phase considers several deterministic and geospatial models, such as Inverse Distance Weighted (IDW) and Kriging variants employing the SAGA GIS module. The objective assessment relies mainly on the Geographical Information System software QGIS (*QGIS, Białowieża*, 2022), where the main correlations between spatial and acoustic data have occurred.

The subjective approach focuses on a survey instrument that tackles Four core topics: Soundscape perception quality, Outdoor satisfaction, Sonic mind mapping process, and residents' acoustic preferences. This stage incorporates a psychoacoustic assessment of acoustic physical attributes within the affective responses claimed by these individuals. Meanwhile, the collected data statistical processing was handled by SPSS (*IBM SPSS Statistics*, 2021).

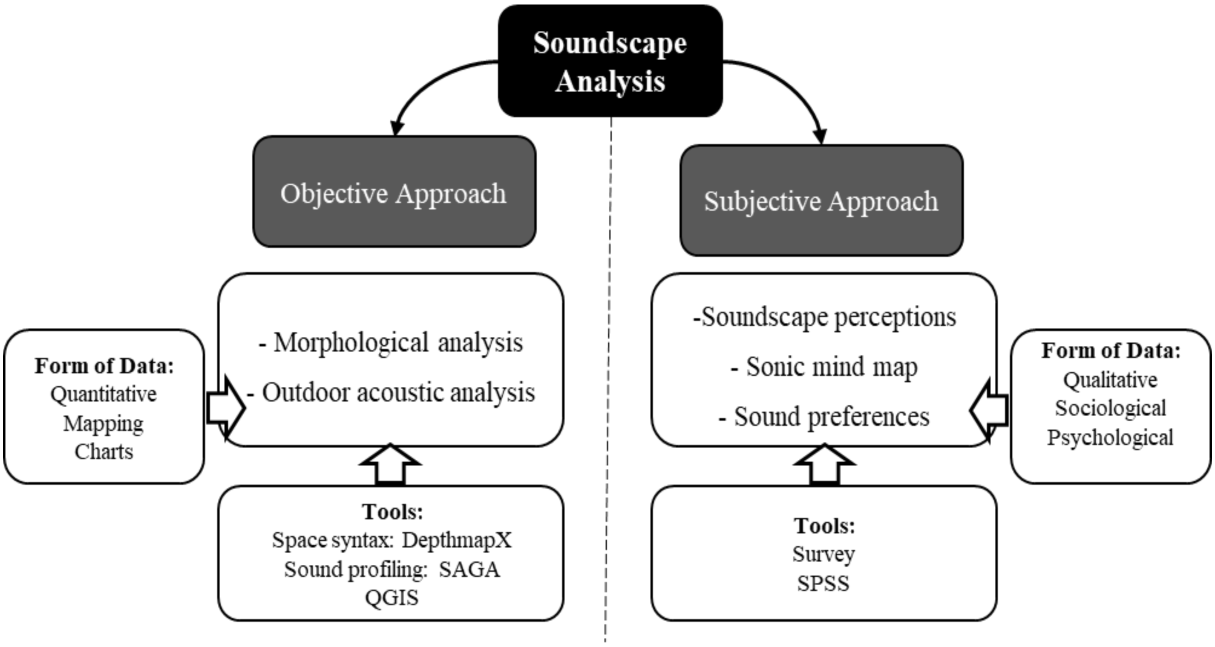

Fig. 1. 1. Metholodological approach flowchart

Further details on the methodological approaches are covered in Chapter 3 under the second section about Methods.

1.5. Thesis Outlines

This dissertation is organized into eight chapters, as illustrated in Fig. 1. 2. The structure of each chapter is presented below:

Chapter 1 — *"Introduction"* orients the framing of the research, highlighting the background context and the problem statement in matters of the urban acoustic environment in Saharan regions. The chapter culminates with a thorough overview of the present research questions and objectives.

Chapter 2 — *"Literature review"* discusses the theoretical design of the two key concepts, notably urban morphology and urban acoustics. It highlights the existing morphological approaches and focuses on space syntax methods, tools, and measures, along with foundational insights and achievements in the urban acoustic modeling field from a wide range of viewpoints. Additionally, it comprises the fundamental studies investigating the relationship between urban form and the acoustic environment from an objective and subjective perspective.

Chapter 3 — *"Methodological Approach"* displays the research design process by presenting first the case study, with an overview of the local laws related to evaluating the acoustic properties, environmental noise protection, and cross-references to the International Standards (ISO).

Furthermore, this chapter outlines the methodological approach, which encompasses three main phases: Urban morphological assessment, Urban acoustical assessment, and Perceptual and psychological assessment.

Chapter 4 — *"Urban Layouts Assessment of Biskra City"* confines a compilation of findings and insights drawn from the spatial assessment of Biskra urban configurations. Therefore, it presents the space syntax outcomes on the global and local scales, besides the four-pointed star model and some relevant correlations involving scatterplots.

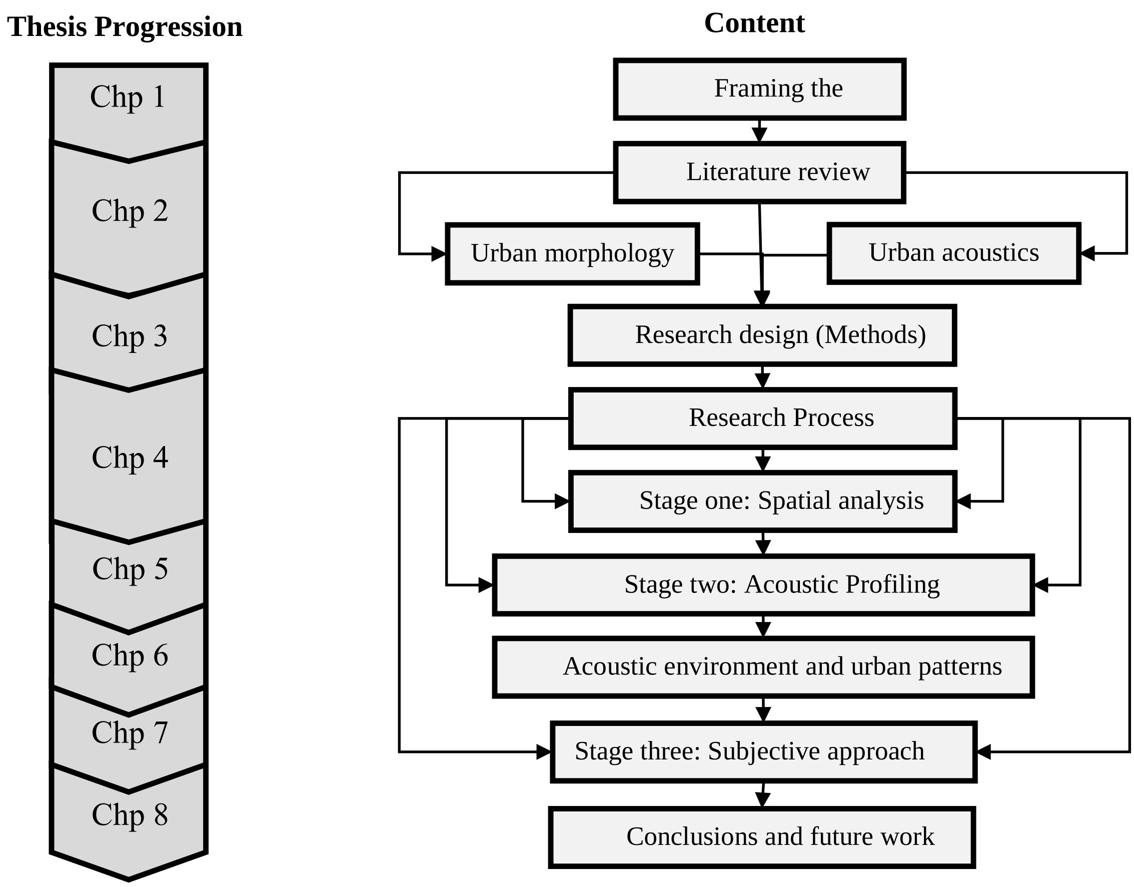

Fig. 1. 2. Flowchart of thesis progression

Chapter 5 — *"Modeling and Assessment of the Acoustic Environment in Biskra"* emphasizes the analytical developments of the acoustic data collection process, and the computational modeling using various geospatial interpolation models. It includes a detailed assessment of the tested methods to analyze the city's acoustic environment by urban sector.

Chapter 6 — "*Acoustic Patterns and Spatial Configurations"* presents the main correlations between the syntactic measures of Space Syntax and the modeled acoustic data. Besides, it provides an overview of the relationship between urban and acoustic patterns in different contexts.

Chapter 7 — *“Synthesis of Soundscape Perceptions and Preferences”* illustrates the subjective assessment of the soundscape and provides a global synthesis of the acoustic environment in Biskra City.

Chapter 8 — *“Conclusion and Prospect”* encompasses an overview of the key findings, the research technical and scientific barriers, and potential prospects.

1.6. Scientific Contributions

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CHAPTER 2:

LITERATURE REVIEW

Chapter 2: Literature Review

2.1 Introduction

Urban morphology aims to investigate urban fabrics beyond the simple architectural analysis of buildings and to identify underlying patterns and structures. Thus, urban space serves as a platform for human activity, principally designed to meet the inhabitants' requirements while also improving the circumstances of their interactions and behaviors (Oliveira et al., 2015). Besides, urban fabrics, public spaces morphology, building textures, and materials may significantly influence sound propagation and, therefore, the auditory sensation they produce (Kang et al., 2016).

This chapter discusses the theoretical underpinnings of the two core concepts that underlie our thesis, namely urban morphology, on the one hand, and urban acoustics, on the other. Firstly, it illustrates the genesis of various morphological approaches and, specifically, Space Syntax methods, tools, and measures.

Secondly, it focuses on the fundamental insights and achievements in the urban acoustic field, involving the modeling process from a wide range of perspectives.

Moreover, this chapter also includes the relevance of Geographic Information System (GIS) in handling urban planning and acoustic domains. It emphasizes the potential of developed platforms for spatial syntax theory, on the one hand, and the empirical models of the acoustic environment that incorporate interpolation methods, on the other.

Finally, the last section is devoted to recent surveys and investigations examining the relationship between urban and acoustic variables from an objective and subjective perspective.

2.2 Urban Morphological Theories

The theory of urban morphology encompasses several approaches that contribute in comprehending the urban form. In the analytical process, these diverse and antagonistic approaches should interact for an ultimate mainstreaming. Consequently, four main approaches emerged chronologically: "historico-geographical approach" (British tradition), "process-typological approach" (Italian tradition), "configurational approach" (Space Syntax) and "spatial modeling approach" (mathematical simulation).

2.2.1 Historico-geographical approach

The Historico-geographical approach was initiated by Whitehand in 1981, relying on the research of Conzen and Larkham. A theory wherein broader economic and social activities constitute a core explanation of urban form (see Fig. 2. 1). It examines the roots and key traits of the morphogenetic tradition or the formative processes that underlie forms emergence. The facts and artifacts of land, landscape, and settlement, as well as related socioeconomic and cultural contexts, are thus central to this multifaceted approach (Duffy, 2009).
Currently, this approach is further advanced and developed by the Urban Morphology Research Group (UMRG) at the University of Birmingham

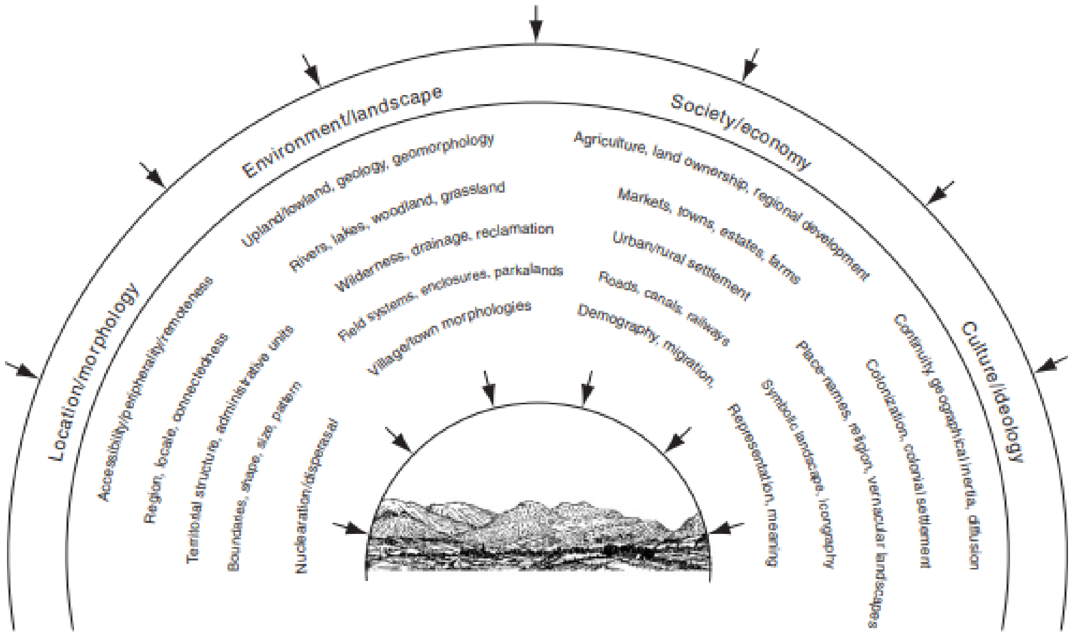

Fig. 2. 1. Scope of the Historico-geographical approach (Source: Duffy, 2009, p. 137)

2.2.2 Process-typological approach

The typological process is a succession of types in one cultural area through time (diachronic changes) or in numerous cultural areas simultaneously (synchronic changes). This approach is as complex as landscapes and mainly based on Caniggia and Maffei 1984 works.

It consists in reconstructing the changes experienced by a type over time within specific periods known as phases. A phase refers to a fixed period of time for observable variations between two successive types. Thus, this approach contemplates building components and tiniest construction details (see Fig. 2. 2). Furthermore, Caniggia has examined the spatially correlated features of the architectural elements, emphasizing the relevance of subdivisions hierarchy (Kristjánsdóttir, 2019).

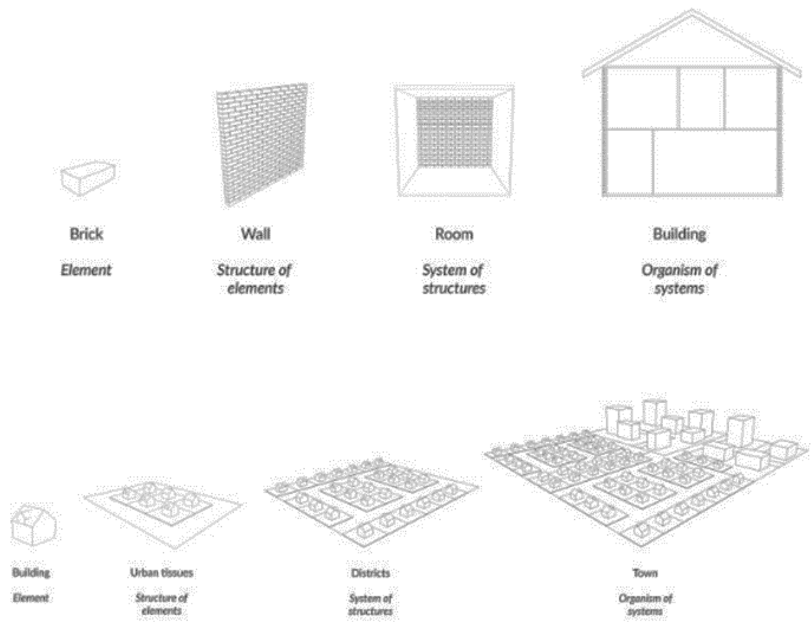

Fig. 2. 2. Schematic diagram demonstrating the Typological process according to Caniggia (Source: Kristjánsdóttir, 2019, p. 27)

2.2.3 Configurational approach

Configurational approach or Space Syntax represents a concept embracing a set of theories and methods to analyze spatial patterns. This theory was developed by Bill Hillier, Hanson, and other researchers at the Bartlett University College of London in the late 1970s and early 1980s. It supplies an efficient tool assisting architects in simulating the social effects of buildings' spatial organization—Alpha analysis—and city's planning—Beta analysis—as reported Hillier and Hanson (1984). Moreover, the space designates a common language capable of revealing the geographical translation of social ties by examining the accessibility of locations and their layouts (see Fig. 2. 3).

Fig. 2. 3. Space signification according to space syntax theory
(Source: Rose, 2013, p. 10)

2.2.4 Spatial modeling approach

The spatial modeling is a mathematical approach established by Batty and Longley in 1994 via their book entitled "fractal cities: a geometry of form and function".

Currently, the evolution of the spatial modeling approach, originating in Land Use and Transport Interaction Models (LUTI), has led to the introduction of Cellular Automata (CA) and Agent Based Models (ABM).

Additionally, there has been a shift in scale and scope, particularly for CA models, from focusing on social and economic processes to physical land development. Despite the broadened scale, ABM models are commonly used at a fine spatial scale to assess pedestrian and local mobility (Oliveira, 2016).

Therefore, as mentioned earlier, two simultaneous schools of thought in building theory and urban morphology remain rational to develop. Both attempts to evaluate their application to explain specific types of urban forms empirically observed and reported. The first stream allows for the articulation of novel sorts of theoretical insights. Instead, the second perspective should pursue a path of fundamental investigation within the "deep structure" of urban morphological arguments in order to identify their similarities and strengthen their interconnectedness and effectiveness (Oliveira et al., 2015).

In light of these definitions and theoretical developments, the Space Syntax theory would be implemented for this particular investigation owing its features and ability to examine the phenotype and genotype of an urban morphology.

2.3 Space Syntax Theoretical Foundations

Space Syntax was broadly framed as a combination of methods for representing, quantifying, and interpreting the spatial configuration of buildings and settlements. Such configurations designated the intricate relationships between spaces, considering all other spatially related structures.

The idea behind space syntax was inspired by the revelation that physical and social cities share a common basis in space. The initial idea was published for the first time in *"The social logic of space"* (Hillier & Hanson, 1984).

Moreover, the main goal of this book was to outline a new theory, within new methods, for investigating the relation between society and space. It attempts to develop a conceptual model for exploring this relationship based on both the social content of the spatial pattern and the spatial content of the social pattern. Subsequently, it aims to establish an analytical method of spatial patterning, emphasizing the relationship between local morphological relationships and global patterns. It provides a core descriptive theory then a method of analysis. The latter are initially implemented for human settlements, and thereafter for buildings' interior.

For Hillier, the external spaces such as streets, paths, and squares represent a continuous network formed of voids and shaped by the building's boundaries and some other obstructions. Each void possesses its own access and vision. Likewise, cities are composed of spaces with complex connections and a discrete structure. Depending on the urban scale, these structures can yield an organic, uniform and deformed shape (Hillier & Hanson, 1984).

According to Hillier et al. (2007), the application of the space syntactic technique to urban studies entails four components ranging as follows:

1. The notion of the concerned spatial units is made clear and well-defined.
2. The SS is used to analyze cities as space networks generated by the placement, clustering, and orientation of structures. Its methods explore the spatial relationships between urban entities.
3. It provides a set of techniques for monitoring the relationship between space networks and functional patterns including vehicle and pedestrian movements in cities, land use trends, area segregation, criminal dispersion, property values, migration flows, and indeed social welfare.
4. The application of Space Syntax has led to various theories developments and interpretations of the spatial character as a product of social, economic, environmental,

and cognitive factors. This indicates the role of urban space as a generator of cultural and socio-economic activities.

Furthermore, this theory rests on three basic conceptions of space to generate three syntactic maps (Axial, Convex and Isovist) as depicts the Fig. 2. 4. Correspondingly, the analysis methods encompass Visibility Graph Analysis, Axial Map, Angular Segment Analysis, and Based Agent Model simulation. Likewise, it considers two aspects: configurational analysis and pedestrian simulation (Penn & Turner, 2002).

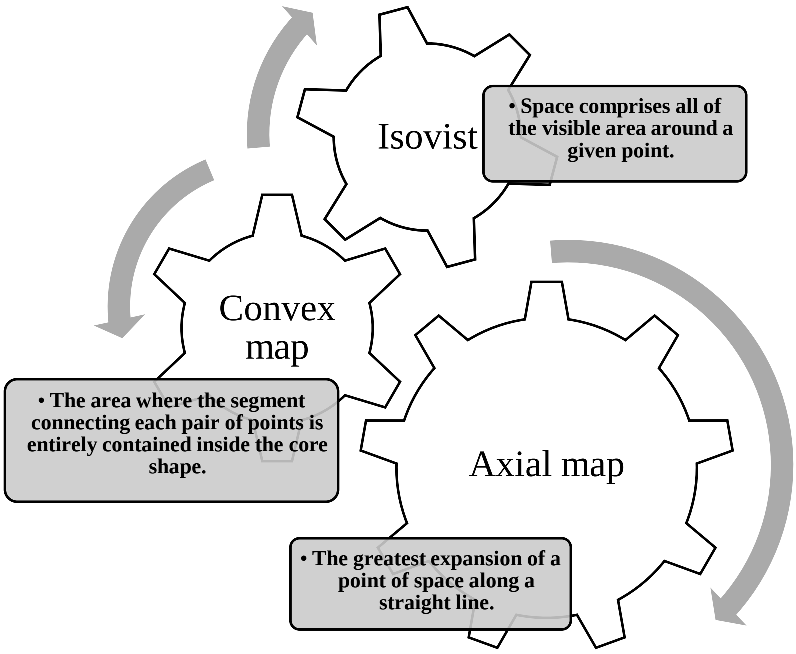

Fig. 2. 4. Space Syntax theory's foundational concepts of space (Source: According to Hillier, 2007)

When scrutinizing spatial layouts, we may apply the Visibility Graph Analysis (VGA) on two distinct levels: knee level for individuals' movement and eye level for what they probably see. The visibility graph, in this case, refers to a spatial arrangement of mutually visible spaces (Turner, 2001). Moreover, in terms of pedestrian movement, Penn and turner (2002) suggested the Based-Agent model, which remains a specified visual field produced from visibility graph analysis. This model represents the ability of "agents" to select the best way to proceed. Agents can access pre-calculated data about what is visible from any particular place on the map. The developers may mimic people's expected behavior as they move around a specific space.

In this research, we emphasize the segment analysis as a component of the axial map to fulfill the objectives set for the urban configuration analysis, as discussed in the preceding section.

2.3.1 Axial map analysis

According to the principal definition given by Hillier and Hanson, the axial map of an urban structure represents *"the least set of lines which pass through each convex space and makes all axial links."* (Hillier & Hanson 1984, pp. 91–92). Correspondingly, an accurate base map is used to create the axial map of a settlement by intersecting drawn lines across all the open public space (streets, squares, etc.) to fulfill the circulation layouts. Recently, segment analysis has partially supplanted axial maps (Vaughan, 2015).

2.3.1.1 Axial networks:

In this method, the axial network is represented by a specific graph G_A (See Fig. 2. 5. [c]), which includes two sets of information, namely graph Vertices (V_A) and a set of Lines (L_i).

Where:

$$\mathrm{VA} = \{vA1, vA2, \dots\ vAn\}$$

$$LI \;=\; \{lI1, lI2, \dots\ lIn\}$$

With:

$(vi, vj) \;=\; (vj, vi)$ within a non-directional relation.

Also, it's noteworthy to recall that depth is a topological measure that excludes geometric value.

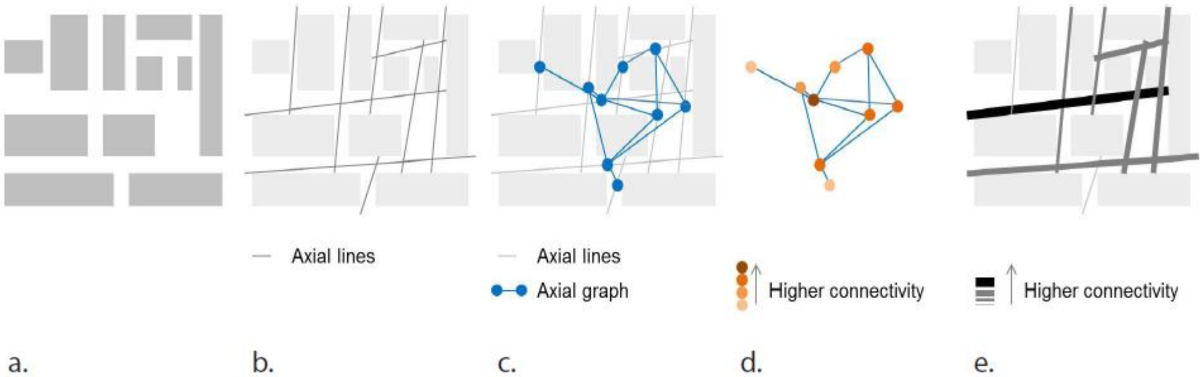

Fig. 2. 5. Space syntax axial representation. urban form (a), axial lines (b), axial lines graph (c), Connectivity graph (d & e) (Source: Al_Sayed, 2018, p. 12)

2.3.1.2 Convex map:

Generally, spaces are connected when there is a direct access. Alternatively stated, the rate of connectivity increases as space becomes more connected (see Fig. 2. 6 [d & e]).

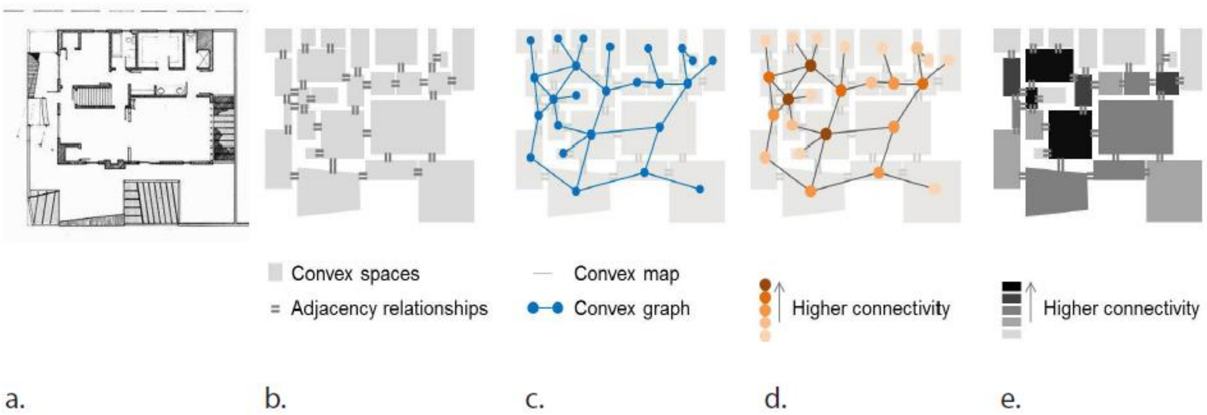

Fig. 2. 6. Space syntax convex representation. analyzed building (a), convex spaces (b), convex map and convex graph (c), connectivity graph (d & e)
(Source: Al_Sayed, 2018, p. 13)

Justified graph, also known as j-graph (see Fig. 2. 7), reads a spatial network of convex spaces from one space (root) to all the others. Thus, it permits the exploration of symmetry as an internal property (Hillier, 2007). Meanwhile, the Depth value is measured by relative asymmetry (RA).

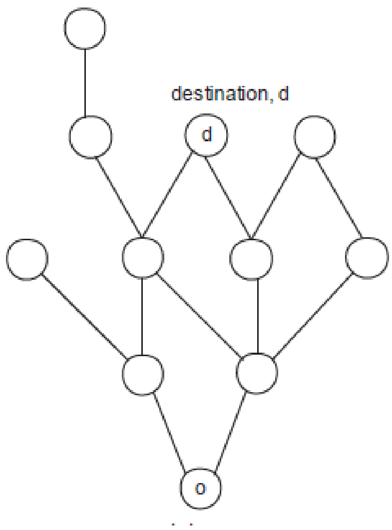

Fig. 2. 7. Simple j-graph representation (Source: Hillier et al., 2012, p. 157)

Moreover, both axial and convex graphs may be demonstrated using the justified graphs' representational scheme. It is therefore necessary to employ the ringiness of Axial Graphs to discern the ordering patterns underlying the network structure. Thus, the Grid axiality measure is suggested for assessing these qualities. It represents the ratio of circuits/rings in the axial graph to the number of axial lines. Usually determined as follows:

$$Grid\ axiality = \frac{\left(\sqrt{I} \times 2\right) + 2}{L}$$

Where: I represent the number of islands,

L is the number of axial lines.

This value varying from 0 to 1, where the high values illustrate a regular grid, and low values indicate a deformed system.

2.3.1.3 Syntactic measures of the axial map:

For axial and convex analysis, we generally use a topological distance. Where, the radius n represents the relation of each node within the whole system. However, the topological radii 2 or 3 are related to the neighbors located two or three steps away from it.

Furthermore, the axial analysis involves multiple syntactic measures:

- *Connectivity:* number of immediate neighbors directly connected to a space
- *Integration:* also known as “mean depth (RA)”. This measure corresponds to rates of social encounter and retail activities occupied by people. Which represents ten percent of the overall core or a bit more.
- *Control:* number of alternative connections that each neighbor has.
- *Choice:* measures movement flow through spaces. As reported Hillier, 1984: *“Choice is a powerful measure at forecasting pedestrian and vehicular movement potentials. It’s usually applied to segment analysis rather than convex analysis, because it’s descriptive of movement rather than occupation.”*

Besides, the correlation between some indices results in a couple crucial measures:

- Intelligibility: correlation between axial connectivity and axial global integration. It identifies how easy for one in a local position to comprehend the global structure.
- Synergy: relationship between smaller radii of integration and larger radii in axial analysis. In other words, it explains the relation between the parts and the whole in an urban system (HH R2) and (HH Rn).

2.3.2 Angular Segment Analysis

Given the limitations of axial representation, this technique determines some improvement. The theoretical background of angular analysis is essentially based on computational fluid dynamics and even cellular automata given their ability in predicting and modeling the movements and occupancy of spatial systems (Turner, 2000).

These two attributes represent the main objective of this technique, which is identifying "to-movement" and "through-movement" potentials.

Accordingly, it employs integration and choice to measure accessibility and compare configurational properties of space with observed urban activity.

2.3.2.1 Justified graph and tulip analysis:

The angular segment analysis (ASA) uses the principle of the tulip analysis, which represents a diagrammatic turn analysis (see Fig. 2. 8).

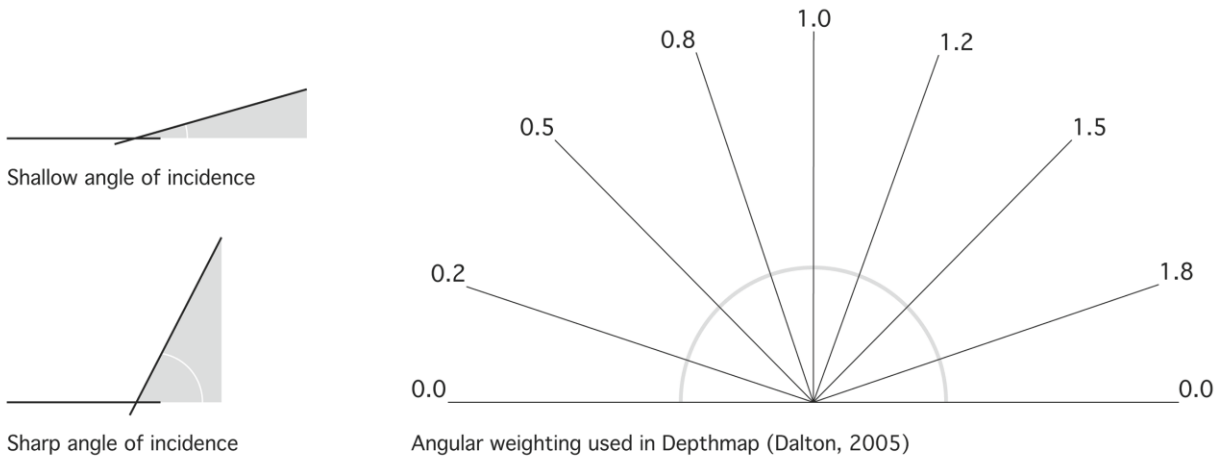

Fig. 2. 8. Angular weighting of street segments "Tulip" (Source: van Nes & Yamu, 2021, p. 59)

Starting from the associated justified graph, the notion of angular depth computation in segment analysis utilizes a weight value according to degrees (from an angle to a weight value), as shows Fig. 2. 9.

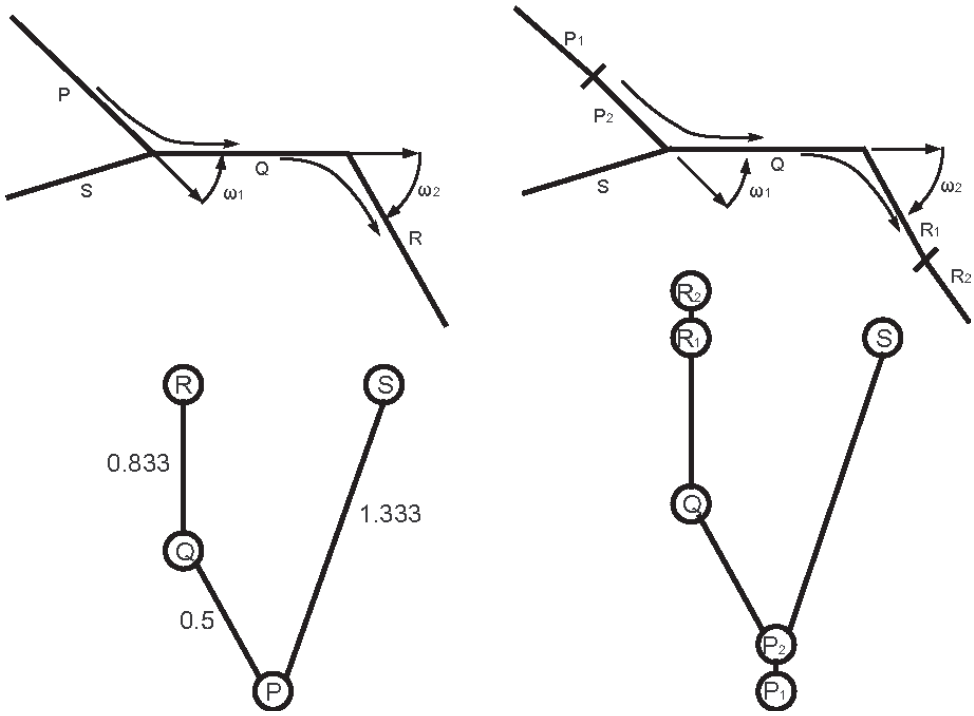

Fig. 2. 9. Justified graph of angular segment analysis
(Source: Turner, 2007, p. 5)

2.3.2.2 Syntactic measures of the Angular Segment Analysis:

For the Angular segment analysis, Normalized Angular Choice and Integration remain two significant measures of morphology analysis which correspond to the "to-movement" and "through-movement" potentials (Turner, 2007).

The overall syntactic measures of the angular segment analysis were defined by (Turner, 2004) as follows:

- *Angular Connectivity:* the quantity of segments linking a root segment directly. Or cumulative turn angle.
- *Step Depth:* follows the shortest path between the chosen root segment and every other segment in the system.
- *Node Count:* Number of segments from the current segment to all other. For example, NC=3 represents the shortest angular path through 3 segments.
- *Total Angular Depth:* the cumulative total of the shortest angular paths to a selected segment as root.
- *Mean Depth:* the total angular intersections of the entire system divided by the sum of the shortest angular paths or the number of nodes. Calculated as:

$$Mean\ Depth\ (A) = \frac{Total\ Depth\ (A)}{Node\ Count}$$

In the case of radius "n" the mean depth refers to the total depth and becomes less meaningful.

It's worth noting that Relative Asymmetry (RA) and Real Relative Asymmetry (RRA) are not considered using this method.

2.3.3 Closeness and betweenness centrality indices

2.3.3.1 Closeness centrality index (Integration):

Closeness refers to a segment's degree of connection to others at different scales and distances, also known as "to-movement". Thus, an integrated area expresses the ease of reaching one of its segments from all other segments of the analyzed network. Realistically, it implies that individuals reach a particular location more frequently and more easily. This spatial feature determines the appropriate land use pattern for an area (Turner, 2005).

In general, the integration is calculated as follows:

$$Integration = \frac{Node\ count \times Node\ Count}{Total\ Depth}$$

For the Angular Segment Analysis:

$$Integration = \frac{Node\ Count}{Mean\ Depth} = \frac{Node\ Count \times Node\ count}{Total\ Depth}$$

The formula for global integration radius n is given as:

$$Integration_{(n)} = \frac{1}{Total\ Depth}$$

2.3.3.2 Betweenness centrality index (Choice):

Segment angular choice is determined by counting how many times each street segment is on the path that connects all adjacent pairs within a distance. The term "shortest path" describes the route across the system that has the fewest angular deviations or the straightest line. The choice depicts the potentials for each segment to be chosen by vehicles, pedestrians, or both. Choice values might also specify the land use type that perfectly matches a specific space.

Generally, it is computed automatically on Depthmap software. All segments hold a value of 1, and if the shortest routes pass through an element twice, the angular choice computation records a value of 2 …, in an ongoing process.

We should mention that for the angular segment analysis, both measures of choice and integration can be weighted by segment length. A longer distance indicates more intense movement due to the proximity of blacks and entrances along this segment.

2.3.4 Normalizing choice and integration

The ultimate purpose of normalizing choice and integration values is to compare various urban networks of varying sizes. Nevertheless, this feature cannot be achieved by axial and convex graph. NACH and NAIN remain useful indexes in investigating the inner structure of urban form. For example, the normalized angular choice explores the relationship between high choice and high total depth, more segregated the system is, the higher values are. Meanwhile, the normalized angular integration represents the ease of accessibility throughout a given network.

The mathematical equations used are listed below:

- Normalized Angular CHoice:

$$NACH = \frac{\log(Choice(r) + 1)}{Log(Total\ Depth(r) + 3)}$$

- Normalized Angular INtegration:

$$NAIN = \frac{Node\ Count^{1.2}}{Total\ Depth}$$

$$NAIN = \frac{\sqrt[1.2]{Node\ Count(r)}}{Total\ Depth\ (r) + 2}$$

The methodological process was further developed in detail in a fundamental research published by Hiller and Lida in 2005.

2.3.5 Local scale and angular segment analysis

Performing an angular segment analysis using various metric radii signifies the specification of a distance from each segment along all the available streets and roads from that segment up to the radius distance. Alternatively, this method defined meters along the neighboring segment lines starting from each one.

Moreover, a radius "n" means that each segment is related to every other segment in a City without any radius restriction (global scale).

A radius of 400 m indicates a five-minute walk, and 800 m represents another significant radius of a walkable distance equal to ten minutes, any distance beyond 800 m tends to a vehicular movement. In other words, vehicle flow rates correlate with global integration values, whereas pedestrian flow rates with local integration values (Hillier, 2007).

2.3.6 Space Syntax application in GIS based environment

The implementation of space syntax in GIS platforms has expanded the scope for exploring multiple variables simultaneously, including geographic, demographic, spatial and environmental attributes. One of the pioneering studies that introduced space syntax to Geographic Information Systems was conducted by (Cutini et al., 2004). The novelty of their approach, called “Mark Point Parameter Analysis” (Ma.P.P.A.), was to establish numerous mark points to optimize configurational urban analysis based on axial map measures.

Besides, several operating tools for Space Syntax eventually evolved in a GIS environment, in particular:

- “Confeego” tool set for spatial configuration studies, developed for MapInfo Professional (Gil et al., 2007),
- “Intangible Value of Urban Layout” (i-VALUL) toolkit (Chiaradia et al., 2008),
- “Urban Network Analyst” (UNA) toolbox for ArcGIS includes the building’s weight (Sevtsuk & Mekonnen, 2012),
- “Axwoman 6.3” toolkit for ArcGIS (Jiang, 2015),
- “spatial Design Network Analysis” (sDNA) for GIS which recently added the possibility to perform 3-d scrutiny (Cooper & Chiaradia, 2020).

Furthermore, the exchange of data between the standalone spatial syntax platform “Depthmap” and QGIS software prompted the development of “the Space Syntax Toolkit (SST)” python adds-on that facilitates the spatial network analyses and visualization (Gil et al., 2015). The plugin comprises two main modules, "Attribute Explorer" and "Graph Analysis", providing exploratory tools for spatial data analysis.

The first module offers a bench of symbology settings to visualize a selected feature by providing all descriptive statistics, such as mean, median, maximum and minimum values, quartiles, standard deviation, and range.

The second module enables to plot a frequency histogram and scatter plot correlations between two features. Furthermore, the functionality of this package, the data type and availability are two crucial factors that strongly influence the implementation of spatial syntax analysis.

Additionally, Ståhle, 2012 has developed a new paradigm of spatial analysis known as “the Place Syntax Tool” (PST) within a geographic information system. This analysis technique combines the accessibility indexes provided by the traditional spatial syntax approach alongside geographic and geometric parameters, including building boundaries and their functions.

Consequently, the interpretations become considerably simpler when projecting the integration outcomes of an urban area onto its functions.

2.4 Urban Acoustics

Comprehending the complexity of the acoustic environment appears to be challenging since it considers various elements. These elements have a relationship with the diversity of sound sources, their spatiotemporal aspects, and even the socio-physiological behavior of users. These parameters are involved in addressing numerous hypotheses related to this topic.

2.4.1 Physical fundamentals of sound

2.4.1.1 Sound pressure level

Sound pressure level represents a logarithmic ratio of the measured sound pressure to the reference pressure, which is the sound at the threshold of human hearing (Bhatia, 2014). The sound pressure level equation is given as follow:

$$Lp = 20 \times \log 10 \frac{Pmeas}{Po}$$

Where:

Lp, is the sound level (dB).

$Pmeas$, is the measured sound pressure (Pascal).

P_o, is the reference pressure ($P_{ref} = 20 \times 10^{-6}\ Pascal$).

2.4.1.2 Sound environment global indicators

Dynamic characteristics of sonic energy and time durations represent the main global indicators for assessing the sound pressure level Lp in indoor and outdoor environment.

Accordingly, two exponential time weightings for fast (F) and slow (S) time constant occurs in a wide range of sound level meters. Additionally, some of them feature an impulse time weighting, a quasi-peak detection characteristic with a quick rising time and a considerably more gradual decay. Where:

F: Fast Sound Level = Rise and Decay Time of 125 milliseconds.

S: Slow Sound Level = 1 second up and down.

I: Impulse Sound Level = 35 milliseconds while the signal level is rising, and 1.5 seconds when it is declining.

The sound meter’s fast and slow settings tend to analyze dynamics, while the “I” option indicates the impulsive sounds.

Moreover, the equivalent sound level "Leq" represents the time-averaged sound pressure level over an extended time (period T). This physical metric is commonly labeled by the time weighting function letter assigned to the sound level meter (i.e. Leq,F, Leq,S, Leq,I).

Furthermore, the equivalent sound level is typically measured using the A-weighting curve to determine the sound loudness. Thus, these values refer to Leq,A,F or Leq,A,I. Since the sound level is expressed on a logarithmic scale, we should consider all n observed sound-pressure level values while averaging the I instantaneous sound levels Li,A, and F that we measure over the period T. Therefore, it might be expressed as Leq,A,F,night (Leq,n) for the night-time, between 10 pm and 6 am. Or as Leq,A,F,day (Leq,d) for the day time averaged.

It thus becomes necessary to use the LAeq, LA50, LA90, spectral measurements, or even dynamic like the standard deviations of the level equivalent sound. At first glance, these global measurements don't seem to reflect the existence of specific audible sources.

Nevertheless, in a specific context, these indicators may be able to attest to the presence of distinctive sources. For instance, high frequencies in urban parks may indicate the presence of birds and human sounds, whereas the LA90 will be indicative of slow distant traffic (Brocolini, 2012). Therefore, interpreting these global measurements can offer crucial insights into the nature of the existing sources and it further enable a better understanding of the studied acoustic environment.

2.4.2 Computational methods of outdoor acoustics

In several instances, such as noise monitoring and sound mapping, the sole available indicators are those based on acoustic recordings or simulation models. Over the last few decades, various sound field prediction systems have been developed.

These approaches incorporate two principle modalities, namely Geometrical Acoustics methods, wave-based and diffuse methods. Pertaining to the research targets and specifications, choosing a hybrid model provides further complicated prediction scenarios (Georgiou et al., 2016; Lakka et al., 2018). The Fig. 2. 10 provides an outline of the developed methods within each category.

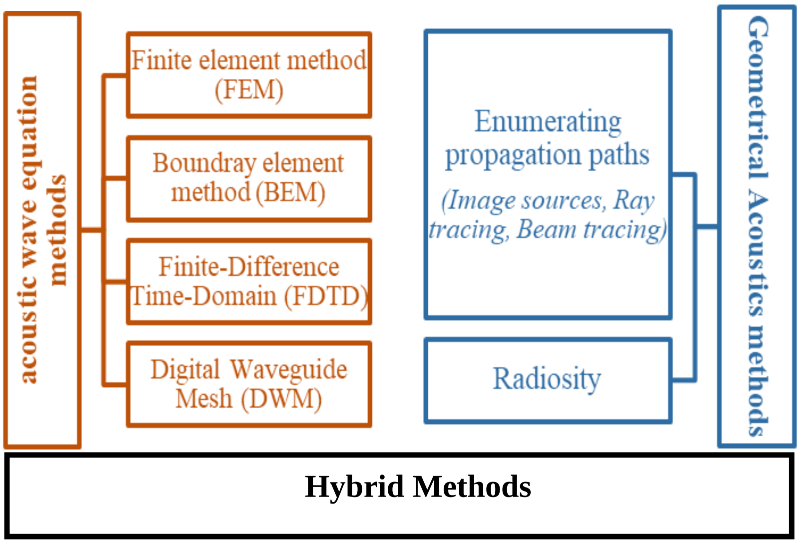

Fig. 2. 10. Computational methods of outdoor noise propagation (Source: according to Lakka et al., 2018)

Some reviewers also include, Acceleration and Non-graphic techniques (Charalampous & Michael, 2014). All these methods and tools are required to ensure the accuracy of digital predictions (Hornikx, 2016). Acoustic urban analysis relies primarily on the energetic indicators of continuous equivalent sound namely Ln (night), and Lden (day, evening, night). These limit values were recommended by the Environmental Noise Directive (END) (European Parliament and Council of the European Union, 2002).

The fundamental scientific papers that addressed the urban environment auralization methods are summarized in Table 2. 1.

Table 2. 1: Overview of urban acoustics computational methods (Source: Benameur et al., 2021)

Method (Acronym)	**Objectives**	***References***
Boundary element method (BEM)	Numerical analysis of Noise barrier using 2.5-D BEM	*(Toyoda et al., 2014)*
	Combining BEM to other methods to solve coupled vibro-acoustic problems	*(Kirkup, 2019)*
	Solve large acoustics problems by 3D BEM, including Fast Multipole Method	*(Bashir & Carley, 2020)*
Digital waveguide mesh (DWM)	2-D modeling, application and limitations	*(Murphy et al., 2007)*
	Coupled DWM-FEM for modeling wave propagation in irregularly shaped streets	*(Pelat et al., 2011)*
Discontinuous Galerkin (DG)	Hybrid approach using DG-PSTD to compute arbitrary boundary conditions and complex geometries	*(Georgiou et al., 2016)*
	ExWave code based on DG method for modeling complex geometries	*(Schoeder et al., 2019)*
	DG for solving the AwRascle traffic system of hyperbolic partial differential equations	*(Buli & Xing, 2020)*

Equivalent source method (ESM)	2.5-D ESM for modeling an exposed and sheltered urban canyons	*(Hornikx & Forssén, 2007)*
	Using the multi-point multipole technique, to improve the calculation's precision	*(Gounot & Musafir, 2011)*
	Beam tracing to analyze road traffic segmented to equivalent points	*(H. Wang et al., 2019)*
Finite-differences times-domain (FDTD)	Coupled FDTD-PE method for Long Range Propagation	*(Toyoda et al., 2014)*
	Comparing FDTD to TOA (observed first times of arrival) for an impulse source	*(Cheinet et al., 2016)*
	Application of 3-D Moving Window (MW-FDTD) to large-scale analysis	*(Oikawa et al., 2017)*
Finite element method (FEM)	Using FEM to predict sound propagation in buildings with a periodic distribution	*(Molerón et al., 2012)*
	Introduction meteorological effects by Linearized Euler equation (LEE) provided by a CFD software (Open FOAM)	*(Toyoda et al., 2014)*
	Insertion loss measurements of noise barriers using FEM in 2-D	*(Papadakis & Stavroulakis, 2020)*
Lattice Boltzmann method (LBM)	Application of LBM used for incompressible flows in outdoor acoustic propagation	*(Fraser & Hall, 2006)*
	Determine the numerical dissipation and dispersion resolution dependency	*(Viggen, 2009)*
	LBM as a performant Bottom-up method to compute micro and macroscale algorithms	*(Brès et al., 2009)*
Parabolic equation (PE)	3-D wide angle PE to model low frequency propagation in irregular urban canyons	*(Doc et al., 2015)*
	Wind's speed and height effect on outdoor noise propagation	*(Toyoda et al., 2014)*
	Coupled FDTD-PE for modeling acoustic reduction through vegetation	*(Ow & Ghosh, 2017)*
Pseudo-spectral time-domain (PSTD)	Modeling scattering of a small tree geometry using PSTD	*(Van Renterghem et al., 2012)*
	Analysis of noise sources directivity and physical properties	*(Georgiou et al., 2016)*
	Comparing Fourier PSTD domain to DG boundaries for wave propagation in cities	*(Pagán Muñoz & Hornikx, 2017)*
***Waveguide Web (WGW)**	Second-order accuracy in modeling sparsely reflecting outdoor acoustics	*(Stevens et al., 2017)*

WGW is reverberator design for outdoor, it differs from Digital Waveguide Method.

The complementarity of these numerical approaches helps to model realistic acoustic parameters. Besides, the literature review states that most of these investigations addressing the auralization process at the macro scale.

The use of such procedures, however, necessitates the availability of specific, readily available data and an efficient computing infrastructure to perform the calculations. In our study context, implementing these computational methods is yet challenging.

2.4.3 Urban acoustics and Geographic Information System

2.4.3.1 Noise mapping purposes:

Towards the end of the 1990s, a simplified two-dimensional mapping led to the development of research projects on the visualization of urban sound using GIS systems. Nevertheless, this representation is limited and cannot accurately interpret the global acoustic properties due to the background noise occurrence. As a first initiative, Servigne et al. attempted to design a prototype visualization system in order to describe the acoustic behavior of various urban designs (Fig. 2. 11).

This research focuses on a basically interpolation method using a set of quantitative measures including average, maximum, and equivalent continuous sound level, as well as background noise and distance between people, which represents the "*speech intelligibility*". Further qualitative parameters have been considered, namely noise type, time fluctuations, and noise sensitivity (Servigne et al., 1999).

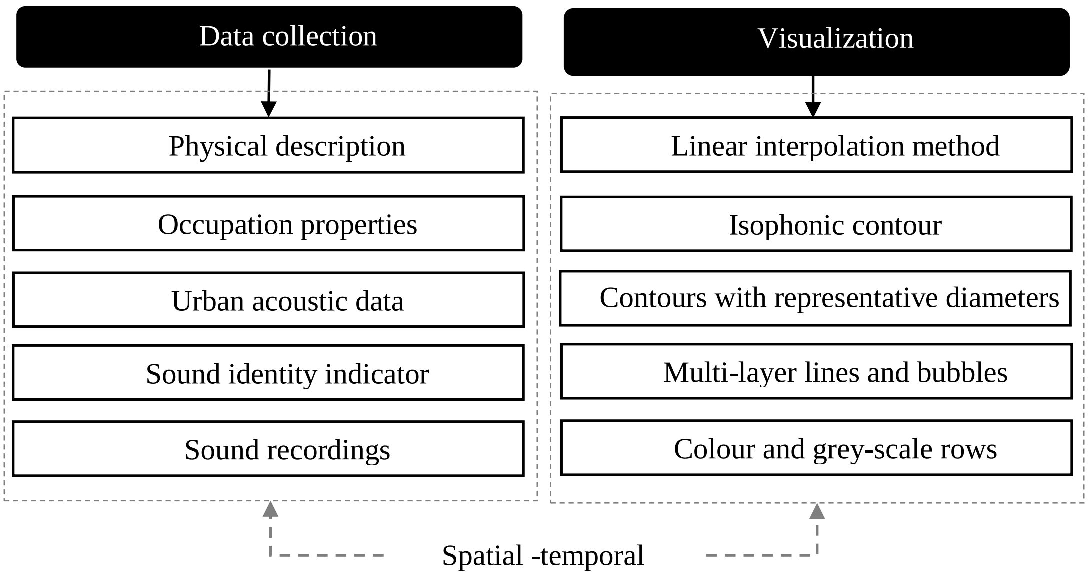

Fig. 2. 11. From data collection to urban acoustic visualization (Source: Author based on Servigne et al. 1999)

An additional study attempts to enhance urban soundscape mapping using GIS (Serrhini et al., 2016). This study investigates the environmental noise in an objective and subjective approach. Firstly, a set of daytime and nighttime measurements aims to generate prototype noise maps. Secondly, a perceptual assessment sought to determine people' ability to comprehend and discern the new figurative symbols and colors introduced to these maps.

2.4.3.2 Interpolation models and sound profiling:

Numerous interpolation models, such as Inverse Distance Weighted, Kriging and spline, were primarily assessed for landform and topography analysis (Ikechukwu et al., 2017; Mitas & Mitasova, 2005). Thereafter, these models extend to several fields comprising environmental applications.

Generally, interpolation is a mapping process of a variable V_0 at unsampled locations using a set of samples of a known location and V_0 value.

Spatial interpolation encompasses two main categories: Deterministic and Geostatistical methods. On the one hand, Deterministic approaches appear less likely to represent the spatial structure of the data. Thus, they predict only values at unsampled locations using specified mathematical formulae (by weighting attribute values of samples with known locations).

Geostatistical methods, on the other hand, attempt to conform the data to a spatial model. This gives rise to the possibility of the forecast's reliability and enables the development of a prediction value in unsampled locations (rather like deterministic approaches). Moreover, Deterministic approaches include techniques like the trend surface analysis, IDW, and TIN. Likewise, Geostatistical approaches encompass Kriging and its variants (Graser et al., 2017).

The theoretical foundation of spatial interpolation models, is therefore described as follows:
A) Inverse Distance Weighting methods. One of the simplest and most used methods for spatial interpolation is the inverse distance weighting (IDW) model. It represents an exact local deterministic interpolation technique, where the undefined value may anticipate as a weighted average of the measured locations nearby. Observations that are spatially closest to those under prediction gain a higher weight, while distant ones will have a relatively weak influence.

The generic formula for estimating the value u at an unsampled location x, as $u_i = u(x_i)$ for $i = 1,2, \dots \dots, N$, using IDW is given as follows:

$$u(x) = \left\{ \frac{\sum_{i=1}^{N} \frac{1}{d(x,x_i)^p} u_i}{\sum_{i=1}^{N} \frac{1}{d(x,x_i)^p}} \text{, if } d(x,x_i) \neq 0 \text{ for all } i \right\}$$

Where:

x denotes interpolated point,

x_i is an interpolating point,

$d(x, x_i)$ is the distance from the interpolating point x_i to the interpolated point x,

N is the total number of known points used in interpolation,

and p is the power parameter.

The weight assigned to each sample is controlled by a power parameter, often referred to as p. When p increases, the weight assigned to distant samples decreases. This factor represents the smoothing parameter. If the smoothing effect is too high, this hides interesting variability or gives the impression that the variable to be predicted is much more homogeneous on the plot than it is in reality. In fact, when p is too small, neighboring and distant samples have a strong influence on the predicted observations. Consequently, the prediction risks being very smooth since it does not consider the local weight.

Otherwise, if p is too large, only very local processes will be regarded, which may give the interpolated map a granular, non-smooth appearance (Tan & Xu, 2014).

B) Kriging interpolation methods. Kriging is a geostatistical method frequently applied for spatial interpolation. Kriging performs under the presumption that the distance between interpolation points is representative of a spatial correlation and eventually uses semivariance to measure this spatial correlation. This spatial interrelationship may assist us in tracking the surface variation. A semivariogram represents a plot of semivariance over distance or lag. It permits to model the similarity of observation points as a function of distance or lag. In other words, a semivariogram provides the similarity degree between observation points separated by a given distance.

The following equation may be used to calculate the semivariogram from sample points:

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \{z(x_i) - z(x_i + h)\}^2$$

Where:

$\hat{\gamma}(h)$ is the estimated semivariance at a separation distance h,

$z(x_i)$ and $z(x_i + h)$ are known values at two points x_i and $x_i + h$, spatially separated by the distance h,

$N\ (h)$ indicates number of sample point pairs physically separated by the distance h. Besides, for Kriging methods, it is necessary to select an empirical equation to generate the semivariances for all possible separating distances.

To this end, popular models exist, including Spherical, Exponential, Gaussian, and Linear. Once the model fits the empirical semivariogram, it becomes operational to compute the weights λ_i that minimizes the variance of the predicted value. Hereafter, the estimation can be performed through the following formula:

$$\hat{z}(x_0) - \mu = \sum_{i=1}^{k} \lambda_i [z(x_i) - \mu(x_0)]$$

Where: μ denotes the stationary mean, that is computed as the mean of the dataset, λ_i is the Kriging weight, k and $\mu(x_0)$ are the total number of observation points and the means of observation points in the search neighborhood.

There are many variants of Kriging, among which some classical methods are ordinary Kriging (OK) and universal Kriging (UK). For ordinary Kriging, the formula derives by replacing μ with a local mean $\mu(x_0)$, which is the average of the observation points in the search neighborhood.

The universal Kriging is an extension of ordinary Kriging, implying that the spatial variation of z-values has a specific trend apart from the spatial correlation between sample points (Ajvazi & Czimber, 2019; Tan & Xu, 2014).

Correspondingly, the literature review has revealed a wide application of these interpolation models in the urban acoustic field. For noise mapping purposes, research has been conducted in the metropolitan area of Tainan, Taiwan. The acoustic data was acquired by establishing 345 temporary noise stations using a Bruel and Kjaer (*B&K*) sound level meter, during the daytime in both the summer and winter seasons. A grid layout of 500m x 500m has been used to locate the monitoring stations. The mapping process was carried out using the Kriging spatial interpolation method (see Fig. 2. 12), then examined in light of the local regulations' noise control standards. The main findings were discussed based on two key factors, the land-use zoning of the urban sectors and the population rate exposed to noise (Tsai et al., 2009).

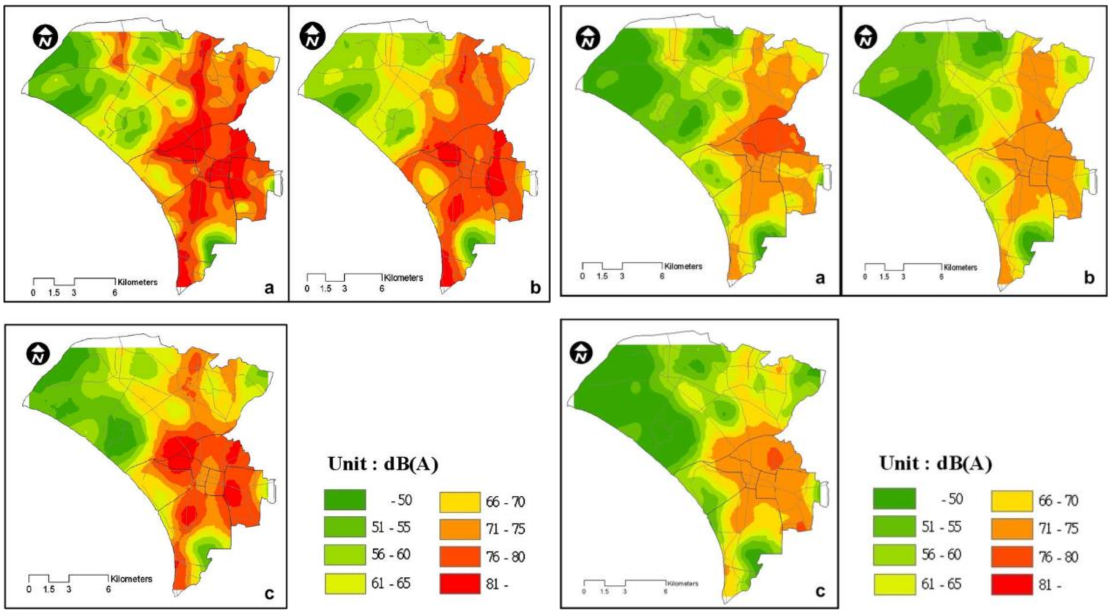

Fig. 2. 12. Noise mapping in Tainan City during Summer and winter: a. morning; b. afternoon; and c. evening (Source: Tsai et al. 2009)

In a different urban context, identical research in the Turkish City of Kahramanmaraş sought to measure noise pollution generated by urban traffic. During the daylight hours, 114 noise equivalent measurements (LeqA) were performed in 38 urban sectors, including distinct land use. For noise mapping, the data were modeled using the standard Kriging interpolation approach. The outcomes were compared to the upper and lower limitations of the local municipal noise regulation (Doygun & Kuşat Gurun, 2008).

Wusten (2016) conducted a noise analysis study in the city of "Isparta" intending to generate a noise map using a mathematical algorithm on GIS-based software. This investigation explores three distinct interpolation models, including Inverse Distance Weighting, Kriging, and Multiquadric. The procedure was initially assessed over four grid systems at various resolutions (10*10 m, 50*50 m, 100*100 m, and 200*200 m).

Thereafter, only the 50*50 m grid resolution was involved in the comparative analysis. Through 120 measurement points, three acoustic variables were determined: Lmin, Lmax, and Leq for a time duration of 10 minutes. Each station was connected to a GPS receiver between 4 and 7 p.m., coinciding with the prime time for both motor and vehicular noise pollution. Various settings were implemented, such as the inverse distance equations type: linear, square, cube, and larger power (k=1,2,3,4), along with the effect of three distinct radii: 750, 1500, and 2500 m. The authors emphasized the solid performance of the Kriging (cubic) and multiquadric hyperboloid kernel functions, indicating that even when changing the search circle radius, a squared inverse distance induces insignificant changes (Wusten, 2016).

In 2016, Garcia and colleagues demonstrated the performance and efficiency of ordinary Kriging when coupled with a Wireless Acoustic Sensor Network (WASN) in predicting the environmental noise in the urban area of Algemsi located in Valencia, Spain (Garcia et al., 2016).

In addition, it has been shown that geostatistical interpolation methods performed better than some parametric approaches in determining noise hotspots. One recent study was carried out in the Central Business District of Melbourne. The primary purpose was to compare two alternative methods for mapping noise: The GIS-based spatial interpolation through the Kriging model and the parametric design approaches employing Rhino and Grasshopper via the acoustic simulation tool known as Pachyderm (Chen & Wang, 2020).

The modeled noise maps reveal a high level of compatibility, according to the research findings. Fig. 2. 13 shows the variation of the Lmax values measured during weekday mornings for both modeled maps.

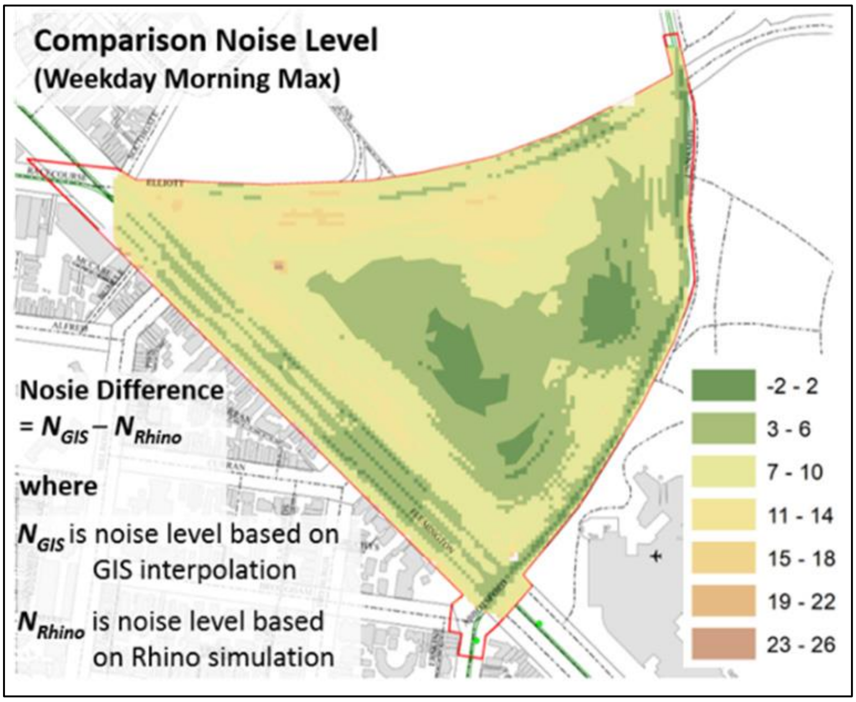

Fig. 2. 13. Noise difference of GIS interpolation and Rhino simulation (Source: Chen and Wang 2020)

Therefore, this investigation highlights the usefulness of GIS in analyzing large study area across a broad point data set, and hence the relevance of simulation functions in Rhino when dealing with indoor acoustic analysis or a small urban zone. Numerous factors, such as landscape properties and physical sound attenuations are properly considered in the parametric design to generate a more realistic model, which would be hard to accomplish using GIS.

The researchers suggested combining both approaches, employing GIS interpolation to highlight the noise hotspots for cities and regional scale and parametric tools to analyze urban and landscape design features at an inner-complex scale.

2.5 Influence of Urban Form on Outdoor Acoustics

The relationship between urban morphology and acoustic environment has been widely discussed across many perspectives, taking into account a variety of components, including urban form indexes, syntactic variables, and user perception.

2.5.1 Urban form indicators and noise exposure

An inquiry conducted by Silva and co-authors (2014) aimed to examine the correlation between urban form indicators and noise exposure, considering three urban metrics:

- The Compactness Index (CI) evaluates the size and form of an urban patch within the global urban environment’s fragmentation degree.

- The permeability indicator, known as the Porosity Index (PI) or Ratio of Open Space (ROS), determines the ratio of open space to the total area.
- The perimeter fractal dimension, or the perimeter index (Fractal), describes the relationship between a specific area and its boundary.

The authors proposed ten analysis scenarios using the “NMPB96” calculation method via “CadnaA” software combined with a realistic case validation process.
Most scenarios revealed a positive average correlation between the arithmetic mean of sound level pressure and the three urban indexes.

Furthermore, following a data collection process, Guedes et al., 2011 modeled the acoustic noise using “SoundPlan” software throughout a variety of scenarios, taking into account the floor number, the elevations’ orientation—at frontal and rear façades of the buildings—and ultimately, with and without enclosure walls.

Considering traffic as the principal noise source, Salomons and Berghauser Pont (2012) conducted an insightful study that correlates the noise traffic variables with spatial variables in two European towns of Amsterdam and Rotterdam. This study highlighted a proportional correlation of sound level pressure with the ground space index (GSI), floor space index (FSI), and population density (ρ). However, it demonstrated its inverse correlations with vehicle kilometers per square kilometer per 24 hours (W1), vehicle kilometers per inhabitant per 24 hours (Winh), and road network density (N).

2.5.2 Syntactic variables and soundscape

Currently, the theoretical foundation of space syntax has enabled the dissemination of this paradigm across various fields as it develops and refines its tools and explores numerous correlations with other phenomena. Therefore, only two studies in the literature addressed the correlation between space syntax and outdoor acoustics.

Firstly, research conducted in 2014 by Dzhambov et al. introduced the space syntax theory as a predictive tool for noise pollution in two different road systems located in the Bulgarian municipalities of Sofia and Plovdiv. This investigation covers two distinct datasets. The first employs an axial map, involving choice and integration for a radius “n” as a final output. Meanwhile, the second data set comprises the equivalent continuous level (Leq) values computed based on many factors, ranging the average speed of both light and heavy vehicles, lanes properties, and traffic flow types. The main findings demonstrated its potential in predicting traffic noise and revealed positive correlations with a moderate rate exceeding 0.6 (M. Dzhambov et al., 2014).

Secondly, through a comparative investigation of three distinct urban configurations in the city of Tripoli—a historic center, a residential area, and a commercial district—the noise exposure issue along pedestrian paths (soundwalks) was addressed based on space syntax indices. For this purpose, the segment analysis focused on two metric radii at 500 m and 800 m and the global scale radius n. Regardless of the potential factors, comprising temporal variation (day and night) and land use inference, the outcomes were relatively diverse, depicting moderate to low significant and nonsignificant p-values (Mohareb & Maassarani, 2019).

2.5.3 Soundscape perception

The "soundscape" concept refers to the various perceptual components that constitute the sound environment. The first set of indicators aims to describe the entire audio experience using generalized verbal descriptors. Several adjectives like "exciting and pleasant" or "disturbing and unpleasant" have been used. These numerous various attributes could be grouped into two axes labeled "Calmness" and "Vibrancy" during a study of primary components (Cain et al., 2008). Generally speaking, these two axes are referred to as "Pleasantness" and "Eventfulness", as stated by (Axelsson et al., 2010). Another adjective "Familiarity" would be added as a third dimension.

From this perspective, numerous studies have been developed, such as a rudimentary collective book entitled "Soundscape and built environment" edited by Kang and Schulte-Fortkamp (2016). This publication explores the relationship between the landscape and soundscape, the role of context and languages differences, as well as several aspects such as soundscape mapping, cultural heritage and quality of life, a management approach of acoustic environment and soundscape, and finally applied soundscape practices.

In addition, a solid paper addressed the soundscape topic from different perspectives according to ten important questions (Kang, Aletta, Gjestland, Brown, Botteldooren, Schulte-fortkamp, et al., 2016). More recently, an International Standard was established to analyze sound qualitative data (ISO/TS 12913-3, 2019).

Accordingly, these investigations were applied throughout several case studies, and more specifically in open public spaces. W. Yang & Kang, (2005), evaluated the soundscape in 14 urban squares in different European regions. The authors used measurements and interviewed 9200 people who frequently visit these places for the period between the summer of 2001 and the winter of 2002. The findings highlighted the main differences between the objective acoustics measures and subjective sound comfort.

Marry & Defrance, (2013) examine the perception and representation of soundscape in various public spaces through onsite surveys, acoustic indicators, and in-depth interviews. Measurements were performed in three public places combined with 176 questionnaires to assess sound perception.

Recently, Cerwén, (2019) suggested a Soundscape Action design tool, which consists of 23 design actions that landscape architects and urban designers can use to improve a given soundscape. These actions are structured around three main categories: localization of functions, reduction of unwanted sounds, and introduction of wanted sounds as depicted in Fig. 2. 14. Whereas, the main objectives of these actions are:

Initially, ensure that the various functions in the landscape—such as distances, directions, and topography—are audible.

Secondly, consider a noise reduction strategy via the acoustical properties of materials, topographical variations, and noise scene settings.

Thirdly, take into account tangible elements like water, vegetation, and gravel for enhancing the existing sound environment, in addition to introducing preferred sounds, and considering the allure of activities, and masking (Cerwén, 2019, 2020).

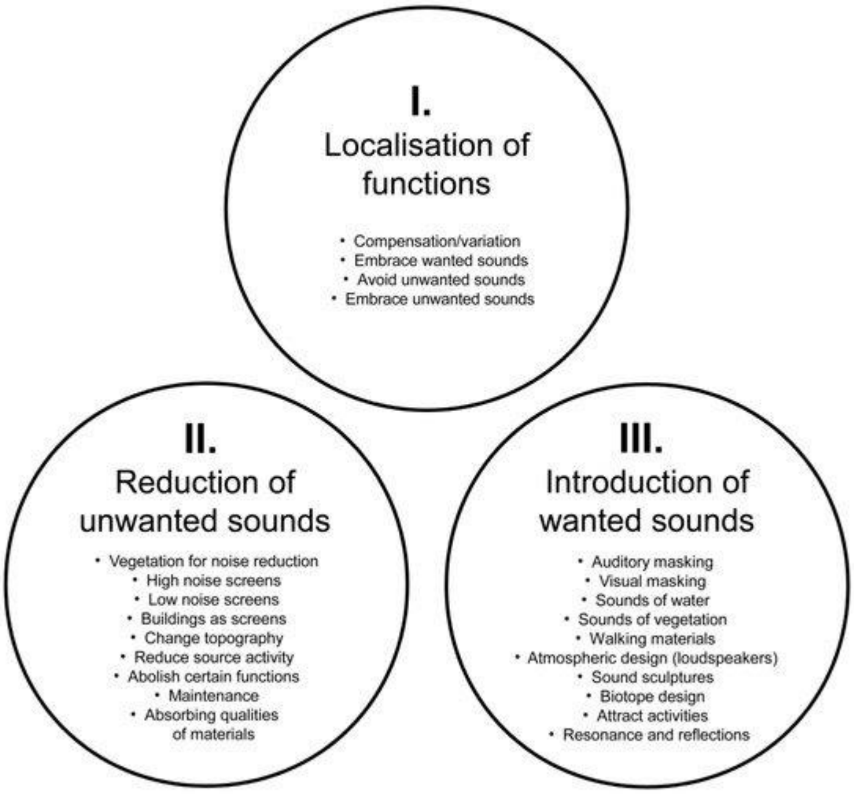

Fig. 2. 14. Soundscape action design tool (Source: Cerwén, 2019, p. 6)

2.5.4 Soundscape in the Algerian urban context

According to the literature review regarding the Algerian context, there are scrutiny and a lack of research projects addressing the acoustic or its relationship to urban configurations. Instead, the few available investigations focus on sound ambiances. Nevertheless, some experiments have been realized in different locations in the country.

For the coastline region, Djellali et al. (2013) conducted an analysis to compare two public spaces in two different urban contexts: the martyrs' square in Algiers, Algeria, and the victory square in Bordeaux, France. The study examined the relationship between human activity using the Sound walk method, which represents an empirical method for tracing a soundscape and its subcomponents in various locations. This research has yielded a set of recommendations to be adopted on both urban and architectural scales, as it provides the main requirements and actions to guarantee the comfort of these places' users.

Another recent study in Béjaïa City sought to explore the sonic landscape of open spaces through two aspects: the formal characteristics of the architectural design of the public space that influence the acoustic quality, as well as the sound activities that contribute to the ambient environment. This study involved several methodological approaches, including data collection, identification, analysis, and modeling on QGIS software, to understand the temporal usage of these locations. Despite the limited sample size, the case study's restriction to public spaces, and the research's analysis of urban morphology's technical limitations, the study revealed some associations between the urban setting and the aural environment (Ikni et al., 2020).

Regarding the high plateaus area, a single experimental study intended to determine the acoustic quality criteria that define the sound identity of Constantine's old town (Medina), Algeria. This research relied on a perceptual approach based on observations, acoustic measurements, and sound sequence recordings using professional microphones connected to a sound card. Moreover, it targeted the public and sensitive areas of the city, such as the souk, the market square, and the road network (Sahraoui, 2009).

For the Algerian Saharan region, the single study that addressed the urban acoustic environment was conducted by Bouzir & Zemmouri (2018). This study focused primarily on some representative urban fabrics of the city of Biskra, such as the old city, colonial urban fabric, and indigenous arrangements, to establish a series of acoustic measurements to determine the most sensitive configurations to noise disturbance based on threshold values.

2.6 Conclusion to this chapter

This chapter has provided an extensive overview of the literature dealing with the two key concepts of urban acoustics and urban morphology, including their theoretical backgrounds to explore their interconnectedness. Given the nature of our investigation, the data availability, the main objectives previously outlined, and the targeted correlations, the underlying epistemological position informs the usefulness of Space Syntax theory in processing diverse dimensions of urban form analysis.

This theory encompasses a series of methods to quantify and interpret the spatial configuration of buildings and urban settlements. It operates according to three fundamental conceptions of space to provide three syntactic maps (Axial, Convex and Isovist). Therefore, the analytical procedures include visibility graph analysis, axial map, angular segment analysis and agent model simulation.

The Angular Segment Analysis, in particular, focuses on movement patterns throughout its two normalized measures of Choice and Integration. It provides information on the preferential routes of vehicular and pedestrian flow and the ease of accessibility, as it depicts the socio-economic centers of a given urban structure.

In terms of urban acoustics modeling, several computational methods are being widely developed to address specific acoustic issues on micro and macro scales. Thus, predictive interpolation models, such as Inverse Distance Weighting and Kriging, have shown robust accuracy in dealing with noise variables distributions. These methods remain appropriate in case of insufficient adequate data allowing realistic computational modeling.

Furthermore, the literature review on the relationship between urban morphology and the acoustic environment revealed that the main correlations have generally involved a range of components, including urban form indices, syntactic variables, and perceptual attributes. As pointed out, a very limited number of investigations elaborated on Algerian urban context.

In this study, a GIS-based environment seems to be the appropriate platform to perform the principal correlations incorporating multiple variables. The subsequent chapter will further discuss the case study and the conceptual framework of the present research project.

CHAPTER 3:

METHODOLOGICAL APPROACH

Chapter 3: Methodological Approach

3.1 Introduction

This methodological chapter describes the design process of this research, divided into two distinct parts. The first provides a brief presentation on the Saharan city targeted by this research (Biskra City). Proceeding with an overview of the genesis of the diverse urban sectors and the emergence of several residential units and their principal characteristics.

At this point, it's worth noting that the delimitation of these sectors has been elaborated based on the current state previously designated by the respective land use plans (POS). This part also includes the Algerian laws related to acoustic environment assessment and noise pollution control, along with a cross-reference to International Standards (ISO) and French Norms (NF).

The second part further discusses the methodological approach focusing on three main axes: a) Urban morphology assessment, b) Urban acoustical assessment, and c) Perceptual and psychological assessment of the Biskra soundscape.

This section illustrates the methods of spatial and acoustic data collection, the meteorological conditions under which the measurements were conducted. As it incorporates the employed instruments, the modeling techniques applied, the correlation variables, and the subjective indicators.

3.2 Case Study Presentation

3.2.1 General context

Biskra is a Saharan city located in the southeastern region of Algeria, approximately 470 Kilometers away from the capital, Algiers (see Fig. 3. 1). Recently, the province comprised 27 communities, according to the Law N° 19-12, 2019.

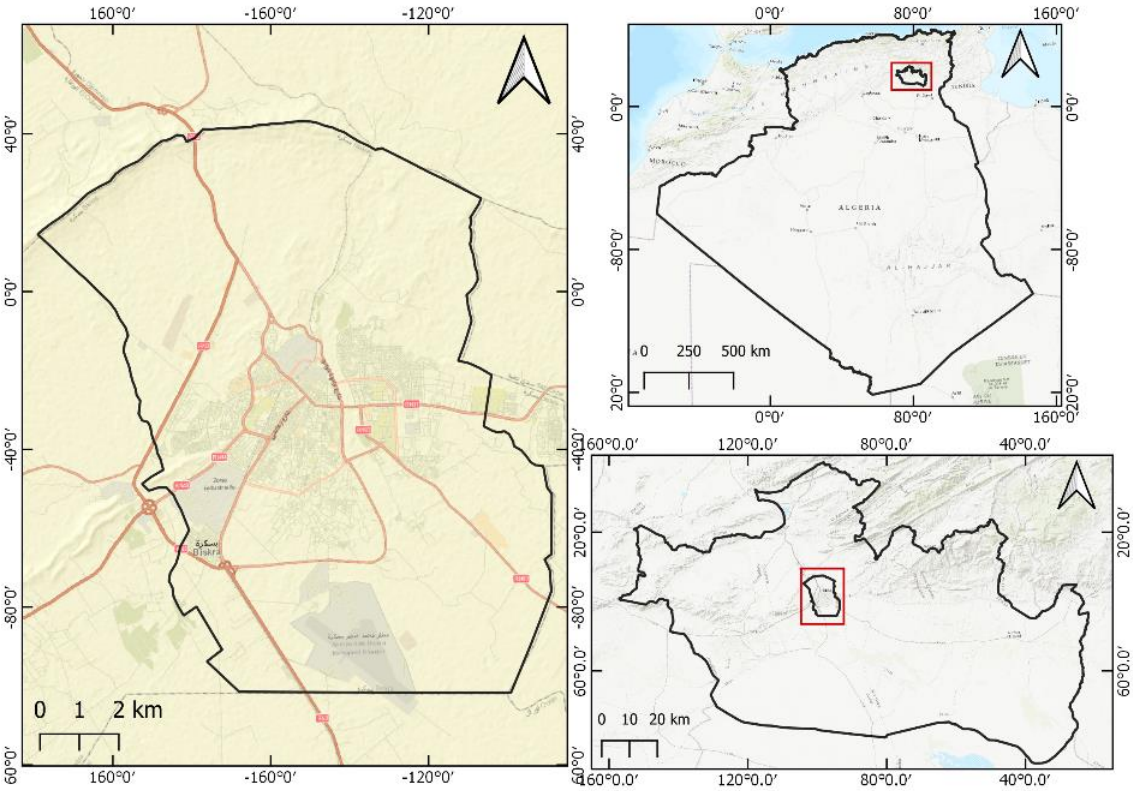

Fig. 3. 1. Study area location (Source: Author, 2020)

The capital city Biskra covers a total area of 127.7 km squared and had a population of 205 608 inhabitants in 2018. The Fig. 3. 2 illustrates the distribution of population density by urban districts, according to the last census established in 2008.

Moreover, this Saharan region faces a semi-arid climate with an extremely low precipitation rate (Directorate for programming and budgeting, 2018).

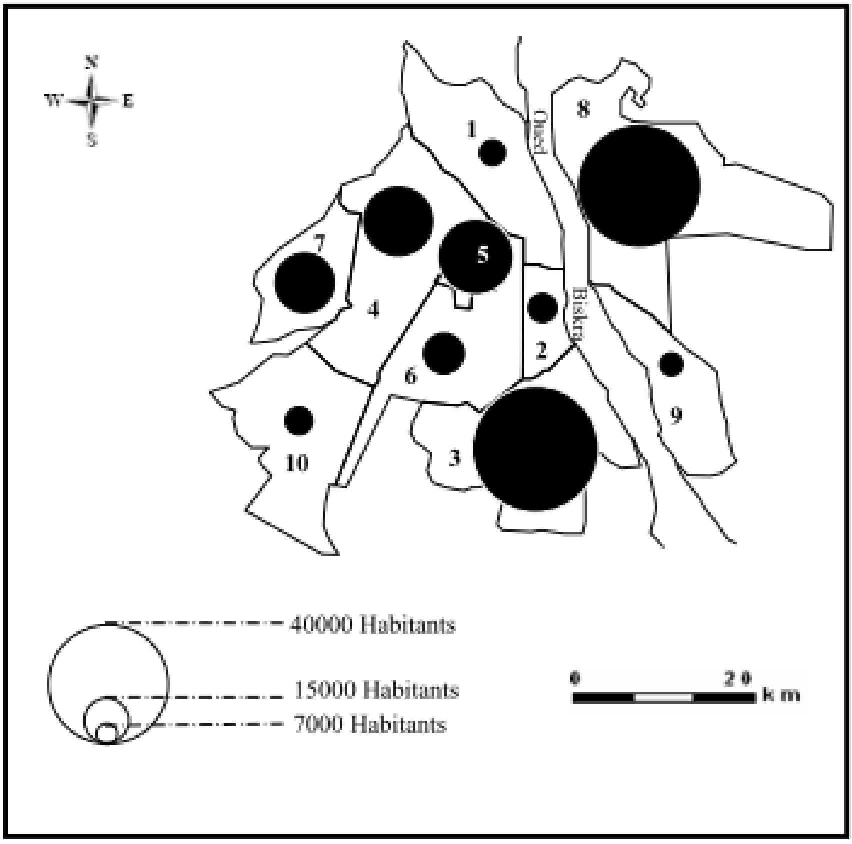

Fig. 3. 2. Population density in Biskra urban sectors
(Source: Bouzahzah, 2015)

3.2.2 Overview of the analyzed urban sectors

The current urban state of Biskra has undergone three major historical phases. These have determined its silhouette, its milestones, and its morphology. Therefore, they are detailed as follows:

- *The pre-colonial phase:* is characterized by the settlement of the city's first core on a hill slope high above ground level, when Turks had built up a fort to control the palm grove and the rivers to protect themselves against any external dangers. This position also allowed them to control the caravans crossing the palm, or that made halts for their rest. The Turkish occupation led to the construction of several fortresses. The most important one lies in the southern part near the primary core, while smaller ones are in the north on the relief near the Wadi.
- *The colonial phase:* is distinguished by two urban poles located around the Turkish fort (old core) and the colonial pattern near Saint German fort (Saint Germain). Along with the emergence of a principal thoroughfare joining them, known as "Hakim Saadane Avenue."

During this period, significant changes occurred, particularly following the completion of the first railroad leading to Batna City. Besides, it marked the beginning of the city structuring, initiated with the extension of the colonial settlement towards the east and west, in addition to the implantation of several residential districts, such as Djouala 1–2, Star Melouk, as well as the emergence of EL-Alia, Feliache, and north and south River neighborhoods.

- *The post-colonial phase:* is distinguished by an urbanization process crossing the Wadi and the railway boundaries. It presents a significant expansion of a low-density settlement pattern in the East-West direction, as well as the densification of the central core around the colonial fabric, Star Melouk, and El Alia, along with the Extension of Bab Darb (in 1977). Besides, the government implemented two New Urban Habitat Zones in 1986, a first one towards the East (ZHUN East) and a second one towards the West (ZHUN West) carrying industrial buildings and a planned urban fabric. This period experienced the arrival of the University near El Alia or else the Equipment Zone. The southern part of the city shaped an extension of illicit urban fabrics, including Sidi Ghazal, Ermaiche, Lebchache, Boukhari, El-haouza, Sidi Barkat, and Drouman. Then in 1996, the city experienced an extension by the east and west sides due to the allocation of land for individual housing (Sriti, 2013). This procedure remains in use currently yet has formed Biskra's contemporary urban landscape.

Accordingly, our case study encompasses the overall urban sectors as depicted in Fig. 3. 3, which have been previously delineated by Land Use Plan (POS) for each zone. The exception is the northern region of El Alia (above Zone 13) due to some constraints encountered during the experimental stage. This issue will be illustrated afterwards (see Chapter 4) via the potential of spatial syntax in addressing concerns of accessibility and safety.

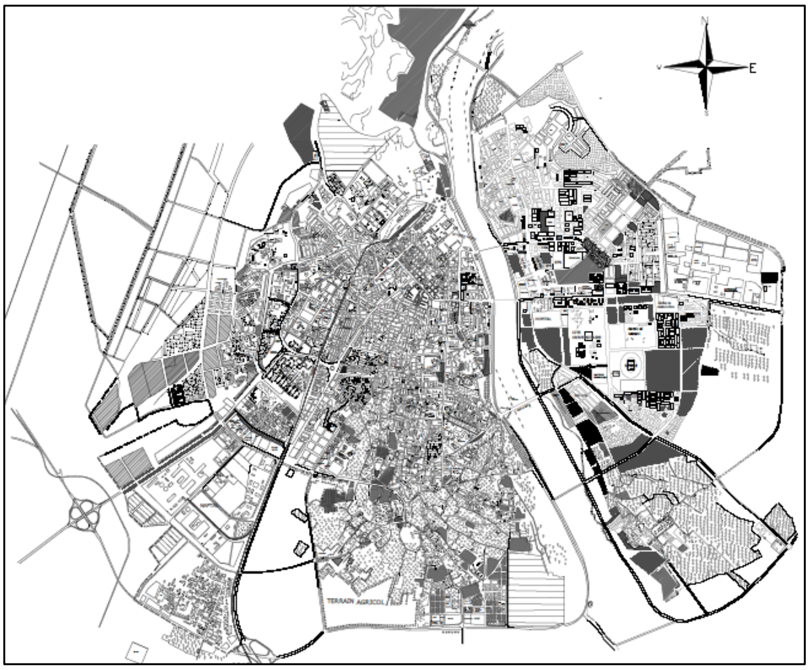

Fig. 3. 3. The Master Plan of Biskra City (PDAU, 2016)

A preliminary phase of geometry preparation is essential (see Fig. 3. 4). It entails the extraction of the urban sectors' geometry from the Master Plan, followed by a mapping process, geo-referencing, and merging with the Open Street Map (OSM) accessible data platform. This phase is performed using GIS software that permits multiple prospective applications.

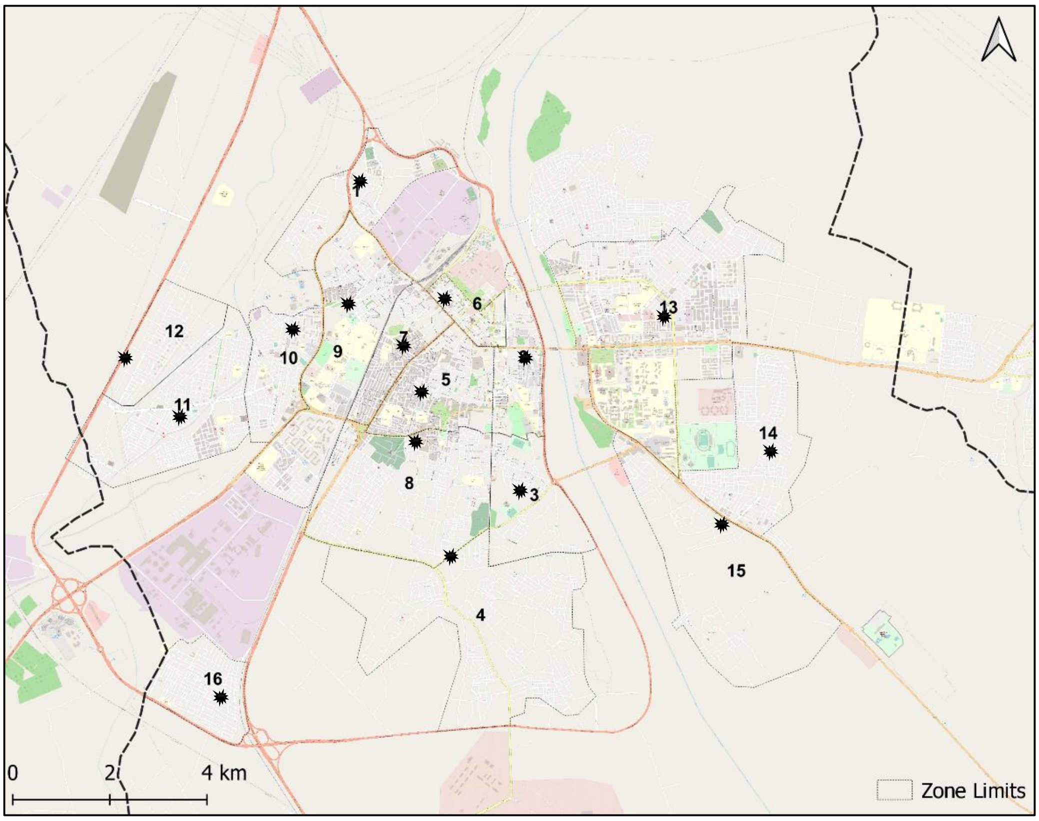

Fig. 3. 4. Study area location with the boundaries of the urban sectors

The following figure shows some panoramic photos of these urban sectors:

	
(ID 1)	(ID 2)
	
(ID 3)	(ID 4)
	
(ID 5)	(ID 6)
	
(ID 7)	(ID 8)

(ID 9)

(ID 10)

(ID 11)

(ID 12)

(ID 13)

(ID 14)

(ID 15)

(ID 16)

Fig. 3. 5. Urban sectors panoramic photos

Moreover, the main properties of these urban sectors namely land use, building typologies, and sectors' area, are illustrated in the table below:

Table 3. 1: Urban sectors properties of Biskra City (Source: Benameur et al., 2022, p. 3)

ID	Sectors Name	Land use	Building typologies	Area (Km^2)
1	North Zone	Residential, tourism.	Collective, Individual	0.98
2	Wadi Zone	Residential, administration	Collective, Individual	0.68
3	Ancient City (M'cid)	Residential, administration, education	Individual	0.99
4	Ancient City (Old Core)	Residential, administration	Individual	3.29
5	Downtown (Star Melouk)	Residential, commercial	Individual	0.99
6	Downtown (Colonial Fabric)	Residential, administration	Individual	0.30
7	Downtown (Dalia & Dalaa)	Residential	Individual	0.60
8	Sixth Zone	Residential, commercial, services	Individual	2.18
9	West Zone	Residential	Collective, Individual	1.87
10	West Zone 1	Residential	Collective, Individual	0.79
11	West Zone 2	Residential	Collective, Semi collective, Individual	1.76
12	West Zone 3	Residential	Collective, Semi collective, Individual	0.79
13	East Zone (El Alia)	Residential, administration, education	Collective, Individual	3.42
14	East Zone (El Alia South)	Residential	Individual	1.40
15	Feliache	Residential	Individual	2.53
16	Sidi Ghezal	Residential, administration, commercial	Individual	0.77

3.2.3 Noise policy statement in Algeria

The noise policy in Algeria incorporates two laws and an executive decree, in addition to a regulatory technic document.

Law N° 83-03 of February 5,1983, “*Relating to Environmental Protection, Official Journal of the Algerian Republic N° 25, February 1983*” (Law N° 83-03, 1983) incorporates a noise section figured in Chapter V according to Articles 119,120, and 121 (p. 33). These regulations emphasize the requirement of reducing and preventing noise pollution as a way to safeguard the environment.

Executive Decree N° 93–184 of July 27,1993, “*Regulating the Emission of Noise, Official Journal of the Algerian Republic N° 50, July, 28, 1993*” (Executive Decree N° 93–184, 1993) intends to “*legislate noise emissions*” as an application of the previous law. This decree limits sound levels in residential areas, roadways, and public spaces to 70 decibels throughout the daytime and 45 dB at night. During the day, 45 decibels is the limit value adjacent to hospitals, academic buildings, and rest places, while barely 40 decibels are permitted during the nighttime.

Law N° 03–10 of July,19,2003, “*Relating to Environmental Protection Within the Framework of Sustainable Development, Official Journal of the Algerian Republic N° 43, July 2003*” (Law N° 03–10, 2003). As presented in the second chapter within the fourth section entitled “*protection again noise*”. This law highlights the awareness of environmental noise protection by assigning several sorts of noisy practices.

The Regulatory Technical Document (DTR) C3.1.1 is the most relevant tool for acoustic designers, engineers, and researchers in Algeria. It describes the calculation methods for acoustic insulation, besides the overall indoor noise equations and physical properties (CNERIB, 2004). This document is mostly based on the Algerian Norms of the acoustic field (IANOR, 2014).

It’s worth noting that these standards are intimately associated with International Standards (ISO) and French Norms (AFNOR), as depicted the Table 3. 2.

Table 3. 2: Cross references between the Algerian Norms and the International Standards related to the environmental sound and soundscape

Algerian Norm	Identical International Standard
NA 01–7	**ISO 31-7:1978** Quantities and units of acoustics
NA 13433	**CEI 651:1979** Sound level meters
NA 6556	**ISO 3746:1979** Acoustics—Determination of sound power levels of noise sources—Survey method
NA 6560	**ISO 131:1979** Acoustics—Expression of the physical and subjective intensities of airborne sound or noise
NA 6561	**ISO 2204:1979** Acoustics—Guide to International Standards on the measurement of airborne acoustical noise and evaluation of its effects on human beings
NA 3279	**ISO 1996-2:1987** Acoustics—Description and measurement of environmental noise—Part 2: Acquisition of data pertinent to land use
NA 6905	**NF S 31–085:1991** Acoustics—Characterization and measurement of road traffic noise—General measurement specifications
NA 3282	**NF S 31–082:1992** Normal air conduction hearing threshold according to age and gender for otologically normal people
NA 3278	**ISO 1996-1:2003** Acoustics—Description, measurement and assessment of environmental noise—Part 1: Basic quantities and assessment procedures

An overview of the Algerian standards dealing with environmental noise demonstrates an updated lack of these norms. Actually, the NA 13433 describing the Sound level meter’s units and measures equivalent to CEI 651:1979, is already canceled.

Moreover, the NA 3279 remains the most relevant standard since it integrates all the physical and computational details required. However, this norm should be up to date according to the actual standards such as ISO 1996-1:2016 and ISO 1996-2:2017.

Additionally, a bench of recent studies conducted on soundscape physical and perceptual attributes (Mancini et al., 2021; Mitchell et al., 2020; Waters et al., 2021; M. Yang, 2019), were essentially based on the (ISO/TS 12913-3, 2019) that describes the main approaches to analyze quantitative and qualitative data.

3.3 Methods

The methodology employed for developing our hypothesis comprises two facets: an objective and a subjective component incorporating three different approaches. The first approach concerns an urban pattern analysis of the city by implementing the space syntax theory. The methods used in the analytical scheme are discussed hereinafter during the initial phase to select an appropriate technique for the previously identified objectives. The second approach relies mainly on an experimental protocol based on site sampling acoustic measurements and a data modeling process via spatial and geostatistical interpolation models.

Meanwhile, a GIS-based environment lays a foundation for the set of correlations between the syntactic and acoustic variables.

Thirdly, for the soundscape analysis, a subjective approach assessing perceptual and psychological attributes is indispensable and immensely recommended (Kang, Aletta, Gjestland, Brown, Botteldooren, Schulte-Fortkamp, et al., 2016).

3.3.1 Urban morphology assessment—Spatial analysis

According to Netto (2016), the space syntax encompasses three significant representational forms: the key movement that represents spatial practices, the occurrence in public spaces that reflects primarily social interactions, and syntactic properties to define an urban space.

Correspondingly, in this research the spatial analysis will be implemented via Space Syntax theory and, more particularly, the Angular Segment Analysis, following the epistemological position outlined in the previous chapter.

Compared to axial analysis, angular analysis has many advantages. Relying on angles weighting (turns), it provides refined output data regarding integration and choice measures among particular axis. Besides, it remains an efficient representation given its potential in dealing with road center lines. Likewise, it reflects a cognitive model evidencing pathway decision. Moreover, the generated segment map explores the associations between various urban networks, including local and global scales (Turner, 2007).

Hence, in this primary phase, the spatial analysis process is based on the network center lines provided by the Open Street Map (OSM) database. A preliminary step consisted in georeferencing the city map after refining and enhancing any existing segment, as the master plan (PDAU) specifies. Subsequently, a clipping operation is primordial for the urban network based on a buffer radius of 100-meters to prevent splitting up some axes.

Thus, the involvement of a combined road-center line model with angular weighted betweenness within a metric radius improves the exploration of the space syntactic measures (Turner, 2007).

Once the final shapefile is ready, it will be exported to the "DepthmapX" software to implement the angular segment analysis (ASA) using the global radius n and several local radii. The resulting MapInfo will be imported back into QGIS to examine the attributes using the Spatial Syntax Toolkit (SST).

For an insightful spatial analysis, many results were extracted, namely the four-pointed star model and several correlation scatterplots (see Fig. 3. 6).

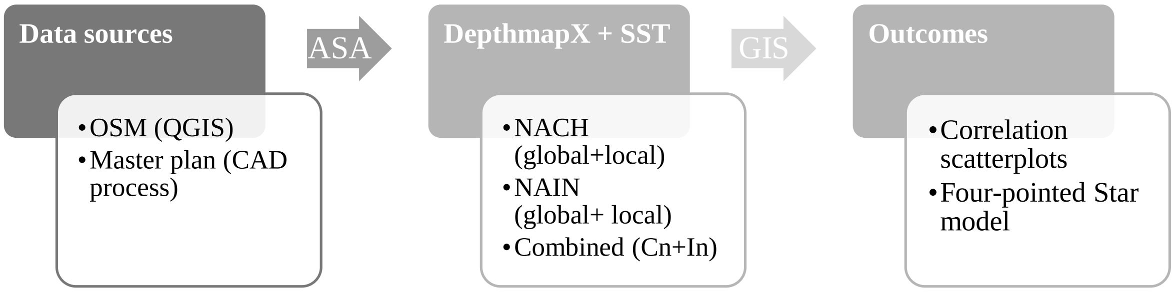

Fig. 3. 6. Spatial analysis framework diagram

3.3.2 Urban acoustical assessment—Sound profiling

The acoustic data were collected using a calibrated sound level meter (Model SL-586P of Merit-mi Brand), as shown in Fig. 3. 7.

It provides four output variables, including sound Level Pressure (Lp), Equivalent continuous sound Level (Leq), Maximum sound Level (Lmax), and Percent of all readings over the alarm value set (LN).

This sound level meter can memorize 30 groups of measurements through different conditions, as it allows one to choose “A” and “C” weightings within Fast or Slow response times.

Fig. 3. 7. Sound level meter model

The acoustic environment is typically determined by the sound sources, receivers' position, and sound dispersion circumstances. Besides, it may vary depending on daytime and season (A. Brown et al., 2015).

Accordingly, intending to assess the noise environment, we have established an experimental protocol. The measuring device was fixed facing the road and near the curb at a one-meter height from the ground for five minutes per station location. The instrument counted about 600 iterations of equivalent continuous A-weighted sound level (LeqA).
These measurements sought to identify the acoustic environment in Biskra City during November 2020 and January 2021 working days.

To fulfill this objective, we monitored a set of 240 stations, as shown in the Fig. 3. 8. It is worth noting that these stations are all located near roads and residential districts, thus excluding the airport, industrial areas, public, educational and military buildings, and hospitals.
Further details about the stations' ID, observations, date and time, and longitude and latitude coordinates, are mentioned in Table 1 Appendix A.

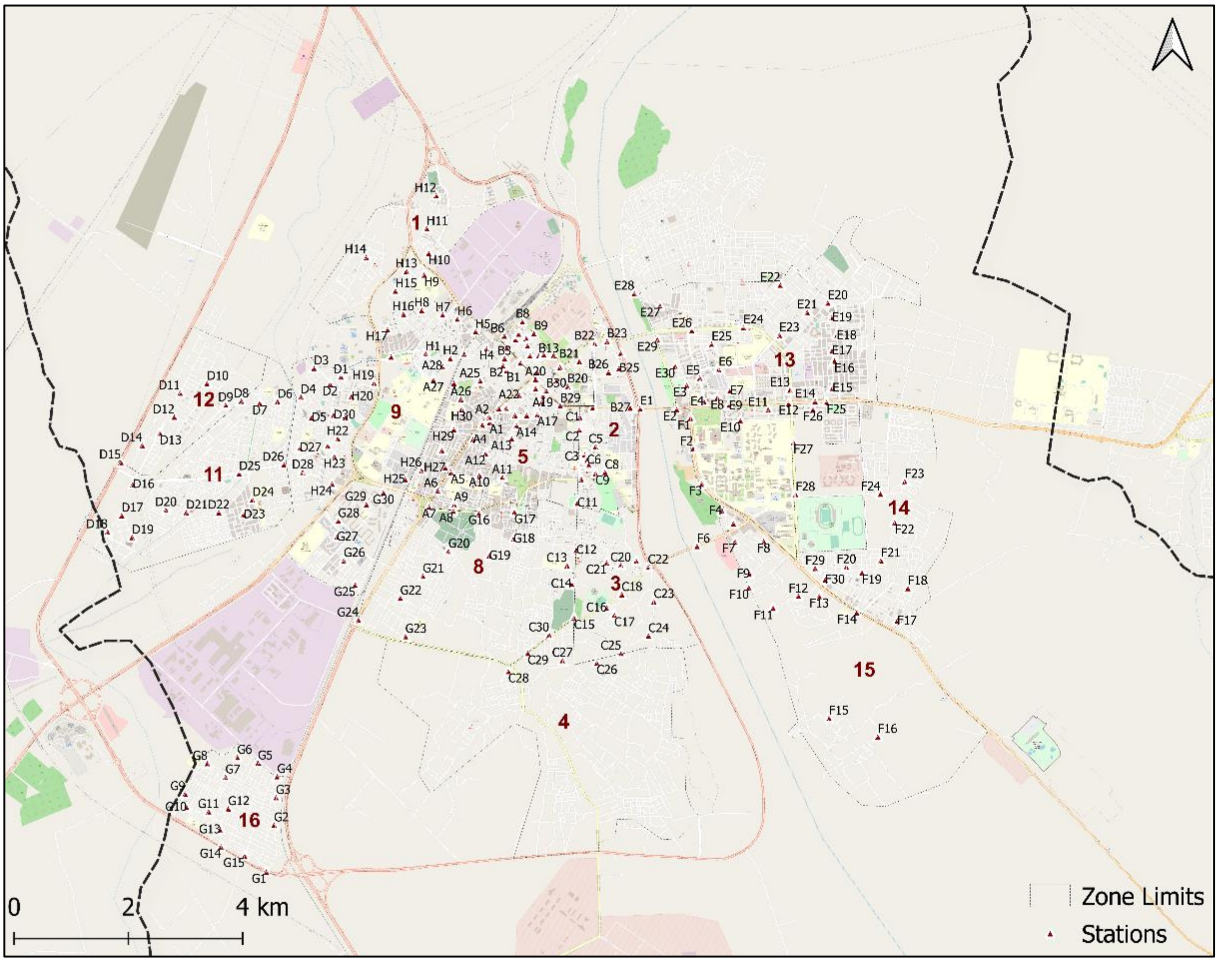

Fig. 3. 8. Spatial distribution of noise monitoring stations

The meteorological conditions under which these experimental measurements were conducted are depicted in Table 3. 3.

Table 3. 3: Overview of the measurement conditions (Source: Benameur et al., 2022, p. 3)

Month	*Temperature*	*Wind Speed*	*Precipitation*	*Humidity*	*Cloud Cover*
November	*Min 16-Max 23°*	*19 km/h*	*11 mm*	*56%*	*22%*
January	*Min 10-Max 17°*	*19 km/h*	*16 mm*	*59%*	*19%*

When the distance between the transmitter and receiver is 30 meters or more, climate change can significantly impact the received source.

Thus, the noise limitations in certain situations must be considered as the weighted value for all relevant meteorological conditions or simply for some defined weather conditions (ISO 1996-3, 1996). For our experimental protocols, the meteorological conditions were suitable, noting a low wind speed (19 km/h) and no precipitation.

Despite the existing methods for mapping noise, this field is yet inexperienced for developing countries. Generally, such a process involves sophisticated software considering all the relevant aspects, such as noise sources, topography, obstructions including buildings and other structures, absorbent and reflecting surfaces, meteorological conditions, also several roads and traffic data. Instead, simplified methods should also be employed because many of the data inputs for these software packages are deficient in specific locations like developed and Saharan countries. Simply interpolating noise measures data samples and overlaying the generated raster on a geographic map might be a practical alternative.

Furthermore, we should mention that we're interested in the spatial location of these stations corresponding to the urban network segments previously analyzed. These measurement stations are determined by the mean values of observations according to their proper coordinates on QGIS before performing the computational mapping of the extent region using IDW and Kriging.

As previously mentioned, these models proved their potential in acoustic and noise pollution studies (Aumond et al., 2018; Chen & Wang, 2020; Harman et al., 2016; Taghizadeh et al., 2013). Thus, this research targets several models for soundscape profiling, namely the Invert Distance Weighting via different weighted functions (Gaussian, Exponential, and Quadratic), in addition to two types of Kriging geospatial interpolation (Ordinary and Universal) resampling by a B-spline interpolation. Meanwhile, the interpolation parameters are adjusted to a cell size of about 1 pixel to generate reliable and accurate noise maps.

The modeling process was performed by SAGA GIS software packed with QGIS software. It features an object-oriented prototype system written in the powerful and robust C++ programming language.

The ultimate scope of SAGA is to provide geoscientists with a powerful yet simple platform for applying geoscientific methodologies. The distinctive Application Programming Interface of SAGA makes this possible (API). The second is to make these approaches user-friendly and accessible via the Graphical User Interface (GUI). All of this adds up to SAGA's fundamental strength: a rapidly expanding collection of geoscientific techniques used in various applications.

The novelty of our methodological approach relies on the final phase of the objective assessment, which involves a fundamental inferential investigation of the spatial and acoustic environment and their interactions by pairing the findings of the preceding assessments (see Fig. 3. 9).

This developed method has already been validated in parallel research dealing with different predefined European urban contexts (Benameur, Altafini, et al., 2021; Benameur, Cutini, et al., 2021). Therefore, it confirms the reliability of the obtained results.

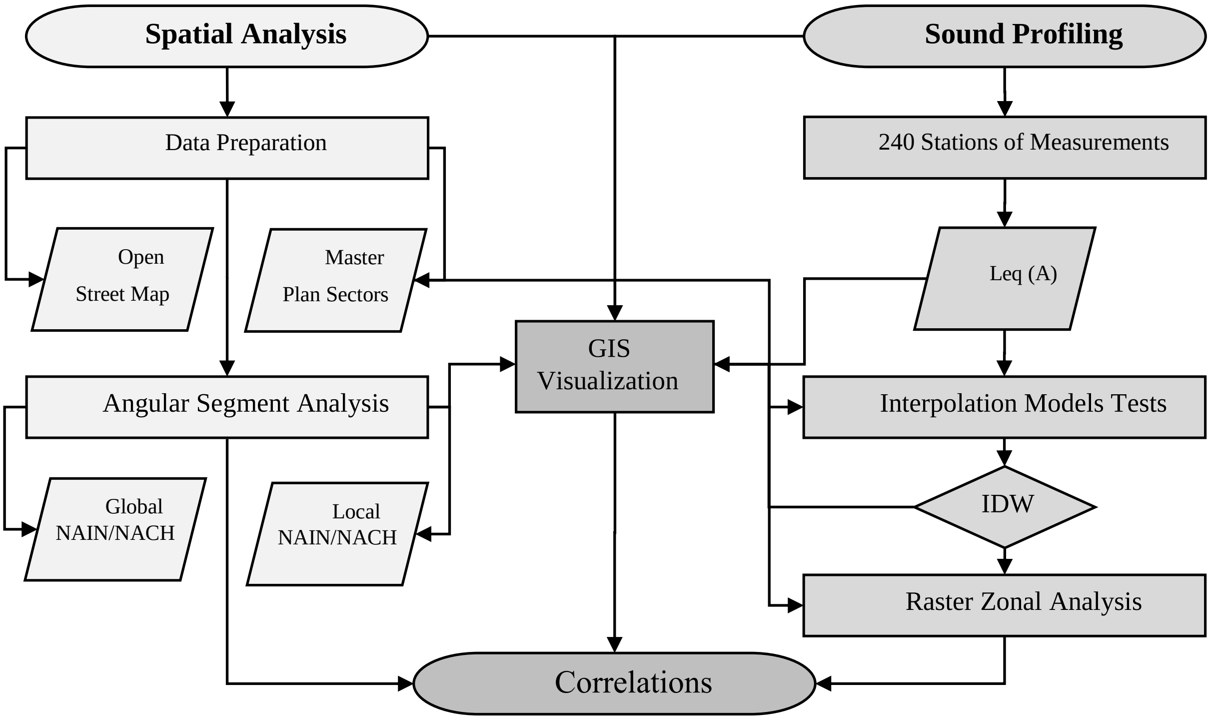

Fig. 3. 9. Assessment of the urban configuration and acoustic patterns flowchart

3.3.3 Psychoacoustical assessment—Soundscape synthesis

The third and final step tackles the subjective assessment to determine whether people perceive sound as a source of pleasantness or annoyance. The questionnaire includes various sociodemographic factors such as age, gender, educational achievement, and profession. Besides, it considers numerous variables specific to each interviewer's neighborhood and residence.

This research tool addresses the main perceptual attributes of soundscape, considering the inhabitants' outdoor satisfaction, in addition to the analysis of some sonic mind maps, which remain a qualitative technique that may describe in detail the imagination of the interviewee towards their built environment. The final section addresses sound preferences as a strategy to reproduce the soundscape.

Furthermore, this phase provides deep insight into the sound's physical and perceptual features to draw a thorough synthesis of the soundscape in Biskra City.

The following figure (Fig. 3. 10) shows the intrinsic process of the soundscape analysis. Further details on the questionnaire design will figure in Chapter 7.

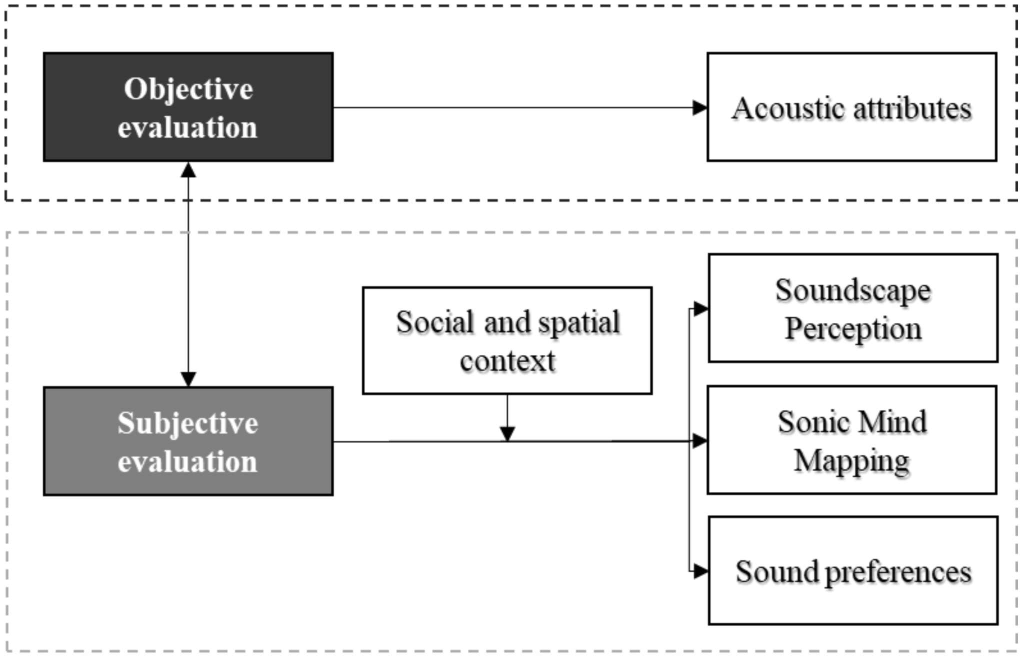

Fig. 3. 10. Psychoacoustical assessment flowchart

3.4 Conclusion to this chapter

To analyze the relationship between noise pollution and urban configuration, the city of Biskra was the subject of this study.

This Saharan city has experienced a succession of civilizations, leading to a particular cultural diversity expressed through the architectural styles and urban planning modalities, noting three distinct phases, pre-colonial, colonial and post-colonial. Therefore, the research case encompasses a variety of sixteen urban configurations.

Moreover, regarding the Algerian context, implementing laws and measures to assess and regulate the soundscape remains challenging. Several gaps are evident in national environmental noise standards, demonstrated by the cancellation of some old norms and the failure to update others. However, it’s necessary to integrate supplemental regulations based on existing international standards, namely ISO 1996-1:2016, ISO 1996-2:2017, and ISO/TS 12913-3, established in 2019.

The argumentation and discussion of the multidisciplinary approaches, methods, and techniques used for this research provide a global overview and an insightful synthesis of the effects and interactions of the spatial and acoustic environment. In the following section, we will discuss the main findings of the spatial analysis phase.

"Each place has a unique spatial signature."

Bill Hillier.

CHAPTER 4:

URBAN LAYOUTS ASSESSMENT OF BISKRA CITY

Chapter 4: Urban Layouts Assessment of Biskra City

4.1 Introduction

Generally, cities' inhabitants have a remarkable ability to perceive and describe the structural complexity of urban space. Their movement depends on the visibility and legibility of the urban fabric. In this sense, space syntax theory considers the wayfinding, as humans have a topological sense in an unknown environment. Thus, they minimize the distance between spaces by pointing to the activity centers (Hiller & Lida, 2005). Accordingly, this approach models these urban structures, their relationship with the movement concept, and the city functions.

The angular segment analysis defines the shortest path as it minimizes the angle between the user and its destination based on choice and integration measures. The first measure expresses the likelihood that a location would be used as city transit, as it ultimately quantifies space accessibility to the urban system to which it belongs. The second syntactic measure indicates the proximity of space to the network or the ease of access (Vaughan, 2015).

This chapter covers the relevant findings of the urban configuration angular segment analysis of Biskra City. It demonstrates the potential of this method and its usefulness in determining accessibility in the network system or built environment. The results of this analytical phase are structured from the macro to the micro, displaying the global syntactic measures of choice and integration first, followed by the combined index of these two variables, then the local syntactic measures by predefined metric radii.

Furthermore, a four-pointed star model is established to recognize the City's background and foreground priorities. The last section emphasizes the relationship between neighborhoods or the relationship between districts and the City. Thus, it exhibits various scatterplot series extracted by the Space Syntax Toolkit plugin (SST).

4.2 Global Syntactic Measures

The global syntactic analysis refers to systemwide examination, commonly termed radius n analysis. The main results shown in this section are performed using QGIS (*QGIS, Białowieża*, 2022). This software considers a wide range of data visualisation based on their distributions, such as equal count (quartile), equal interval, natural breaks (Jenks), pretty breaks, and logarithmic and standard deviation classification. According to Jones et al. (2009), natural breaks represent the best classification for segment analysis data.

Nevertheless, color graphs don't provide complete satisfaction for space syntax researchers. To enhance the representation of some correlated data, we created a "Color Ramp" analogous to the space syntax toolkit plugin and DepthmapX platform.

4.2.1 Global normalized angular choice

Fig. 4. 1 depicts a chromatic representation of normalized angular choice for Biskra. The most significant values pertain to the highways surrounding and crossing the city, namely several national roads (e.g. "N°3" leading to Batna and El-Oued, "N°46" to Tolga, "N°31" to Chetma, and "N°83" to Sidi-Okba). In addition to the principal arterial roads connecting the major urban areas of the city, namely, *"Zaatcha Boulevard"* and *"Emir Abdel Kader Boulevard"* both report a choice value exceeding 1.525.

Moreover, a high range of choice measures (1.061-1.168) was displayed on the boundaries of some urban areas along some arterial streets, namely *"Wadi Front Boulevard"* behind the second and third zones, *"Frères Asmane road"* that separates the seventh and ninth sector, *"Tina Smail"* and *"Reouina Mohamed"* on the limit of the eighth sector. Also, *"Athamnia Djamoui Street"* and *"Seddik Ben Yahia alleys"* that cross the 13th and 10th zone, respectively. Similarly, for Sidi Ghezal (Zone 16), a straight road orthogonal to the highway and crossing the district reported some high NACH values.

Furthermore, the three bridges that rely on the city to El Alia region reported a high level compared to the fourth and newest one that leads to northern El Alia.

The Choice map illustrates a degree of hierarchy regarding the road network at the level of distinct urban zones, starting with the primary highways and moving via secondary streets before arriving at the private space. Consequently, moderate to low values are noticed for little permeable segments referring to some roads running through the neighborhood's core.

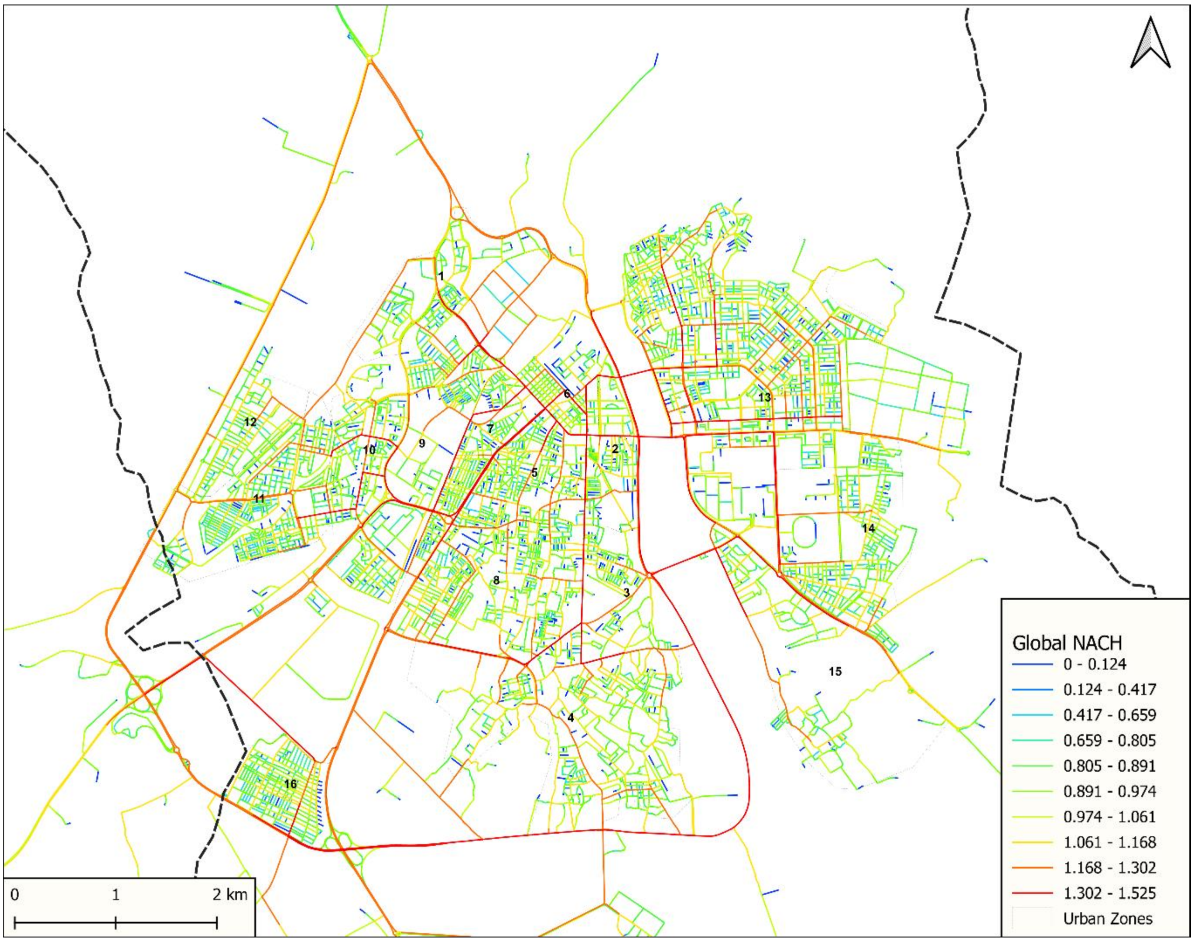

Fig. 4. 1. Chromatic representation of the global Normalized Angular Choice of Biskra

4.2.2 Global normalized angular integration

The integration map exhibits a no-edge effect, emphasized by the segregated pattern around the resulting borders of the map (see Fig. 4. 2). Likewise, the edges on the river boards remain highly integrated. Besides, the most integrated parts of Biskra are highlighted around the downtown, including Star Melouk, Dalia & Dalaa, and the colonial urban fabric, which is distinguished by regular grid system, conversely to the global network that forms an organic pattern.

Moreover, integration scores are relatively less significant for El Alia district and Sidi Ghezal zone. This district represents an independent structure located in the southern part of the town.

The peripheral expansions, specifically the west region besides Feliache and El Alia's southern part (Zone 14), remain the most segregated layouts.

Meanwhile, the sixth sector and the historic core show strong lateral integration on their borders. In other words, it indicates a strong integration on the periphery that becomes weaker towards their centers.

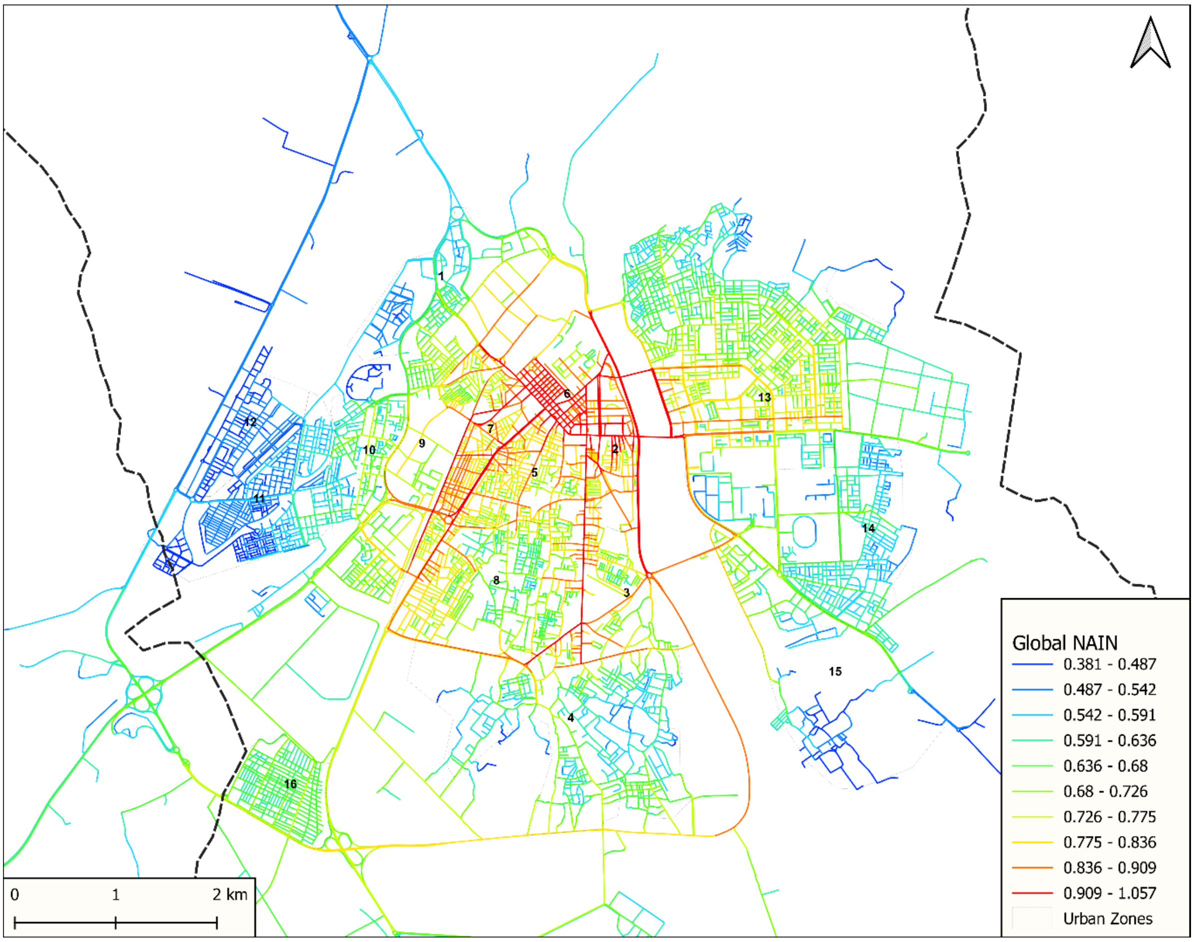

Fig. 4. 2. Chromatic representation of the global Normalized Angular Integration of Biskra

As mentioned earlier in the methodological approach chapter, it was challenging to implement measurement stations in several locations due to accessibility, security, and vandalism difficulties. This issue exhibits in the figure below when staring at both northern El Alia (Zone 13) and slightly southern the old core (Zone 4). These low integration values affirm the space syntax's ability to identify safety concerns.

4.2.3 Global combined choice and integration measures

The “to-movement” have a considerable impact on “through-movement”, since routes leading to integrated locations are more often used than those leading to less integrated destinations. Accordingly, weighing the choice measure for the integration value of a given destination would be an easy way to represent this (Hiller & Lida, 2005).

In this study, we multiplied and combined the global and local integration values to investigate the high potential segments for both to and through movement. As a result, an aggregated map was produced, displaying the total integration values according to the location of the street network (De Koning et al., 2017).

The combined measure of integration and choice for n radius were described by Hillier using the following formula:

$$Integration \times [log\ (Choice + 2)]$$

The aggregated map of Biskra city provides an overview of the configuration trends (see Fig. 4. 3). The highest combined values refer to the boundaries of the urban sectors as initially delineated by the land use plan (POS, or "Plan of Occupation") while also emphasizing the centrally located, most connected, and most integrated parts of the city.

Such measure can be achieved by a specific weighting, depending on the length of the segments. However, only local analysis allows for a close examination of the intersections inside each urban zone.

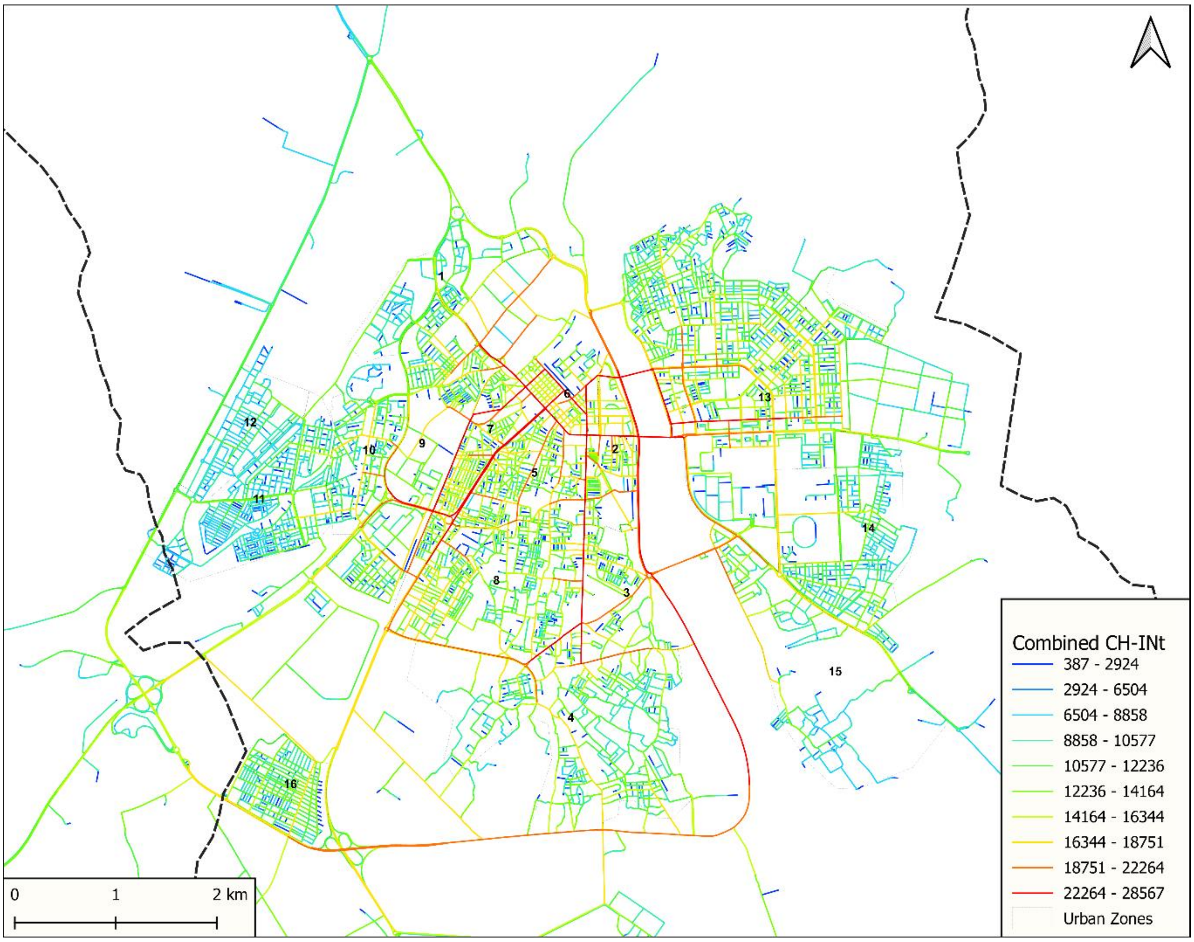

Fig. 4. 3. Aggregated map of the combined measures of Normalized Angular Choice and Integration of Biskra

4.3 Local Syntactic Measures

4.3.1 Local normalized angular choice

Initially, we should mention that local and global analyses are opposed. The first assessment considers a limited number of turns in the system starting from each street. Employing metric distances to analyze a georeferenced map using Depthmap software can explore urban systems at the local scale (Hillier et al., 2012; Serra & Hillier, 2019; van Nes & Yamu, 2021). In this study, we applied various low and high radii metrics to explore the closeness and the betweenness centrality.

The main results of the angular segment analysis reveal that the choice measures at small radii 400, 800, and 1200m relating to pedestrian movement are of equal significance for the entire system, apart from auxiliary streets and cul-de-sacs wherein NACH values would tend to 0.

In addition, at medium distances of 1600 and 2000 m, we notice the appearance of the most chosen routes located in the downtown, the East, and the West region.

Highways surrounded the city and main avenues, such as "Zaatcha Avenue, Amir Abdel Kader boulevard…", and the four bridges are highlighted at high radii 2400 and 3200 m and report 1.29 to 1.44 NACH values (see Fig. 4. 4).

These inferences were previously emphasized by Serra and Hillier (2019), who underlined the importance of the betweenness centrality in characterizing the hierarchical roadways type and vehicle movement using metric distances.

4.3.2 Local normalized angular integration

The local integration enables the location of the main activity centers at various radii. For walkable low metrics of 400, 800, and 1200m, we noticed the occurrence of moderate values ranging from 0.54 to 065, which correspond to the colonial and Star Melouk downtown (6 and 5), besides Wadi zone (2), East zone (13) and Sidi Ghezal (16). The highest values persist for the same zones even at high metric radii. Some urban sectors also reported high integration values, namely the western region and the sixth zone (8). However, El Alia south (sector 14) represents a construction site occupied by a scattered bunch of small dwellings yet scored moderate values 0.97-1.08 since it is connected to the principal road network (see Fig. 4. 5).

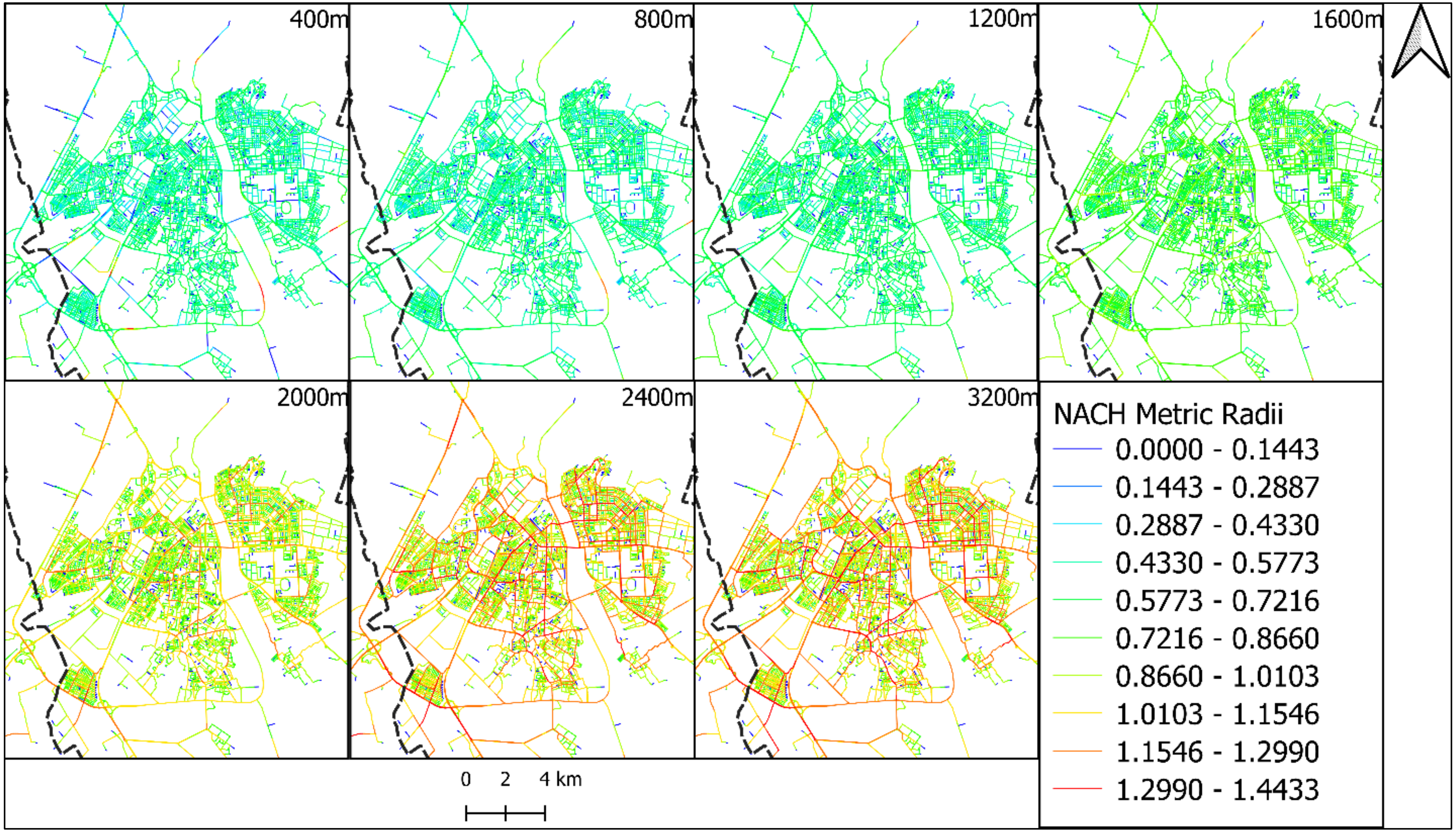

Fig. 4. 4. Normalized Angular Choice metric radii values (Source: Benameur et al., 2022)

Interpreting the high scores obtained at low and high metric radii for each area at the local scale indicates the intrinsic properties of each urban sector.

The historic colonial center of Biskra, which dates back to 1887, exhibits ease of accessibility at high and low radii owing to numerous considerations. For instance, the checkerboard planning pattern, the strategic location between the two parts of the city, the nearness of the major thoroughfare of “Republic Boulevard”—also known as “La rue berth Boulevard”—leading to multiple directions, the proximity to the “Public Garden: 5 July 1962”, and the presence of a massive former colonial market. In addition to the availability of several public facilities, including the municipal registry office (formerly “Town’s Hotel”), the Bank’s headquarters, and primary and secondary schools.

The cited features provide value at several levels: activities, housing, educational, commercial, social, and spatial practices.

Star Melouk either, represents a residential unit characterized by autochthonous habitats. This district merges several administrative, educational, and specifically commercial activities due to the popular marketplace “Zgueg Ben Ramadan”, besides several local shops lining Zaatcha Avenue (Benameur, Cutini, et al., 2021).

The same background extends to Wadi zone (2), Dalaa & Dalia neighborhoods (Zone 7), El Alia (Zone 13), and Feliache (Zone 16), which represents a highly populated residential area including a range of administrative, educational, religious, and entertainment facilities.

Furthermore, these findings align with an earlier experimental survey by Bouzahzah (2015). This study highlighted that the financial status of commercial facilities in Biskra revealed these sectors as the most significant in terms of commercial centrality and attractiveness.

The author mentioned, as well, that modern business activity attracts a new class of actors with a more or less high education level. Therefore, it will contribute significantly to the development and modernization of the commercial sector in Biskra.

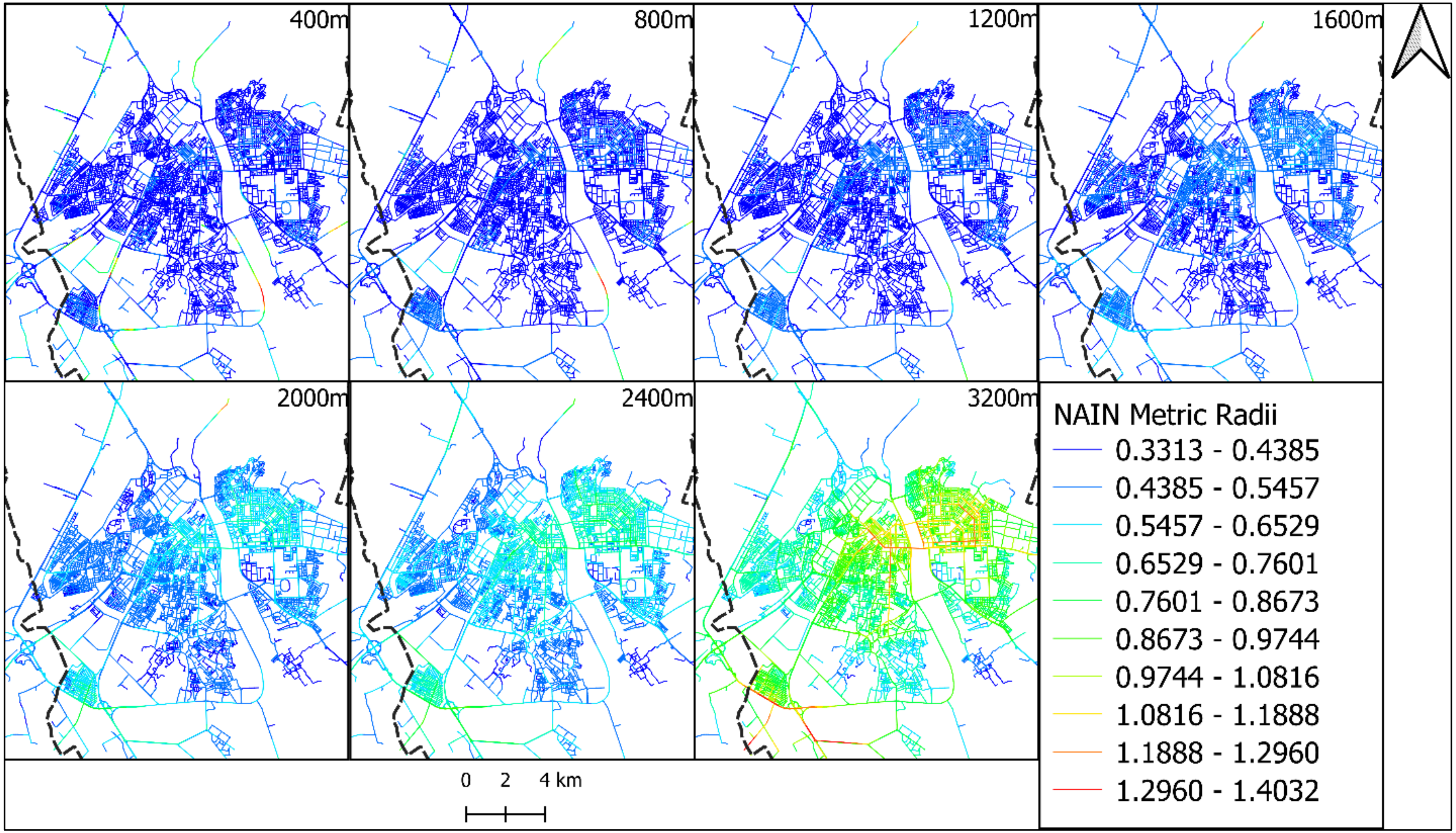

Fig. 4. 5. Normalized Angular Integration metric radii values (Source: Benameur et al., 2022)

4.4 Four-pointed Star Model

The four-pointed star model is a technique for examining cities. This graphical representation combines, simultaneously, the normalized angular choice and normalized angular integration to determine what variables provide information on the spatial organization and morphological properties. These vital variables of the Angular segment analysis can be combined using mean and max values for both NACH and NAIN to characterize how the city's foreground and background networks are integrated (Hillier et al., 2012).

The foreground network, according to Hillier's theory, refers to a few numbers of long lines with relatively straight connections. This system maximizes the flow across microeconomic activities of the linked centers. Whereas the background network contains many lines connected at almost right angles. It mostly reveals itself in residential areas, defined by sociocultural factors.

Hillier, Yang and Turner (2012) assessed the robustness of the foreground and the background network structure by elaborating star models for fifty analyzed cities from all around the world through the USA, Europe, Asia, and Australia.

The following formulae are used to get the Z-scores for both the NAIN and NACH values:

$$\bar{X}_{max} = \frac{\sum_{i=1}^{50} X_{max}(i)}{50}$$

$$Z_{max}(i) = \frac{X_{max}(i) - \bar{X}_{max}}{\bar{S}_{max}(i)}$$

$$\bar{X}_{mean} = \frac{\sum_{i=1}^{50} X_{mean}(i)}{50}$$

$$Z_{mean}(i) = \frac{X_{mean}(i) - \bar{X}_{mean}}{\bar{S}_{mean}(i)}$$

Where $\bar{X}_{max}$, $\bar{X}_{mean}$, are the average value of max and mean NACH and NAIN for the fifty cities sample, and $\bar{S}_{max}$ and $\bar{S}_{mean}$ referred to their Standard deviations generated by (Hillier et al., 2012). These standardized values have previously been employed in several investigations that primarily targeted to compare different urban configurations in France (Fouillade-Orsini, 2018b), Serbia (Fouillade-Orsini, 2018a), and the Netherlands (Yamu & van Nes, 2019).

According to these studies, we first extracted the values of Mean and Max normalized choice and integration respectively from Depthmap, then we calculated the Z-scores, as illustrated in Table 4. 1.

Table 4. 1 : Mean and max normalized choice and integration values for Biskra

	Max NACH	*Mean NACH*	*Max NAIN*	*Mean NAIN*
Biskra City	*1.5253682*	*0.960622108*	*1.0573404*	*0.673693945*
	Zmax NACH	**Zmean NACH**	**Zmax NAIN**	**Zmean NAIN**
	-0.635751868	0.496143959	-1.060182008	-1.047712749

The four-pointed star model of Biskra City depicts that the analyzed urban configuration is relatively more intense on the background network structure than the foreground, scoring a mean NACH value slightly above the average (0.49). This positive value indicates how well the background network maintains a consistent pattern with full connectivity.

The graph highlights a low negative score of max Choice (-0.63), which represents a lack of regular grid geometry. The foreground network of Biskra City is predominantly an organic grid except for a few segments in the colonial urban fabric.

The integration scores are moderately low and similar (-1.06) and (-1.04) for both foreground (max) and background (mean), respectively, indicating modest ease of accessible networks and socio-cultural priorities (see Fig. 4. 6).

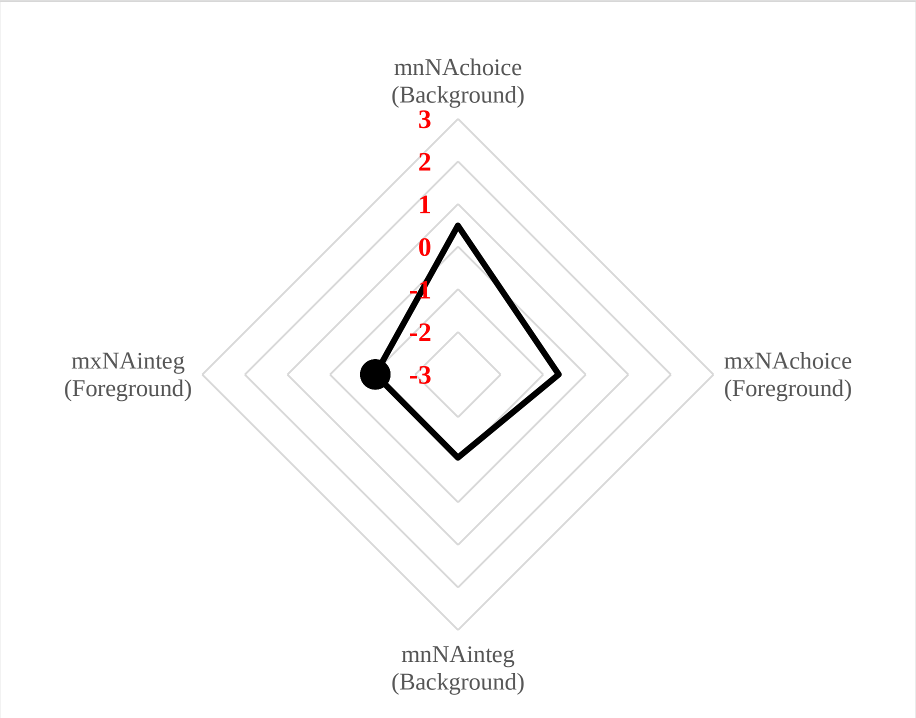

Fig. 4. 6. Four-pointed star model of Biskra urban spatial structure

4.5 Relationship Between the Neighborhood and the City

The selection feature and attributes explorer module of the Space Syntax toolkit have the potential to examine the relationships between a selected neighborhood and the whole city network.

4.5.1 Choice scatterplots

Choice scatterplots have been performed based on high and low radii indicating the degree of street life in a built environment (van Nes & Yamu, 2021). The angular choice correlation for the city's global scale, as demonstrated in Fig. 4. 7, reveals an average value of 0.5234. This value can be explained by the variations scored for the different urban sectors. By examining each neighborhood independently, we notice some high values that exceed 0.8 and close to one, in the image of the Wadi zone (2), Star Melouk (5), Dalia & Dalaa (7), Sixth zone (8), and the first extension of the western area (10), which scored a correlation rate of 0.8085, 0.8156, 0.7923, 0.7688, 0.8206 respectively.

These findings imply that the roads forming these regions have almost the same prominence on the global and local scales. In other words, these routes are preferred by vehicles as they are by pedestrians.

Additionally, the outcomes reveal that the overall urban zones indicate some high correlations compared to the global city, which displays highly integrated routes on a city scale. Apart from the colonial fabric in the downtown (6), the correlation coefficient is nearly equal to the city coefficient.

Peripheral areas, such as the third Western expansion zone (12), El Alia South (14), and Feliache (15), reported a lower correlation compared to the city. These highlight their location far away from the main routes on a city scale.

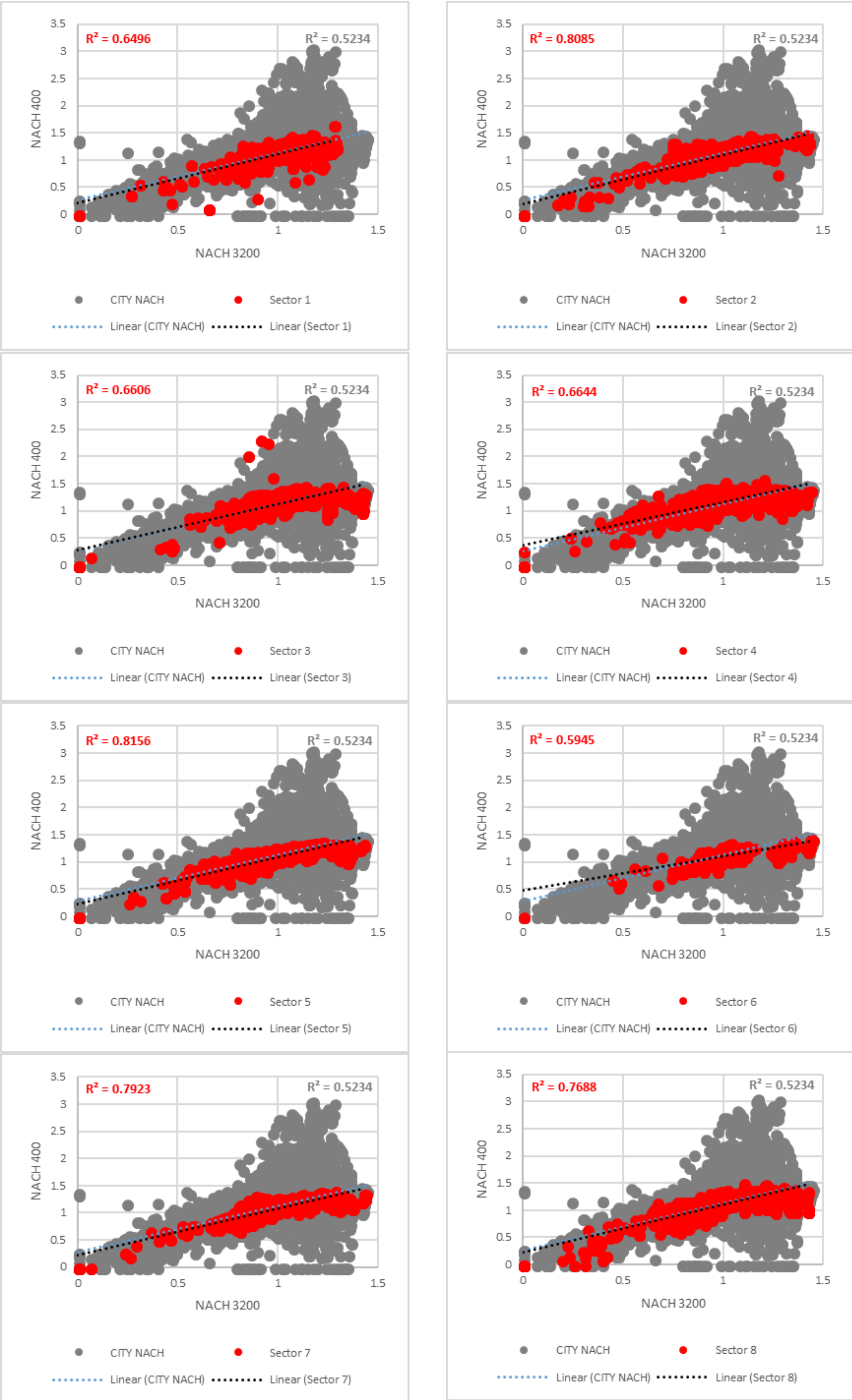

Fig. 4. 7. Angular choice scatterplots of Biskra's urban system (Sector ID from 1 to 8)

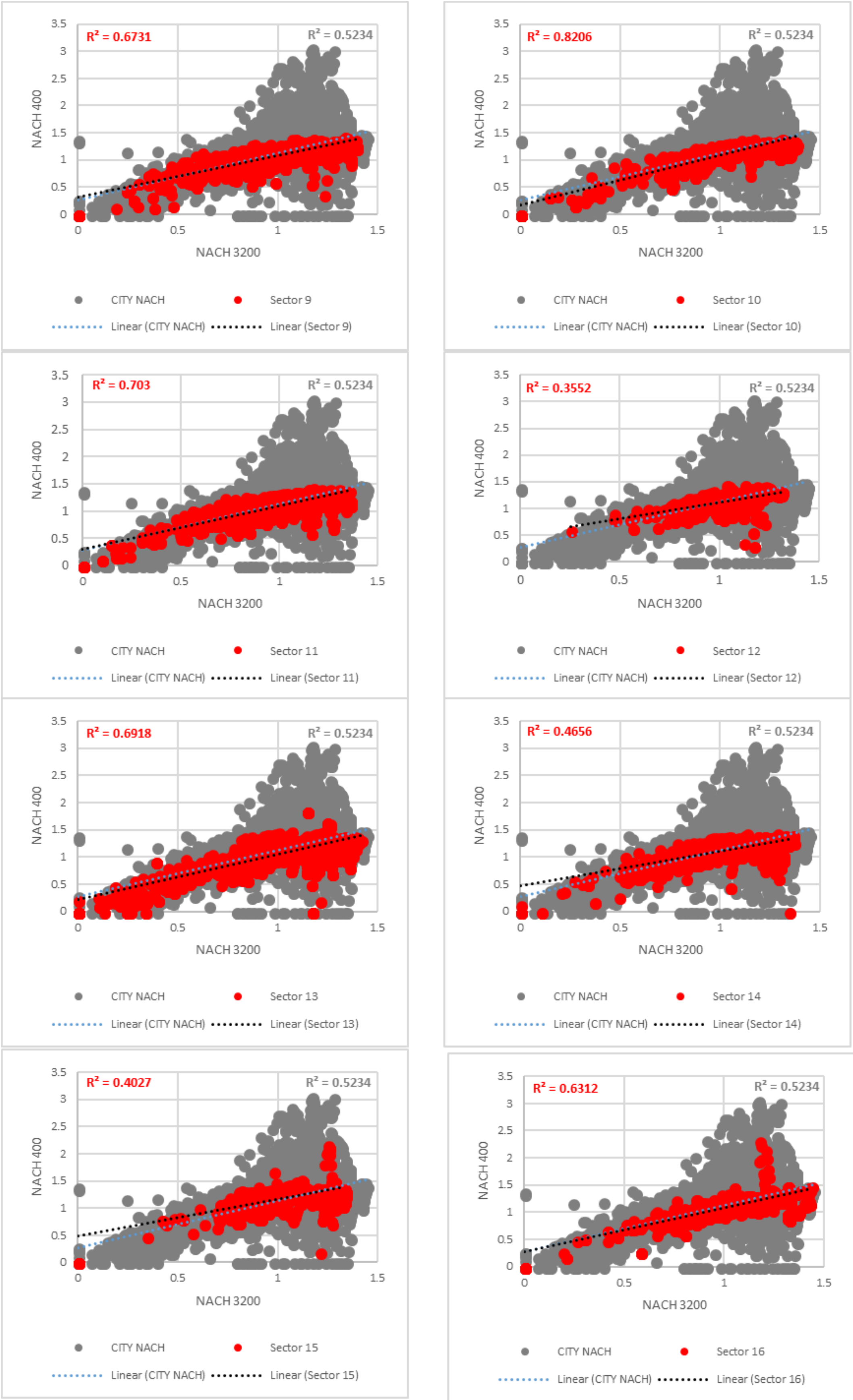

Fig. 4. 7. Angular choice scatterplots of Biskra's urban system (Sector ID from 9 to 16)

4.5.2 Intelligibility scatterplots

As previously established, intelligibility represents an axial analysis measure. However, these scatterplots might be used for angular segment analysis by correlating high and low radii. It demonstrates how straightforward to explain the global structure using the local neighborhood. This concept refers to the cognitive map and Kevin Lynch's approach (van Nes & Yamu, 2021). According to Fig. 4. 8, the global correlation coefficient R2 for the integration on a city scale reported a low value of 0.0473. That points out the high dissimilarity between the inner ad the global structure of Biskra City.

Therefore, Wadi zone (2), Star Melouk (5), Colonial fabric (6), and West Zone 1 (10) reported the highest correlation values, albeit they are still merely moderate at 0.56, 0.55, 0.52, and 0.58, respectively. And considerably lower versus the downtown (Dalia & Dalaa), with a proportion of 0.41. These moderate values indicate that the built environment in these areas is more orientable at varying degrees opposing the overall structure.

The other neighborhoods, similarly, were marked by a variety of small correlation values, all of which were below average.

Only two areas stand out from this rule, such as Feliache (15) and Sidi Ghezal (16), display a lower correlation value relative to the city scale. Likewise, the northern region scored a slightly higher value of about 0.07.

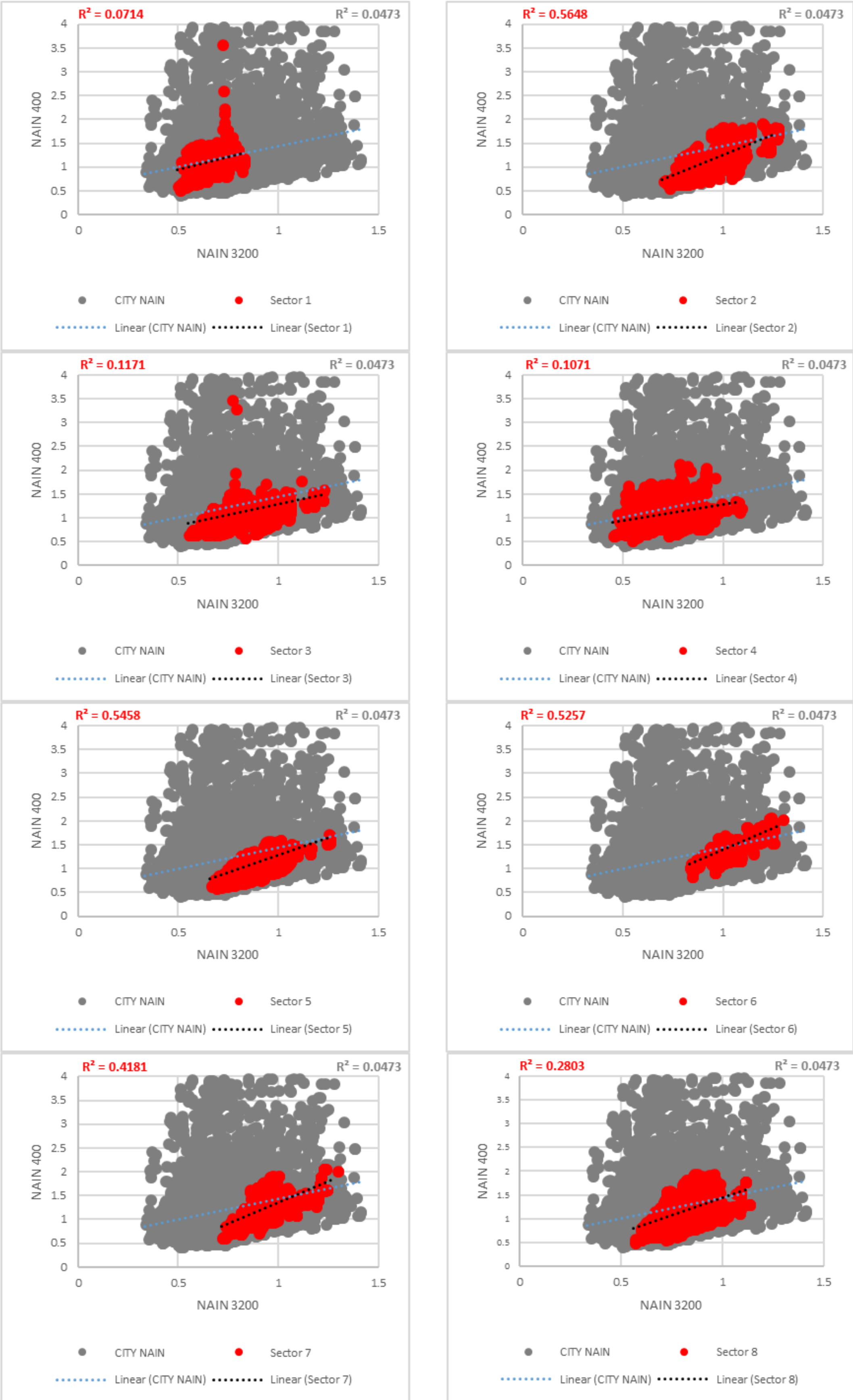

Fig. 4. 8. Intelligibility scatterplots of Biskra's urban system (Sector ID from 1 to 8)

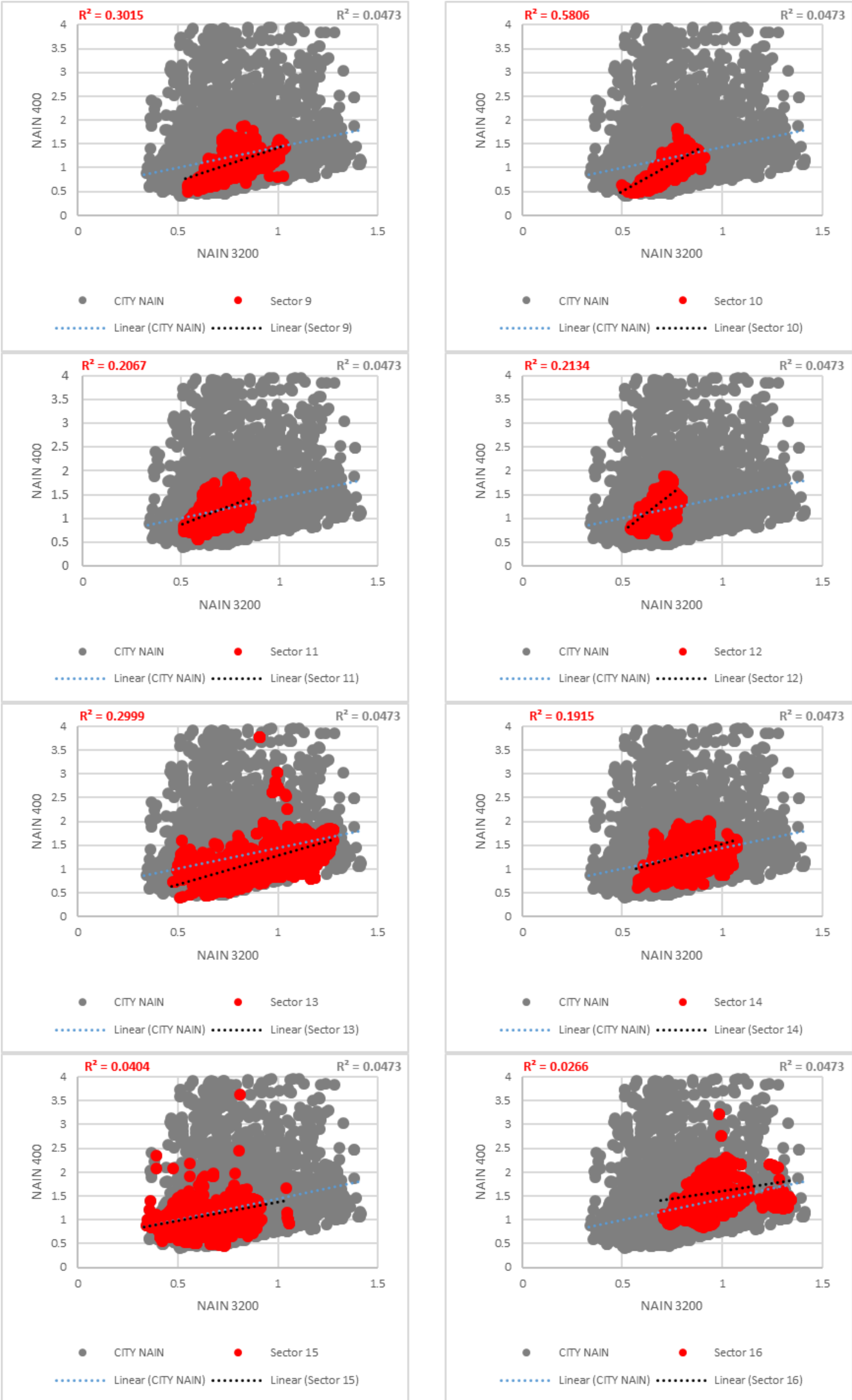

Fig. 4. 8. Intelligibility scatterplots of Biskra's urban system (Sector ID from 9 to 16)

4.6 Conclusion to this chapter

This analytical chapter yields several conclusive remarks:

From a macro perspective – on a global scale, the normalized angular choice map displays an organic and hierarchical network pattern occurring in several pertinent segments connecting the different parts of the city.

The integration map shows a no-edge effect, highlighted by the segregated nature near the borders. Thus, the most integrated districts of Biskra are present in the city center. Besides, it outlines relevant variations for the different sectors due to vital factors.

Generally, the central locations are naturally more frequent and reflect the most intense social co-presence.

Alternatively, we can further interpret these results by implementing an "aggregate map" before the space syntax measures' normalization. The latter combines the integration and choice values and provides an overview of current developments since it indicates both the level of integration of spaces and their relevance in assessing movement and occupancy.

Furthermore, the four-pointed star model shows that the examined urban pattern is considerably more significant in the background network structure than in the foreground. It shows how effectively a full-connectivity background network maintains a constant layout.

The model denotes as well the irregular grid shape. Except for the colonial urban fabric, Biskra City's foreground network comprises a predominant organic grid. These outcomes indicate some sociocultural priorities and moderate ease of accessibility.

From a micro perspective – on the local scale, highways ringed the city, the four bridges, and the principal boulevards, which indicate that vehicular movement can be displayed high choice values at the highest metric radii for the most scrutinized area.

Moreover, the value of small-radius choice measures of pedestrian movement remains identical throughout the entire system. Additionally, at 1600 and 2000 m radii, we may notice the appearance of the most preferential routes around the downtown, Eastern, and Western regions. Besides, local integration from low to high metric distances shows the progressive emergence of six distinguished areas, including Wadi Zone, Colonial fabric, Star Melouk, Dalaa & Dalia, El Alia, and Sidi Ghezal owing to the ease of accessibility, and the convergence of various social and economic activities.

Last but not least, the main correlations between higher and smaller radii (3200 m and 400 m) reveal an average value on the city scale. Therefore, some high values reached 0.8 for downtown zones and adjacent areas. This rate indicates highly integrated routes on a city scale. Conversely, the other peripheral districts reported lower correlations than the city's average.

Likewise, the intelligibility reported high correlation values for the wadi zone (2), downtown (5, 6, 7), and West Zone 1 (10). The scatterplots illustrate that the built environment in these areas is more orientable at varying degrees conversely to the city network.

In summary, engaging a range of techniques and visual graphs in the spatial analysis phase uncovered several insights regarding the city' s morphology, the significance of particular urban areas, and the ongoing interplay of movements and socio-economic activities.

The following chapter discusses the main findings of the experimental process and the sound profiling modeling to assess the acoustic environment of the entire city.

CHAPTER 5:

MODELING AND ASSESSMENT OF THE ACOUSTIC ENVIRONMENT IN BISKRA

Chapter 5: Modeling and Assessment of the Acoustic Environment in Biskra

5.1 Introduction

This chapter proceeds with the experimental results of acoustic data collection and the simulation procedure utilizing numerous deterministic and geospatial interpolation models. These models have proven their efficiency in dealing with acoustic data according to a large body of literature (Aumond et al., 2018; Can et al., 2014; De Mulder et al., 2018; Harman et al., 2016; Middya & Roy, 2021; Murphy, E., Rice, H.J. and Meskell, 2006; Oyedepo et al., 2019; Ozyurt, 2017; Taghizadeh et al., 2013).

Accordingly, Inverse Distance Weighting and Kriging models were compared and cross-validated within the observed dataset. This accuracy evaluation provides the optimal model that best represents the collected dataset and enables a thorough diagnosis based on the raster processing module "Zonal Analysis" implemented in QGIS. The output of this technique involves graphical representations illustrating the frequencies and distribution of these interpolated values.

Furthermore, we should mention that noise classes are generally associated with the nature of the urban sector or land use type (e.g., industrial, residential, rural). Thus, exploring these outcomes will be more relevant once clustering the ranges modeled by the assigned noise classes. Therefore, it enables a thorough assessment of the acoustic environment while highlighting the vulnerable areas affected by environmental noise.

5.2 Statistical Description of the Measured Data

The data collection involved 240 stations counting about 600 iterations each, yielding a set of 144,000 A-weighted sound pressure level values. Due to a large amount of data, we present in this part one single station, randomly, as an instance to display the sound fluctuation (see Fig. 5. 1).

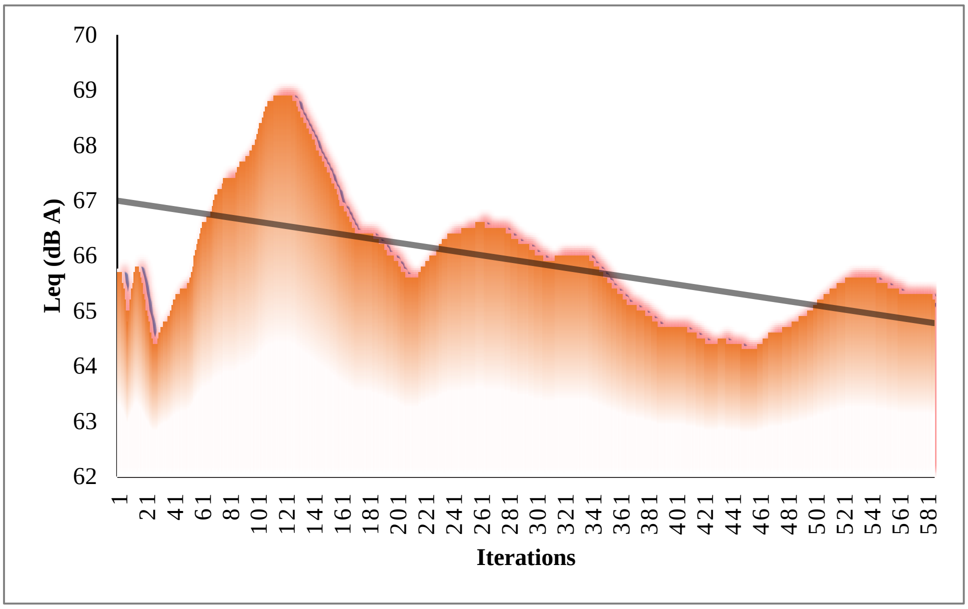

Fig. 5. 1. Sound level pressure fluctuation for a single station—Station G23 sample—

Thus, we should mention that only the mean values of every station are deemed for the acoustic profiling process.

Moreover, these sample points have been clustered by urban zones, and a box plot representation, showing means, medians, and percentiles, is used to describe the collected data, as depicted Fig. 5. 2. A brief overview of these graphs indicates the central distinctions among the sound fluctuations in the urban areas of Biskra.

Further details on the descriptive statistics of the measured stations figure in Table 2 Appendix A.

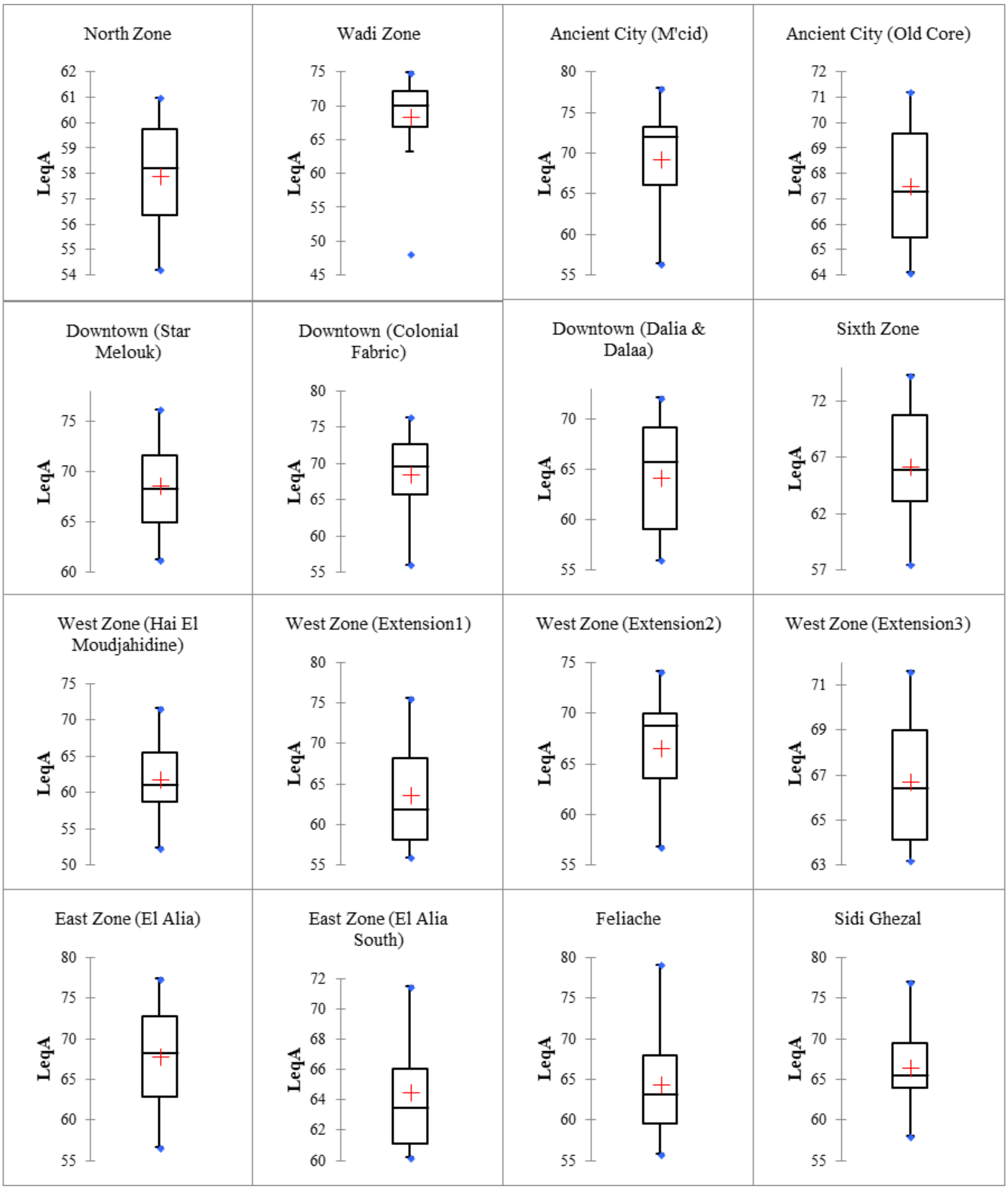

Fig. 5. 2. Box Plot summary of the collected acoustic data by urban zones

5.3 Acoustic Environment Profiling Using Spatial Interpolation Methods

The acoustic profiling has been performed on SAGA GIS software, testing several deterministic and geospatial interpolation methods. This process involves Invert Distance Weighting with different semivariogram functions (Gaussian, Exponential, and Quadratic function power 2) within two types of Kriging spatial interpolations (Ordinary and Universal) resampling by a B-spline interpolation.

The sound maps are illustrated in Fig. 5. 3, with a 50% transparency to visualize the extracted contours of the sample points.

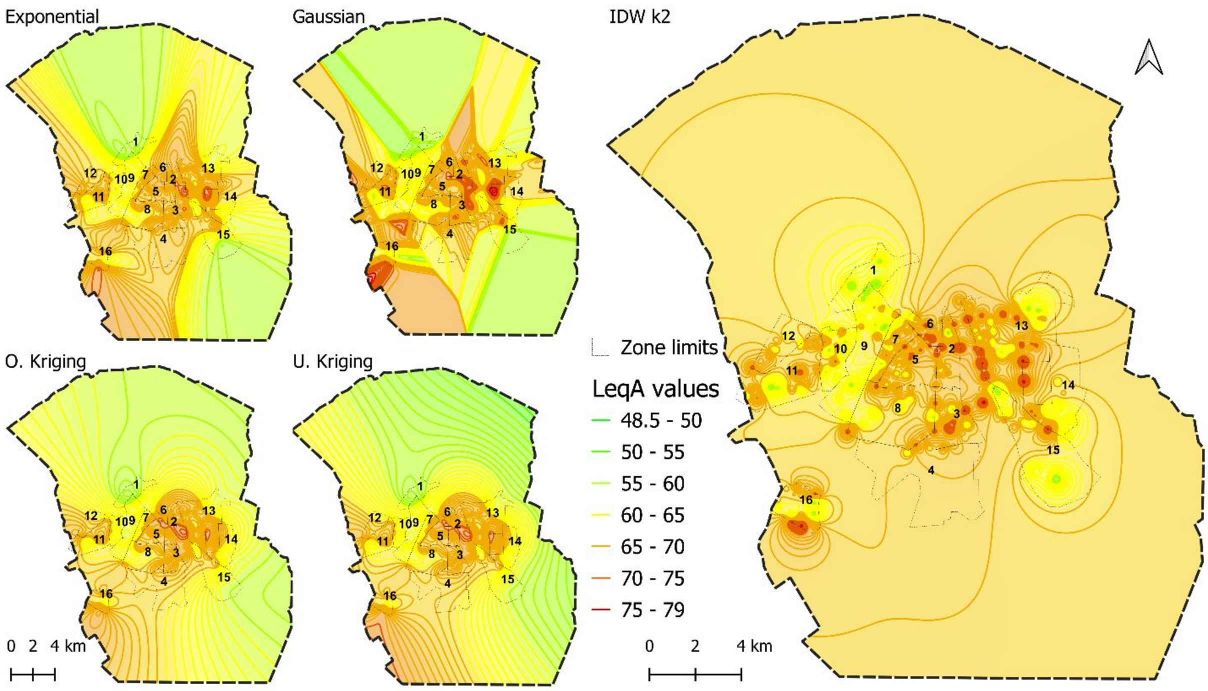

Fig. 5. 3. Visualization of interpolation models (50% transparency) with extracted contours and urban zones limits

The IDW Exponential and Gaussian maps display many predictive observations generated far beyond known values. Thus, it drastically reduces the data readability. However, for quadratic IDW, a more or less granular representation provides a snapshot of the measured data that is slightly streamlined. Meanwhile, both Kriging interpolations remain smooth, comprehensible, and homogeneous.

This preliminary assumption becomes validated and reliable when further diagnosis occurs through a cross-validation procedure.

Further details on the descriptive statistics of tested interpolation models are present in Table 1 Appendix B.

5.4 Accuracy Assessment of the Acoustic Mapping

Two performance indicators are commonly employed to assess the accuracy of these continuous-value estimation models: the mean absolute error (MAE) and the root mean square error (RMSE). The statistical interpretation assumes that the lower the value of these metrics, the better the model fits the collected data.

The following equations are used to calculate the MAE and the RMSE respectively:

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|y_i - v_i|$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - v_i)^2}$$

Where: y_i is the observed value, and

v_i is the predicted value.

The subsequent table depicts the descriptive statistics of the tested models, such as minimum and maximum values, the arithmetic mean, the standard deviation, and the standard deviation error of means (SEM), besides the accuracy performant measures of MAE and RMSE.

Table 5. 1: Statistic description of the interpolation model and Validation (Source: Benameur et al., 2022)

	IDW GAUSSIAN	IDW EXPONENTIAL	IDW k2	Ordinary Kriging	Universal Kriging
MIN - MAX	0 - 77.1	58.1 - 73.0	48.1 - 79.1	58.4 - 71.7	50.7 - 76.7
Arithmetic mean	63.8	64.0	66.2	63.2	62.9
St.D	4.717	3.363	1.007	3.295	5.308
SEM	0.1804843	0.3820647	0.2057886	0.1831411	0.1836344
MAE	3.2499	3.2401	0.0029	3.3425	3.3415
RMSE	4.1175	4.0661	0.0047	4.1607	4.1589

The cross-validation process demonstrates that the least scores for Mean Absolute Error (MAE) and Rooted Mean Square Error (RMSE) correspond to the Quadratic Inverse Distance Weighting (IDW k2). This finding argues the slight variation detected when comparing the minimum and maximum observed values (Benameur et al., 2022), which reveals the IDW k2 as the best theoretical semivariogram model.

Moreover, this former statement affirms the effectiveness of this empirical model in dealing with acoustic sample data and matches the evidence of the investigation established by Harman et al. (2016).

Besides, Fig. 5. 4 displays scattergrams of the observed and the modeled data. These plots target thoroughly to examine the performance and reliability of these datasets.

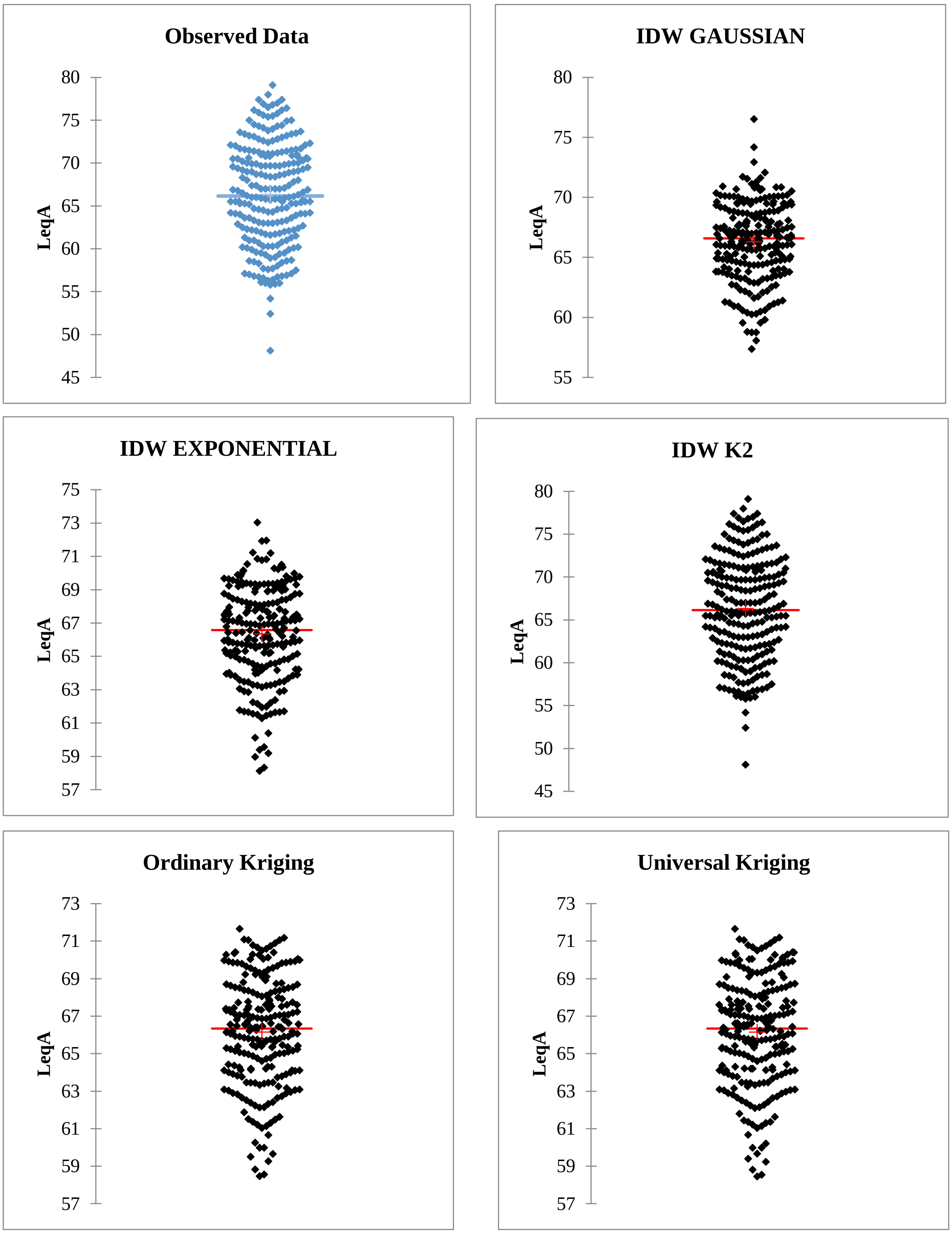

Fig. 5. 4. Scattergram of the observed and modeled data

From a statistical standpoint, the examined scattergrams demonstrate a high similarity between the observed data and the quadratic IDW. Likewise, they display a significant variation when compared to the other variograms.

The Gaussian and Exponential variograms' data spread reveals a considerable variation in mean values. Additionally, we noticed the appearance of some outliers around the maximum within new clustered observations around the minimum values. Furthermore, when we examine geospatial Kriging models, we find that both operated similarly. Nevertheless, the Universal Kriging is smoother and homogeneous compared to deterministic models due to its trend equation and the convergence of many proximate values.

5.5 Zonal Analysis of Biskra Urban Sectors

In this section, we are interested in exploring the distribution of the modeled acoustic variables. The main idea is to segment the dataset according to the urban zone boundaries. Then we generate the frequency distributions to perform a comparative analysis.

For this purpose, a zonal statistical analysis was achieved on QGIS using the Inverse Distance Weighted k2 model raster's output. Thus, various histogram plots were extracted (see Fig. 5. 5). For statistical analysis, the standard deviations may also be relevant. The closer the data cluster around the mean, the lower the standard deviation is. These graphs will provide a glimpse of data distribution, or indeed the mean value, mode, and standard deviation, as described in the following:

- Sector 1 ***(M=62.3, Mo=64.4, St.D=1.82)***: the global fluctuation range for the first urban sector ranges between 58 dB and 65 dB. As highlighted two major spikes at 950 and 850 occurrences equate to 61.7 dB and 63.5 dB, respectively.
- Sector 2 ***(M=68.1, Mo=67.8, St.D=2.51)***: two neighboring spike values were observed, with a high spike measuring 68.1 dB and an average one reporting 1800 occurrences.
- Sector 3 ***(M=67.8, Mo=67.0, St.D=2.13)***: recorded the highest number of occurrences in the whole sample under analysis, reaching 9000 for 65.4 dB. Along with a second average spike value of 4000 occurrences is seen for 65.6 dB.
- Sector 4 ***(M=66.8, Mo=67.0, St.D=0.51)***: multimodal distributions with several peaks displays for 2500, 3400, 5600, and 3800 occurrences, which correspond to a fluctuation range of 66.2–67.2 dB. Compared to the entire datasets, this sector has the lowest standard deviation value (0.51), which highlights the observed values centered around the mean (66.8 dB).

- Sector 5 ***(M=68.0, Mo=67.7, St.D=1.60)***: two prominent spikes identified at 3100 and 4200 occurrences corresponding to 67.1 dB and 67.7 dB, respectively.
- Sector 6 ***(M=68.7, Mo=69.6, St.D=2.63)***: one pronounced peak that comprises 1150 occurrences equivalent to 69.6 dB was observed.

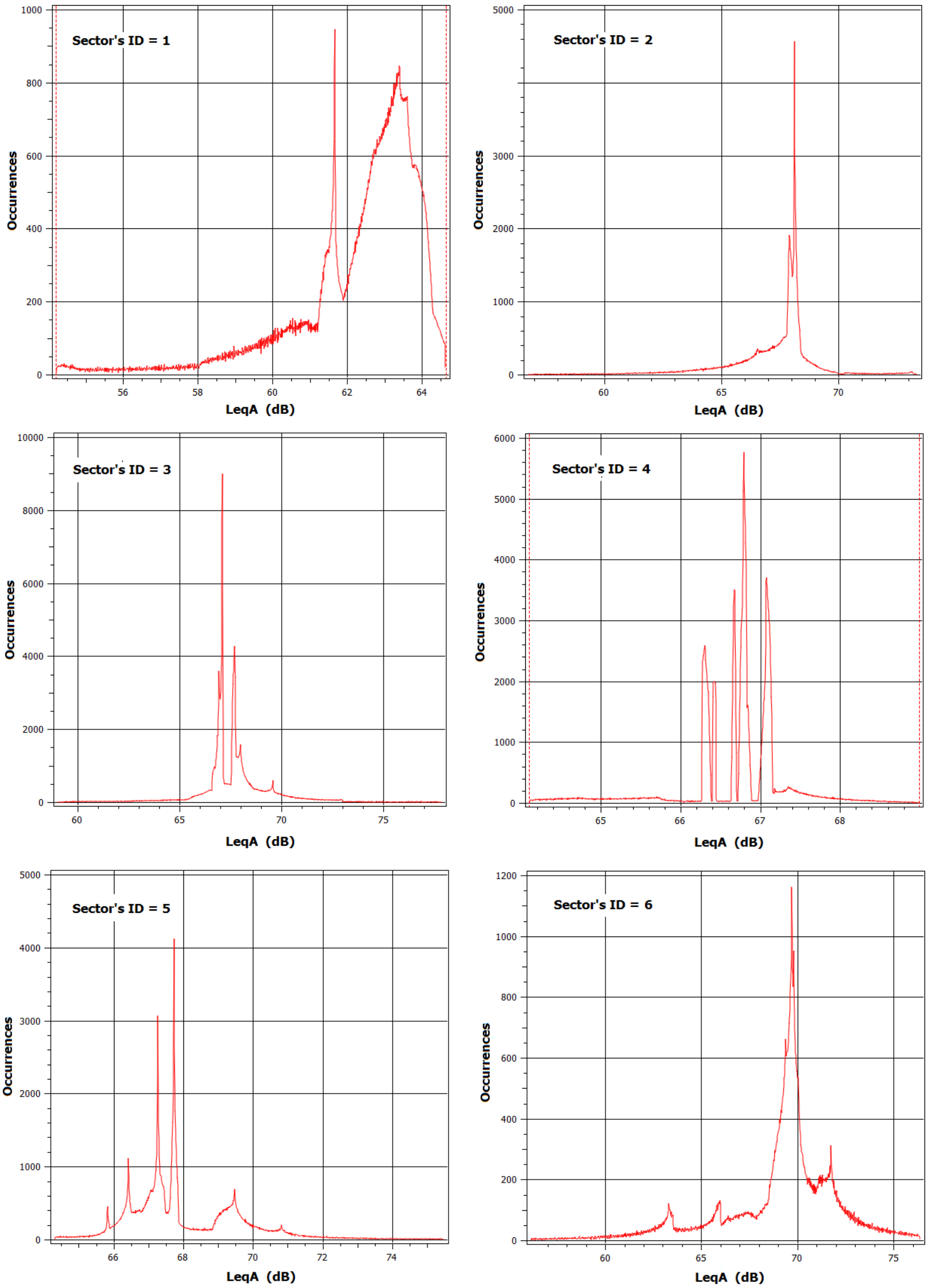

Fig. 5. 5. LeqA distribution for IDW k2 raster divided by urban zones (Sector's ID from 1 to 6) (Source: Benameur et al., 2022)

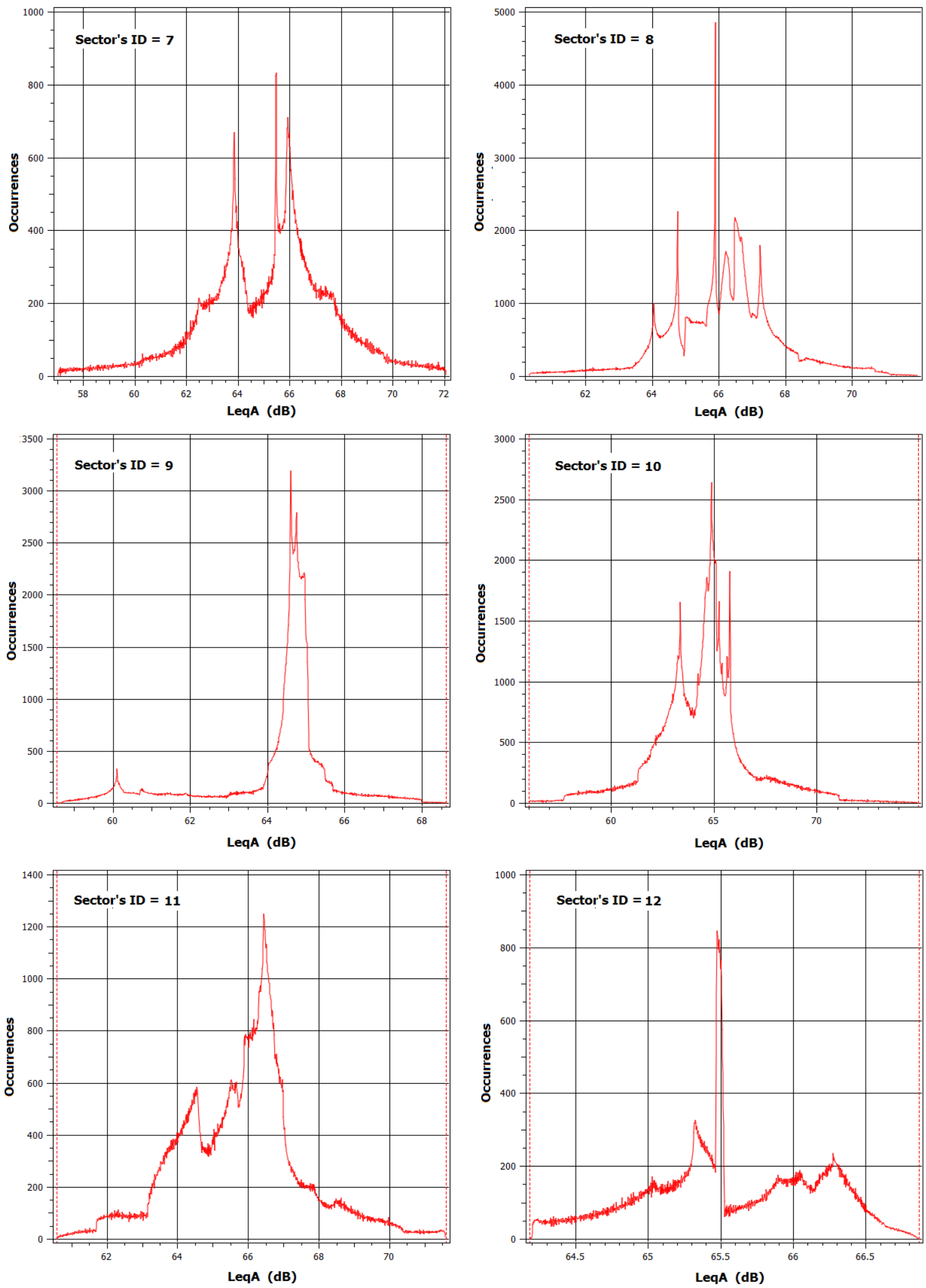

Fig. 5. 5. LeqA distribution for IDW k2 raster divided by urban zones (Sector's ID from 7 to 12) (Source: Benameur et al., 2022)

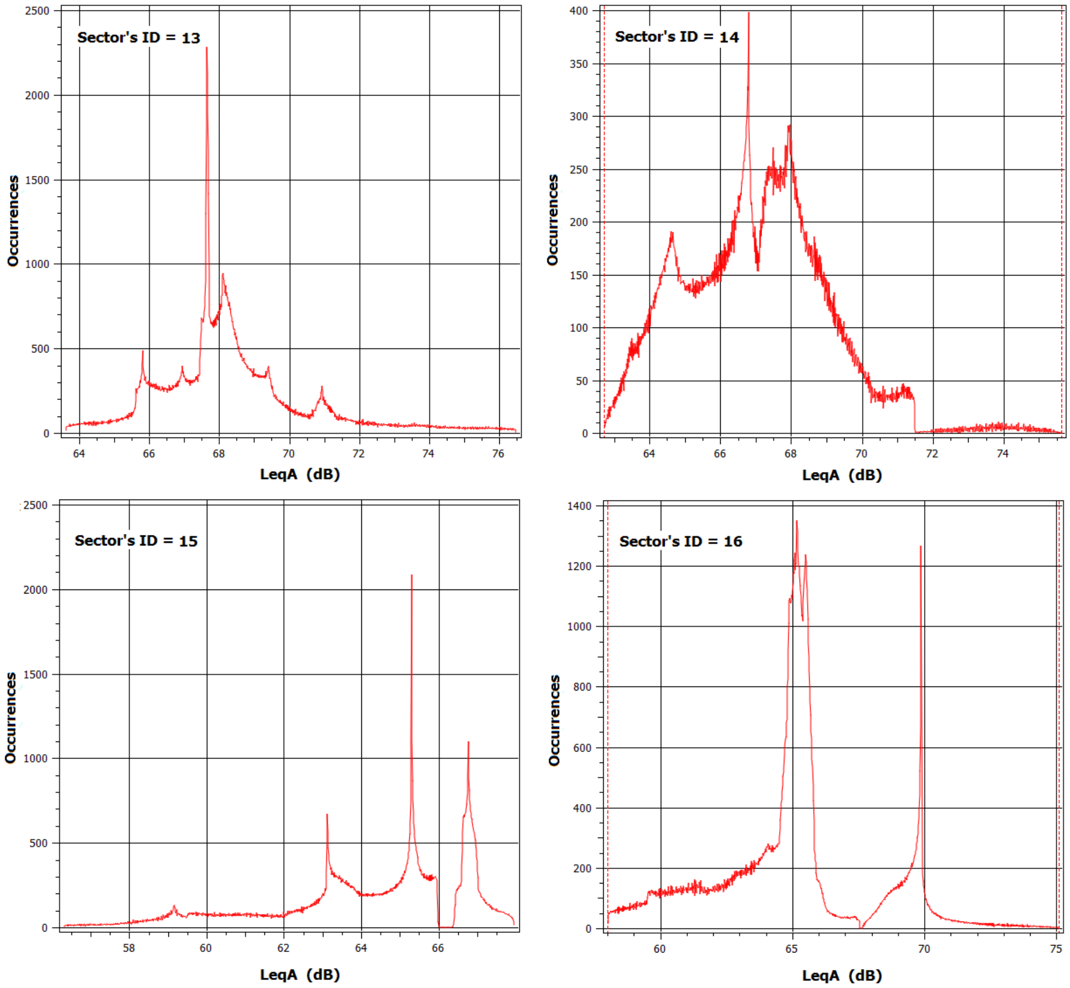

Fig. 5. 5. LeqA distribution for IDW k2 raster divided by urban zones (Sector's ID from 13 to 16) (Source: Benameur et al., 2022)

- Sector 7 ***(M=66.0, Mo=65.9, St.D=2.56)***: several spikes were seen at 650, 820, and 750 occurrences, which equate to 63.9, 64.3, and 65.9, respectively.
- Sector 8 ***(M=66.3, Mo=65.9, St.D=1.58)***: the data have a fairly symmetrical distribution, displaying many peaks at 1000, 2200, 4800, 1600, and 1800 over a range of 64–67.5 dB. Meanwhile, the prominent peak at 4800 occurrences corresponds to 65.9 dB.
- Sector 9 ***(M=63.7, Mo=64.5, St.D=1.81)***: one dominating spike was seen in about 2650 occurrences for 64.5 dB.
- Sector 10 ***(M=64.3, Mo=64.7, St.D=2.26)***: the data had a broadly symmetric distribution, and a dominant spike appeared at 2650 occurrences for 64.7 dB.
- Sector11 ***(M=66.0, Mo=65.9, St.D=2.03)***: displayed a mild spike at 600 with 64.4 and another dominant at 1250 around 66.5 dB.

- Sector 12 ***(M=66.1, Mo=65.5, St.D=1.10)***: identified a flat plot for occurrences not exceeding 200 from 64.5 dB to 66.5 dB, except for 65.5 dB which tends to be considerable, approaching 850 occurrences.
- Sector 13 ***(M=66.9, Mo=67.7, St.D=2.58)***: has a prevailing spike of 2300 for 67.7, an average peak of 950 for 68.2, and a minor peak of 500 for 65.8 dB.
- Sector14 ***(M=65.6, Mo=66.4, St.D=1.95)***: noted multiple peaks at 190, 400, and 290, which equate to 64.5, 66.8, and 68 dB, respectively.
- Sector15 ***(M=64.8, Mo=65.1, St.D=1.89)***: three spikes have been identified in this sector. Low-occurrence spike with 700 occurrences for 63, a dominant spike with 2100 occurrences for 65.2, and a third one noting a medium-occurrence spike with 1100 occurrences for 66.6 dB.
- Sector16 ***(M=65.9, Mo=65.6, St.D=3.00)***: has two dominating spikes, the second of which is significantly narrower, with 1350 and 1250 occurrences for 65.1 dB and 69.9 dB, respectively.

Globally, we have noticed that the distribution of the modeled values varies from one urban sector to another. The highest stacks of dots correspond to the most prevalent values. In other words, most values typically fall in this area, also known as the primary tendency. Furthermore, the width of the distributions mainly indicates the degree of variability. Thus, the overall shape of the values distribution show:

- Roughly symmetric distribution: (for sectors 7, 8, 9, 10, 12, and 14)
- Multimodal distribution: (for sectors 4 and 16)
- Left-skewed distribution: (for sectors 1, 2, 5, 11, and 15)
- Right-skewed distribution: (for sectors 3, 6, and 13)

The identified similarities revolve around the relationship between the wide range of frequencies and the interpolated values for each sector. We emphasize the maximum values of the graphing peaks, which aligns with the statistical Mode value. The outcomes demonstrate that the mode range varies from 64.4 to 69.6 dB. Note that most zones exceed a sound level of 65 decibels, indicating a potentially harmful effect on environmental context.

To further assess the latter, we should compare these findings to the World Health Organization's proposed threshold values regarding urban noise pollution and various regulatory frameworks involved in monitoring noise for different land use types.

5.6 Exploration of Monitored Data by Noise Classes

The urban annoyance issue preoccupies various entities in Europe, such as the World Health Organization noise guidelines (World Health Organization, 2018), the European National Directive (European Parliament and Council of the European Union, 2002), the environmental noise in the EEA reports (European Environment Agency, 2016).

Beyond the different policies that regulate and deal with environmental noise in the European region, this topic is indeed the subject of fierce debate in some developed countries.

Recently, Schwela (2021) reported a growing awareness among developing nations that unusually high noise levels can have short-term and long-term adverse effects on public health. As a response, countries like India, Iraq, and Mexico imposed new daytime and nighttime noise restrictions. Similarly, Costa Rica has reduced authorized sound pressure levels. For the African context, more specifically in Tanzania, the National Environment Management Council, approximately ten years ago, set allowed sound pressure limitations. Besides, the Egyptian Environmental Affairs Agency created a national strategy to control the noise incorporating 11 ministries. Currently, Kenya is also developing an environmental noise management plan.

For the Algerian context, it is necessary to bring out the failure of the local policy monitoring noise by setting a limit of 70 dB for residential districts since 1993.

In this circumstance, the implementation of international standards is essential. Knowing that are ongoing updates to the threshold values, which are continually being decreased and regularized in response to recent evidence on the undesirable effects that the issue of noise pollution has on inhabitants (Basner et al., 2015).

The table below shows the adopted policy for our case study based on the most broadly applied noise threshold for European and African nations.

Table 5. 2: The municipal territory divisions into acoustical classes (Source: D.P.C.M 14/11/97)

Noise classes	**Land use properties**	**Reference Time**	
		Day (6.00-22.00)	Night (22.00-6.00)
Class I	Particularly protected areas	**50**	**40**
Class II	Areas intended for predominantly residential use	**55**	**45**
Class III	Mixed type areas	**60**	**50**
Class IV	Areas of intense human activity	**65**	**55**
Class V	Mostly industrial areas	**70**	**60**
Class VI	Exclusively industrial areas	**<75**	**70**

Fig. 5. 6 depicts the monitored sound continuous level (LeqA) clustered by the urban zones of Biskra City, describing the noise classes attribution.

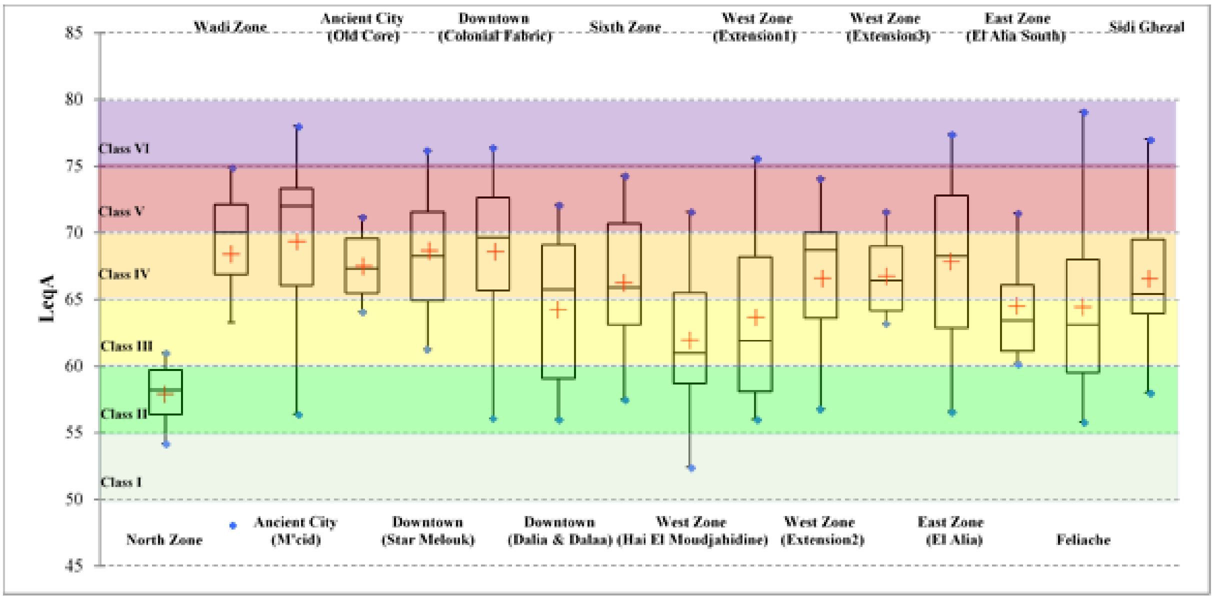

Fig. 5. 6. Boxplot of modeled data distribution by urban zones and noise classes.

The findings show that all lower whiskers fall in Class II, except for the north and west zone (Hai El Moudjahidine), which fall in class I.

An outlier data value for the Wadi Zone appears far from other data values; this single event took place next to a detached house on a dead-end quiet street.

The residential area of the North zone is restricted in Class II and distinguished as the quietest district of the scrutinized urban sample.

The West Zone's (Hai el Moudjahidine and extension 1), El Alia South, and Feliache's middle quartiles are all categorized as Class III, indicating that these areas have reported low to moderate noise levels.

Downtown (Dalia & Dalaa), West Zone (extension 2), and East Zone (El Alia) maintain a fairly tall box plot, showing that they have widely diverse values as a consequence of either a significant functional diversity. With a scoring rate of 65 dB to 70 dB, most urban sectors might occur high levels of intensive human activity.

The top quartile limits fall in class V for the Wadi zone, Ancient City (M'cid), Downtown (Star Melouk and Colonial Fabric), and the East zone (El Alia). Additionally, a few data points from the sixth zone roughly belong to the same category.

Most of the upper whiskers stretch over Class VI. They correspond to the monitoring stations in front of rapid highways, dense traffic networks, and dense activity centers.

5.7 Assessment of the Acoustical Environment in Biskra

To explore the data distribution through noise classes, these statistical data can be projected onto the network system via QGIS as shows Fig. 5. 7.

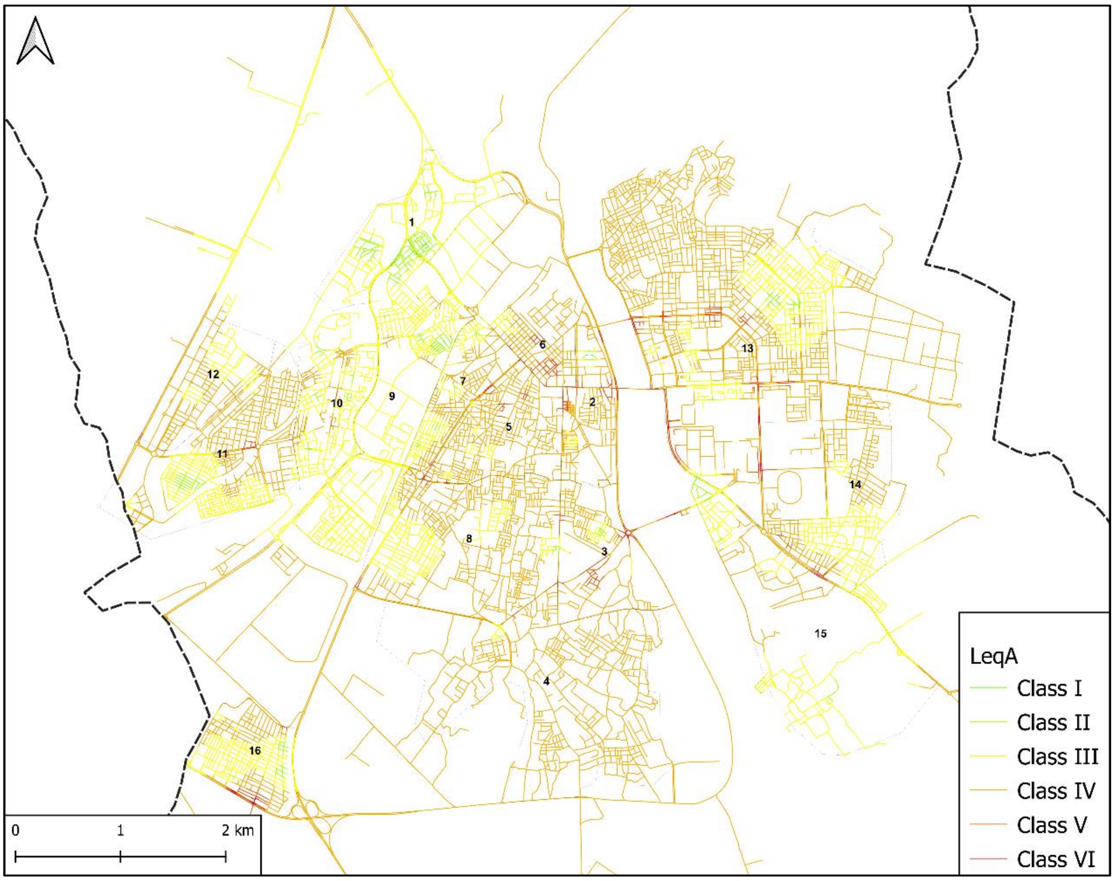

Fig. 5. 7. Exploration of noise classes by the road network system

Before examining the noise class distribution throughout the network, and in order to avoid any misleading interpretation, it is crucial to recall that the observations specified residential areas and excluded industrial and educational buildings. Accordingly, the outcomes reveal that most streets fall into class IV, reporting a very high percentage of 60.01%.

This rate signifies that the overall urban context is supposed to be an area of high-intensity human activities. Yet, Class III reported a relatively low percentage of 30.31%, alarming the noisy character of the analyzed sectors. Moreover, the second and fifth classes have a relatively small percentage representation. Nevertheless, those classes are supposed to be part of residential and industrial districts, respectively. Furthermore, the quietest and most noisy areas corresponding to extreme Classes, seem to be a minority.

The main proportions of noise class distribution are displayed in Table 5. 3.

Table 5. 3: Percent distribution of noise classes in Biskra City

Class I	Class II	Class III	Class IV	Class V	Class VI
0.11%	3.53%	30.31%	60.01%	5.63%	0.41%

As a general rule, the daily equivalent noise level Leq,day should not exceed 55 dB (A) for an acceptable noise burden in residential neighborhoods. In areas where Leq,day hits 65 dB (A), it is unauthorized to introduce new noise sources. Noise levels beyond 75 dB (A) require emergent measures to reduce the sound-pressure level (World Health Organization, 2018). Based on these thresholds, the following map is established (see Fig. 5. 8). It identifies the most urban areas susceptible to noise pollution.

Thus, the acoustic environment across Biskra is not detrimental. However, most urban areas, particularly those distinguished by a high intense residential and commercial activities, necessitate prompt treatment to address this issue. Therefore, setting manageable strategies is required, notably relocating commercial facilities away from residential areas and minimizing traffic noise. Given the area's desertic nature, planting trees and vegetative screens could be beneficial for reducing noise emissions, bearing in mind their nature and dimensions (Ow & Ghosh, 2017). Correspondingly, it is crucial to consider the physical characteristics of the materials used for asphalt and various acoustic insulates.

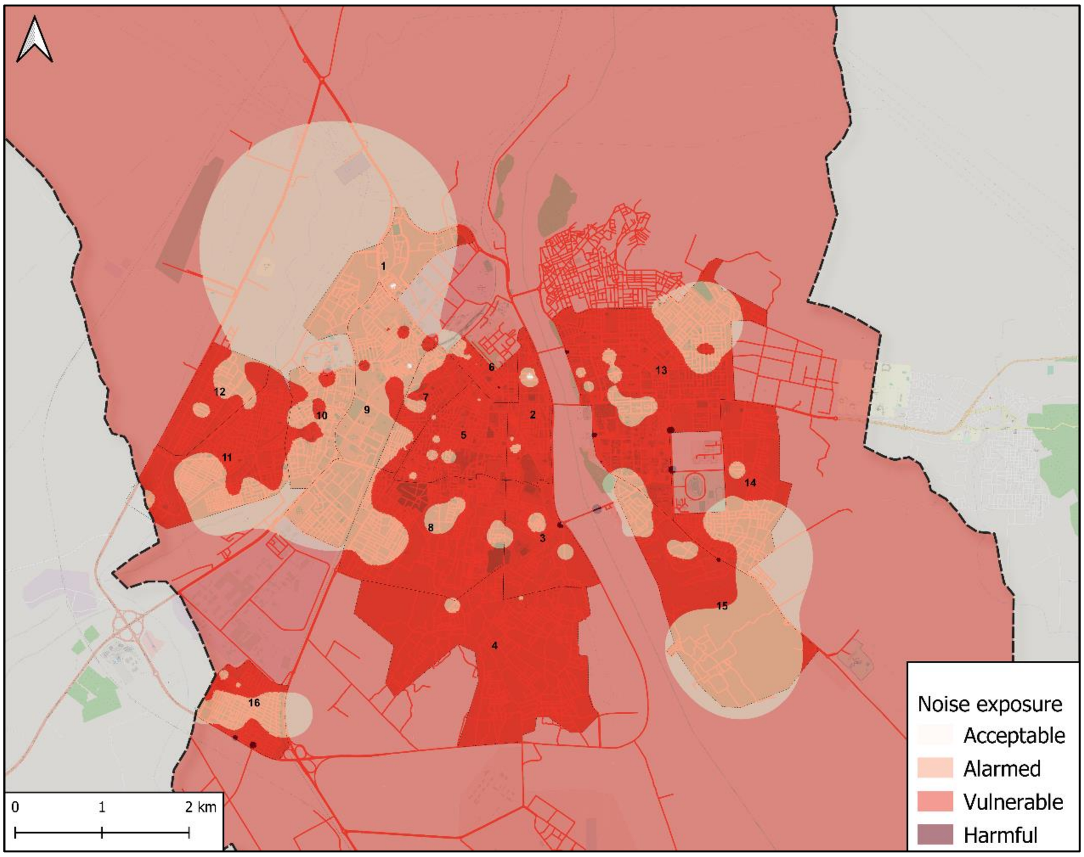

Fig. 5. 8. Noise exposure level in Biskra City districts

5.8 Conclusion to this chapter

The relevant conceived methodology operated for the acoustic assessment in this chapter provides, for the first time, a preliminary prototype noise mapping of an Algerian Saharan city. This strategy was initially feasible by implementing a broad series of measurements in various urban settings. The modeling process integrated Geographic Information System through deterministic and geospatial interpolation techniques via SAGA GIS software.

The findings demonstrated the effectiveness of the quadratic Inverse Distance Weighting k2 in modeling the acoustic environment over a wide area. Nevertheless, the visualization remained granular and only spots the nearest locations to measurement stations (adjacent radius). However, the Kriging models, namely the Universal model, enable a fluid and smooth representation, albeit with a significantly diverse variety.

These conclusions align with the bulk of investigations of acoustic analysis. Nevertheless, relatively few studies report the limited performance of spatial interpolation models, firstly due to their exclusive focus on sound measurements and secondly due to their inability to process a small number of monitoring stations.

The leading studies criticizing the performance of these interpolation models have recommended coupling these techniques to additional inputs. For instance, Xie et al. (2011) provided more sophisticated acoustic maps by carefully considering the realistic aspect and classifications of land use and suggested Land use regression models (LUR).

Besides, Aumond et al. (2018) introduced several parameters, such as the Euclidean distance and the road network distance weights between stations, to enhance the models' performance. The authors highlighted that incorporating the road distance can increase performance accuracy, particularly for ordinary Kriging. Conversely, Universal Kriging yielded satisfactory results due to the linear regression already included in the computing process. This research also outlined the importance of establishing a wide range of observations to obtain a more realistic interpolation.

Likewise, Middya & Roy (2021) attempted to generate dynamic and practical noise maps by optimizing the empirical formulas to improve the interpolation models based on IoT attributes.

Correspondingly, considering the unavailability of further complementary data, it was necessary to increase the number of our observations to ensure an optimal modeling.

Additionally, the QGIS software enables the exploration of the internal characteristics of each urban zone using the zonal analysis toolbox. The outcome of this step offers meaningful graphs that give an overview of the frequency and disparity of the simulated data.

For most urban sectors, the degree of variability of the primary tendencies reported a high range of values that varies from 64.4 to 69.6 dB and exceeds the permitted threshold value of 65 dB.

Meanwhile, adopting International Standards and regulations enables clustering these values into noise classes to better comprehend the city of Biskra's acoustic environment. The findings show that the residential area of the North zone and Hai el Moudjahidine represent the quietest district of the scrutinized urban sample.

The first extension west zone, El Alia South, and Feliache's middle quartiles are all categorized as Class III, indicating that these areas have reported moderate noise levels.

Downtown (Dalia & Dalaa), West Zone (extension 2), and East Zone (El Alia) display a noisy character within multifarious values as a consequence of significant functional diversity.

The highest noise values refer to the Wadi zone, Ancient City (M'cid), Downtown (Star Melouk and Colonial Fabric), and the East zone (El Alia). Likewise, several parts of the sixth zone roughly belong to class V.

Moreover, the general acoustic context of Biskra city reveals that 60.01% of the urban system falls within the fourth noise Class (Class IV) and exceeds 65 dB. Thus, 30.31% were classified as Class III, ranging from 60 to 65 dB. Consequently, this highlights a potentially vulnerable acoustic environment, particularly for areas close to the city center, El Alia, and the city's historic urban fabric. This statement revealed an alarming circumstance that requires a focused strategy that addresses this environmental concern.

Following the diagnosis of the urban layouts and the acoustic environment, the succeeding chapter will address the interrelationship between those distinct dimensions.

“We shape our buildings, thereafter they shape us.”

Winston Churchill.

CHAPTER 6:

ACOUSTIC PATTERNS AND SPATIAL CONFIGURATIONS

Chapter 6: Acoustic Patterns and Spatial Configurations

6.1 Introduction

The relationship between the soundscape and the urban configuration is generally addressed from various perspectives, incorporating different sound physical magnitudes on the one hand and urban metrics on the other.

Such correlation depends on the primary objectives of each investigation, the limitations of measurement instruments, mapping prototype accuracy, and data availability.

As already discussed, acoustic variables could be measured and simulated as it includes traffic data. Likewise, urban metrics include compactness, porosity, and fractal perimeter indices (Guedes et al., 2011; Salomons & Berghauser Pont, 2012; Silva et al., 2014), or syntactic measures (Dzhambov et al., 2014; Mohareb & Maassarani, 2019).

Similarly, our study examines the relationship between the syntactic measurements of the angular segment method and the equivalent continuous sound measurements. Thus, this chapter encompasses the correlation set of the results previously presented in chapters 4 and 5. This phase intends to determine the causality between these variables on both global and local scales.

Furthermore, the statistical processing employs SPSS and XLSTAT software to apply a bivariate Pearson correlation with explanatory matrices and principal component analysis (PCA).

The last section will further illustrate the relevance of this exploration process in various urban contexts by extending our application area to Italian cities such as Pisa, Florence, and Prato.

6.2 Exploration of Acoustic and Syntactic Measures on City Scale

The core correlation on the city scale encompasses all variables without considering the location of each urban sector.

Pearson correlations between combined space syntax metrics at a global and local scale reveal strong evidence against the null hypothesis. Thus, it indicates a high relationship between the tested data, within a significant p-values at 0.05 level, as illustrated in Table 6. 1.

Table 6. 1: Pearson correlations of level equivalent sound and combined syntactic measures overall Biskra City

	Pearson	**p-values**	**R^2**
LeqA/CombINCH	**0.582**	**<0.0001**	0.338
LeqA/CombINCHR3200	**0.490**	**<0.0001**	0.240
LeqA/CombINCHR2400	**0.496**	**<0.0001**	0.246
LeqA/CombINCHR2000	**0.503**	**<0.0001**	0.253
LeqA/CombINCHR1600	**0.496**	**<0.0001**	0.246
LeqA/CombINCHR1200	**0.476**	**<0.0001**	0.227
LeqA/CombINCHR800	**0.388**	**<0.0001**	0.151
LeqA/CombINCHR400	**0.212**	**0.001**	0.045

Values in bold are different from 0 with a significance level alpha=0.05

It's crucial to remember that these variables are indeed the product of integration and choice. Therefore, we noticed the said causal effect through Pearson's coefficient. In other words, for a given metric distance, integration or choice has a significant impact on the acoustic variable. The significance of each single value at 0.05 levels is indeed maintaining this equilibrium.

This assumption is also accurate at the local scale when comparing the various metric rays. Furthermore, based on Pearson and R squared indices, we may infer that the 2000 m radius displays the strongest linear relationship as it gathers a high movement flow within an intense activity throughout the City.

The correlation map displays internships using a color range from blue to red (cold-hot scale). A negative correlation equal to minus one is colored blue, and a positive one close to one appears in red. This graph identifies the relationship between all the variables involved (Fig. 6. 1). It demonstrates that all the correlations are positive within some differences for the r value. Besides, the correlation map highlights, once again, the high correspondence between the high and low metric radii.

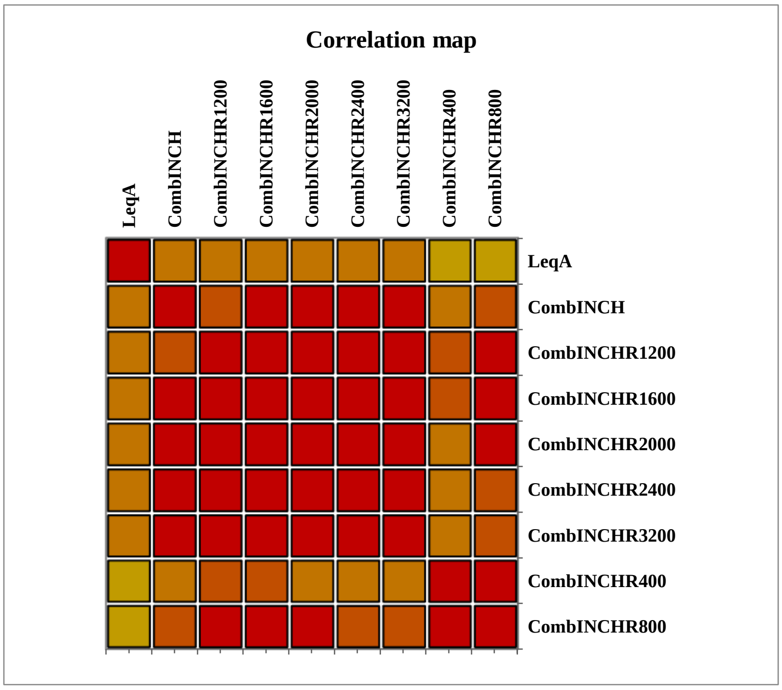

Fig. 6. 1. Correlation map of level equivalent sound and combined syntactic measures overall Biskra City

A separate examination of the two syntactic measures demonstrates a slightly high to moderate positive correlation. We should notice that the choice correlations decrease as a function of the metric distances from the largest to the smallest, except for 400 m, where the R-value is very low and yet significant (0.174).

For integration, the findings revealed a moderate positive correlation, except for the smallest radii of 400 m and 800 m, which yielded approximately a 0.3 value.

Nevertheless, the coefficient of determination (R^2) reported some low rates, which identify the weakness of the tested model. These results indicate that the relationship between spatial and acoustic parameters isn't causal.

In light of these statements, we may thus infer that the space syntax "to-movement" key has a considerable impact in describing the acoustic environment in Biskra.

Table 6. 2: Pearson correlations of level equivalent sound and syntactic measures overall Biskra City

	Pearson	p-values	R^2
LeqA/NACH	**0.622**	**< 0.0001**	0.387
LeqA/NACHR3200	**0.618**	**<0.0001**	0.381
LeqA/NACHR2400	**0.605**	**<0.0001**	0.366
LeqA/NACHR2000	**0.592**	**<0.0001**	0.350
LeqA/NACHR1600	**0.553**	**<0.0001**	0.306
LeqA/NACHR1200	**0.495**	**<0.0001**	0.245
LeqA/NACHR800	**0.401**	**< 0.0001**	0.161
LeqA/NACHR400	**0.174**	**0.007**	0.030
LeqA/NAIN	**0.412**	**<0.0001**	0.170
LeqA/NAINR3200	**0.501**	**< 0.0001**	0.251
LeqA/NAINR2400	**0.523**	**<0.0001**	0.274
LeqA / NAINR2000	**0.498**	**<0.0001**	0.248
LeqA/NAINR1600	**0.458**	**<0.0001**	0.210
LeqA/NAINR1200	**0.410**	**<0.0001**	0.168
LeqA/NAINR800	**0.356**	**<0.0001**	0.127
LeqA/NAINR400	**0.334**	**<0.0001**	0.112

Values in bold are different from 0 with a significance level alpha=0.05

The correspondence of the tested metric distances is highlighted in the following correlation map (Fig. 6. 2). Therefore, the global integration value isn't strongly correlated with the high metric radii, opposing to the global choice, which considerably impacts the other metrics.

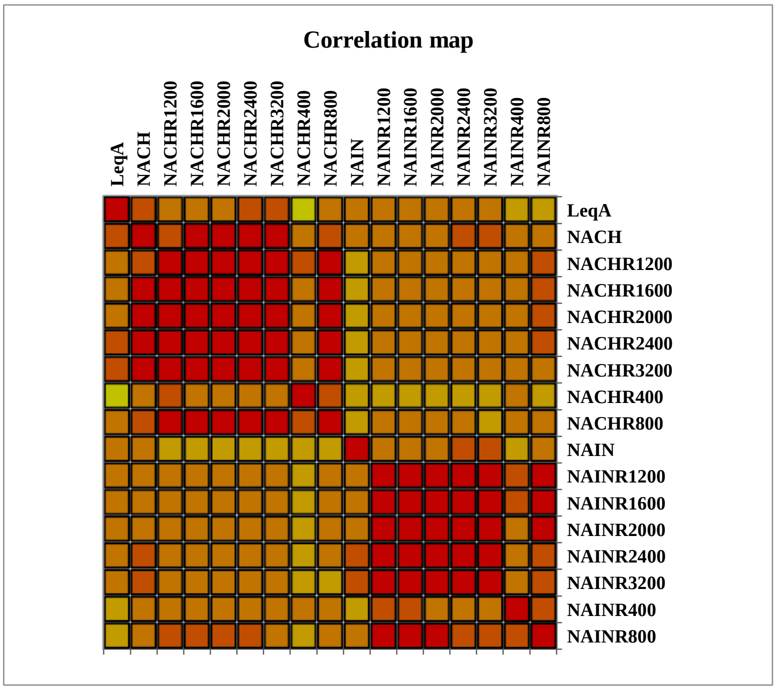

Fig. 6. 2. Correlation map of level equivalent sound and syntactic measures overall Biskra City

6.3 Exploration of Acoustic and Syntactic Measures on Neighborhood's Scale

At the neighborhood level, the correlation tests precisely assign the value of each measurement station to the syntactic measures of the corresponding segment.

For the combined values of choice and integration, we have noticed for the radius n that ten regions out of sixteen have moderate to very potent positive correlations. Correspondingly, the R-value exceeds 0.7 for the cases of the Wadi zone, the first western extension, and Sidi Ghezal. While for the metric distances, we notice a variability that requires case-by-case handling.

In this regard, we can identify three key observations:

- Six areas close to the city center are highly correlated to small and large radii, such as the wadi area, star Melouk, colonial fabric, the western zone, and its first extension.
- Four peripherical areas only correspond to the large radii, namely M'cid region, the sixth area, El Alia and Sidi Ghezal. Hence, Feliache zone is associated with the medium radii 800 m, 1200 m, and 1600 m, conversely to the highest radius that shows no significance.
- Five discarded areas have reported non-significant correlation values, as is the case for the northern area, the old core, the second and third western extension, and the southern part of El Alia.

Table 6. 3: Pearson correlations of level equivalent sound and combined syntactic measures clustered by urban sectors

		Combined Choice and Integration							
ID	**Urban Zones**	**n**	**R400**	**R800**	**R1200**	**R1600**	**R2000**	**R2400**	**R3200**
1	*North Zone*	0.053	-0.192	-0.145	-0.390	-0.534	-0.536	-0.623	-0.507
2	*Wadi Zone*	.727**	0.448	.608**	.660**	.697**	.722**	.733**	.721**
3	*Ancient City (M'cid)*	.656*	0.106	0.535	0.565	.615*	.656*	.668*	.684*
4	*Ancient City (Old Core)*	0.714	0.528	0.634	0.783	0.726	0.692	0.741	0.767
5	*Downtown (Star Melouk)*	.571**	0.219	.434*	.546**	.561**	.602**	.614**	.627**
6	*Downtown (Colonial Fabric)*	.501*	.469*	.541*	.582**	.574**	.568**	.549*	.541*
7	*Downtown (Dalia & Dalaa)*	0.418	0.194	.654*	.670**	.650*	.655*	.689**	.609*
8	*Sixth Zone*	.558*	-0.083	0.296	0.499	0.508	.554*	.615*	.624*
9	*West Zone*	.601**	.559**	.618**	.639**	.609**	.613**	.640**	.688**
10	*West Zone 1*	.749**	.660**	.784**	.826**	.840**	.822**	.782**	.787**
11	*West Zone 2*	0.552	-0.016	0.416	0.533	0.479	0.514	0.517	0.492
12	*West Zone 3*	0.514	-0.310	-0.574	-0.546	-0.484	-0.457	-0.472	-0.552
13	*East Zone (El Alia)*	.596**	-0.218	-0.183	-0.005	0.200	.342*	.417*	.492**
14	*East Zone (El Alia South)*	0.147	0.072	-0.391	-0.195	0.130	0.443	0.548	0.462
15	*Feliache*	.686**	-0.192	.620*	.784**	.733**	.627*	0.486	0.410
16	*Sidi Ghezal*	.874**	-0.107	0.349	.695**	.722**	.788**	.842**	.738**

****. Correlation is significant at the 0.01 level (2-tailed) (Red).**

***. Correlation is significant at the 0.05 level (2-tailed) (Yellow).**

Furthermore, an exploratory statistical analysis has been performed for the overall variables and observation through Principle Component Analysis (PCA) using the XLSTAT plugin (v.21) on excel (see Fig. 6. 3).

The loading factor of the two selected principal component axes represents 71.41% of the total data variance. The horizontal axe F1(64.58%) comprises the main highly correlated factors; hence, the vertical axe F3(6.83%) represents low integration metric radii (800 m and 400 m).

The Biplot representation provides an insightful exploration. Firstly, the variables' position on the positive quarter of the circle, related to the horizontal axe, indicates the positive significance between all the variables. Thus, the small angles between the variables and the main factor demonstrate potential significance among them.

Accordingly, the fairly closed angle (from the origin) formed by the Leq and NACH points indicates that these two variables are well correlated. Conversely, the almost right angle formed by Leq and NACH R400 signifies the independence of these two variables. The fact that the NACH R1600 is close to axis 1 implies its strong representation by this axis. As it is widely distant from axis 3, we may conclude its misrepresentation. Broadly, the distance between the Leq and syntactic variables provides an overview of the correspondence degree.

Secondly, the observations are clustered and colored according to the urban zones. Besides, the centroids of each group are yellow colored. Likewise, the proximity of each centroid to the horizontal axis denotes a perfect data display.

Based on the observations findings and their centroids, we notice the clustering of several areas, implying similar spatial and acoustic characteristics, e.g. (Zones 2, 6, and 13) (Zone 3 and 4) (Zones 5,7, and 8) (Zones 9,10, 11, and 15), in addition to the remoteness and isolation of the north zone.

These clustered groups match the conclusions previously drawn for the spatial analysis. Thus, we may conclude that the acoustic variable slightly affected the spatial variables.

It is noteworthy that the PCA depiction of the circle and its variables is on an arbitrary scale, implying that the proximity of the variable points to individual observations is meaningless.

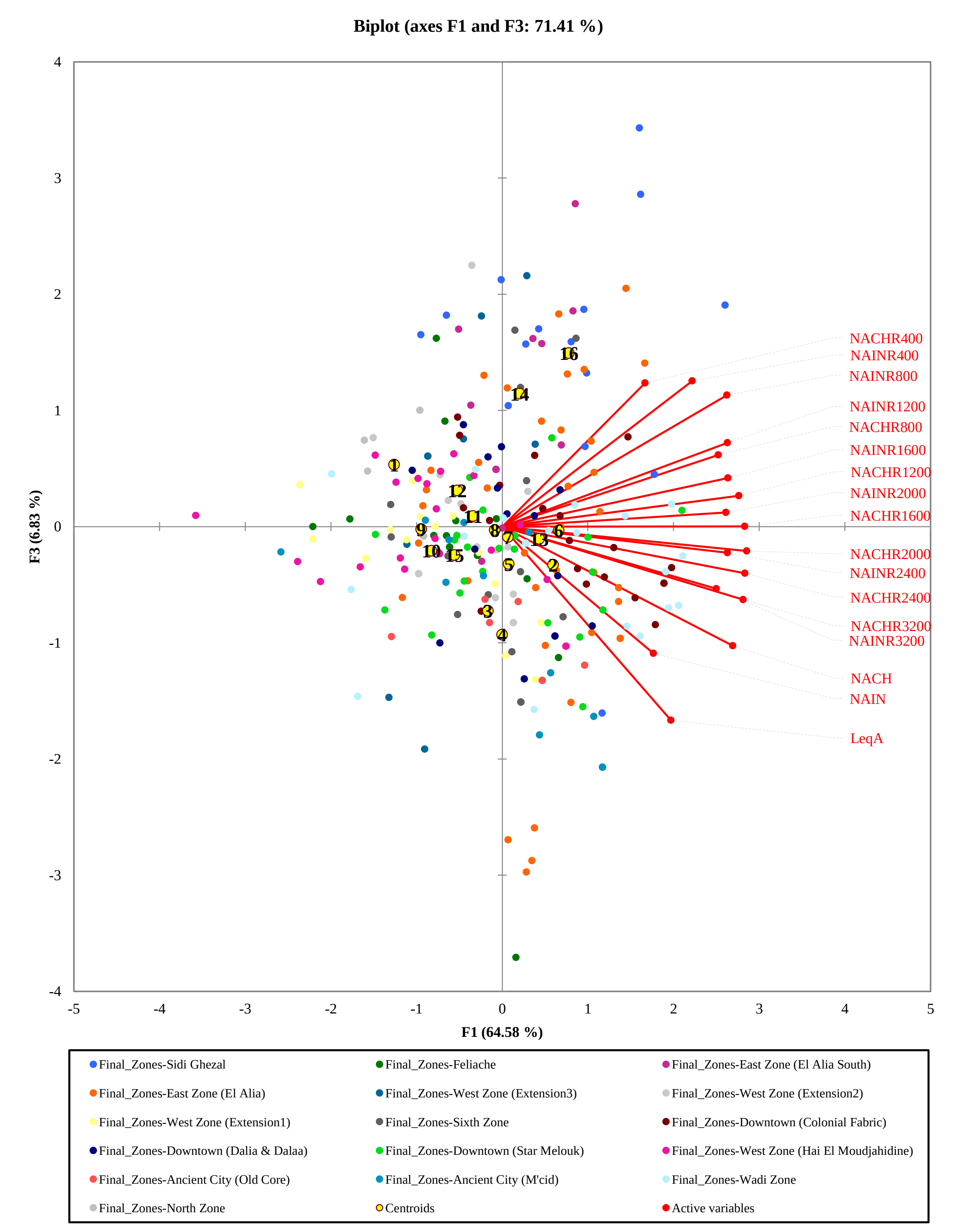

Fig. 6. 3. Biplot showing acoustic and syntactic metrics variables on local scale, observations and urban zones centroids

Generally, the PCA is an exploratory statistical tool and does not test hypotheses. To further examine these acoustic and syntactic variables, a Pearson correlation is required, as shown in the table below:

Table 6. 4: Pearson correlations between global and local measures—Integration and Choice—and level Sound equivalent sound of urban sectors (Source: Benameur et al., 2022)

ID	NACH n	NACH R400	NACH R800	NACH R1200	NACH R1600	NACH R2000	NACH R2400	NACH R3200	NAIN n	NAIN R400	NAIN R800	NAIN R1200	NAIN R1600	NAIN R2000	NAIN R2400	NAIN R3200
1	0.628	0.376	0.183	0.122	0.133	0.202	0.312	0.446	-0.447	-0.312	-0.388	-0.483	-0.605	-0.704	-0.741	-0.881
2	.724**	.560*	.720**	.739**	.752**	.756**	.748**	.738**	.749**	.689**	.722**	.722**	.760**	.756**	.733**	.700**
3	.680*	0.500	.649*	.642*	.687*	.729*	.726*	.723*	.671*	0.562	0.557	.617*	.689*	.750**	.752**	.691*
4	0.537	0.364	0.487	0.496	0.500	0.485	0.503	0.541	.875*	.815*	0.810	.873*	.852*	.857*	.853*	.872*
5	.522*	0.395	.461*	.497*	.496*	.524*	.523*	.553**	.646**	0.420	.544**	.674**	.637**	.718**	.632**	.675**
6	.470*	.454*	0.348	0.368	0.398	0.408	0.411	0.429	.606**	.528*	.491*	.639**	.623**	.596**	.555*	.602**
7	0.328	-0.072	0.355	0.400	0.424	0.425	0.446	0.406	.649*	0.263	.586*	0.527	.548*	.656*	.717**	.602*
8	0.490	-0.223	0.151	0.193	0.263	0.323	0.346	0.373	.561*	-0.318	0.135	0.508	.756**	.808**	.714**	0.506
9	.487*	.507*	.456*	.504*	.532*	.557**	.561**	.556**	.596**	.472*	.602**	.593**	.623**	.623**	.614**	.604**
10	.759**	0.446	.680**	.751**	.776**	.799**	.794**	.782**	0.510	.666**	.757**	.742**	.776**	.745**	.704**	.644**
11	.565*	-0.075	0.403	0.547	.566*	.581*	.595*	.587*	0.385	-0.314	0.375	0.427	0.046	-0.095	0.110	0.293
12	0.461	-0.322	-0.366	-0.231	0.050	0.203	0.285	0.317	0.382	-0.343	-0.394	-0.419	-0.182	0.123	0.361	0.614
13	.663**	-0.179	0.061	0.231	.417*	.536**	.593**	.629**	.370*	0.222	-0.062	-0.044	0.049	0.151	0.281	0.295
14	0.117	0.146	-0.007	-0.004	0.069	-0.039	-0.170	-0.095	0.180	0.032	**-.713***	**-.658***	-0.257	-0.006	-0.234	-0.151
15	.719**	-0.514	0.376	.659*	.694**	.742**	.752**	.705**	0.476	0.550	0.476	.642*	.686**	.724**	.653*	0.548
16	.889**	0.303	.523*	.690**	.777**	.809**	.818**	.843**	.755**	0.204	0.326	.550*	.607*	.559*	.622*	.616*

****. Correlation is significant at the 0.01 level (2-tailed) (Red).**

***. Correlation is significant at the 0.05 level (2-tailed) (Yellow).**

For the global radius n, the outcomes show a moderate to high positive correlation for the whole urban system, except for the quiet north region, which reported a nonsignificant inverse relationship.

Moreover, for the northern zone, the table shows some moderate to low nonsignificant correlations for NACH at all metric distances due to the closeness of the national highway.

Similarly, it reported a low negative correlation for integration values, given its segregated nature and the low acoustic recorded acoustic values.

Strong direct correlations are present for the Wadi zone (Zone 2) within all metric distances for integration and choice. This finding reflects the diversity of building types (individual and collective), the occurrence of socio-economic activities, and the intensity of vehicular and pedestrian movements. Therefore, this specific district illustrates the leading evidence of the relationship between the soundscape variation and the urban mix (see Fig. 6. 4).

Another pertinent specimen concerns the ancient old core distinguished by a hierarchical streets network, a compact housing character, and functions diversity. This historic area showed a very high correspondence on the local scale, specifically for the integration's small and large distances, illustrating the highest values in our sample, attaining 0.875.

It implies relying strictly on the integration values to predict the acoustic environment of the old town.

Around the city center, Star Melouk reported moderate positive correlations for the NACH measures due to the presence of a vital avenue—Zaatcha Avenue—. For integration, it shows a strong direct relationship with the acoustic variable owing to the concentration of residential, commercial, and administrative activities. Moreover, this zone could be spatially associated with the seventh zone of Dalia and Dalaa, as displayed earlier in the PCA map, for their proximity to the low-radius NAIN measures, implying significant pedestrian movement.

Additionally, the colonial fabric shows a strong positive correlation with NAIN values at all metric radii, along with a relevant correspondence with the pedestrian movement at 400 m, despite its regular grid.

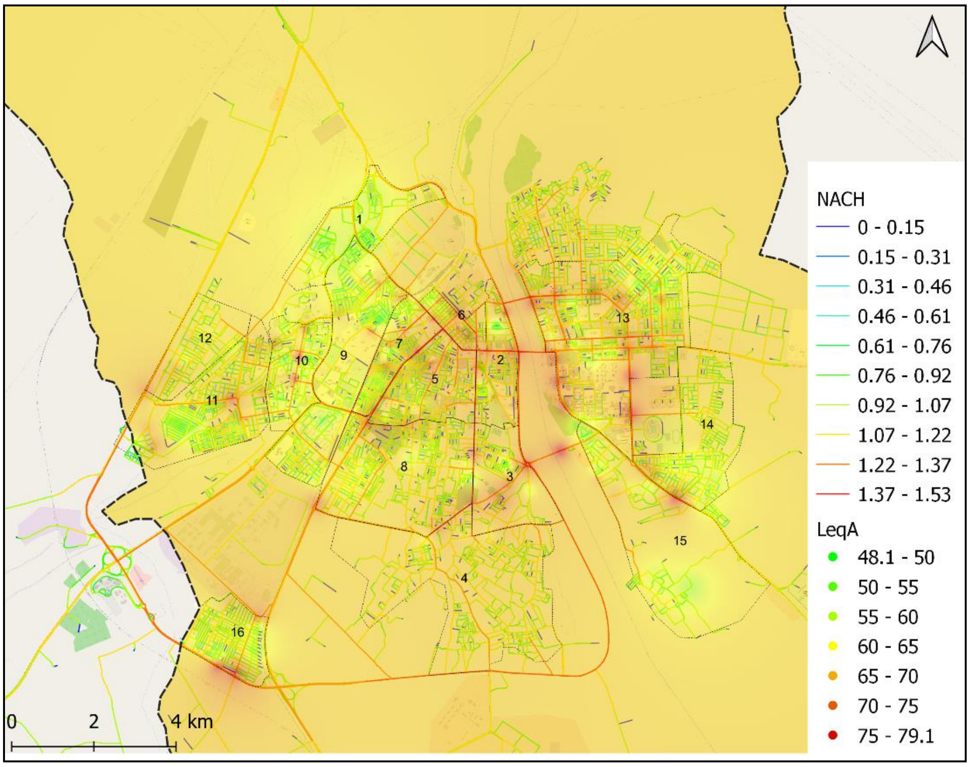

Fig. 6. 4. Visualization of the NACH radius n values with the IDW Power 2

The sixth zone (Zone 8) is a residential zone characterized by buildings with a high compactness ratio. The analyzed network is the product of an unplanned allotment process, leading to the emergence of anarchic pathways. Consequently, it clarifies the insignificant correlations displayed within choice measures. Likewise, this area stands a large market known as "Souk el Boukhari" for vegetable and women's clothing sales. The latter may explain the integration correlating values that exceed 80% at the 1600m, 2000m, and 2400m radii.

According to Pearson correlations and the PCA, the western region can be clustered and paired as: (9 and 10), (11 and 12). The first pair displays moderate to high positive correlation for all metric radii for integration and choice. Hence, the first extension performs slightly higher owing to the movement potential and the spatial pattern of the dominant collective buildings' type.

Meanwhile, the second pair represents a segregated area of residential land use. The resulting moderately significant correlation refers to the vehicular movement at the highest NACH distances exclusively for the nearest zone to the city "Extension 2".

In addition, the two eastern urban areas of el Alia showed contrasting results. El Alia district (zone 13) represents an overpopulated extensive area distinguished by a considerable residential density. That reflects the accumulation of several collective residential sites, such as (300 lodgings, 400 lodgings, the university campus), or even several individual housing neighborhoods, in the image of the "17 cooperatives district". Moreover, it includes a whole administrative district. Consequently, the results highlight some high correlations for choice high metric radii, owing to the magnitude of the streets connecting the different enclosures of the urban sector.

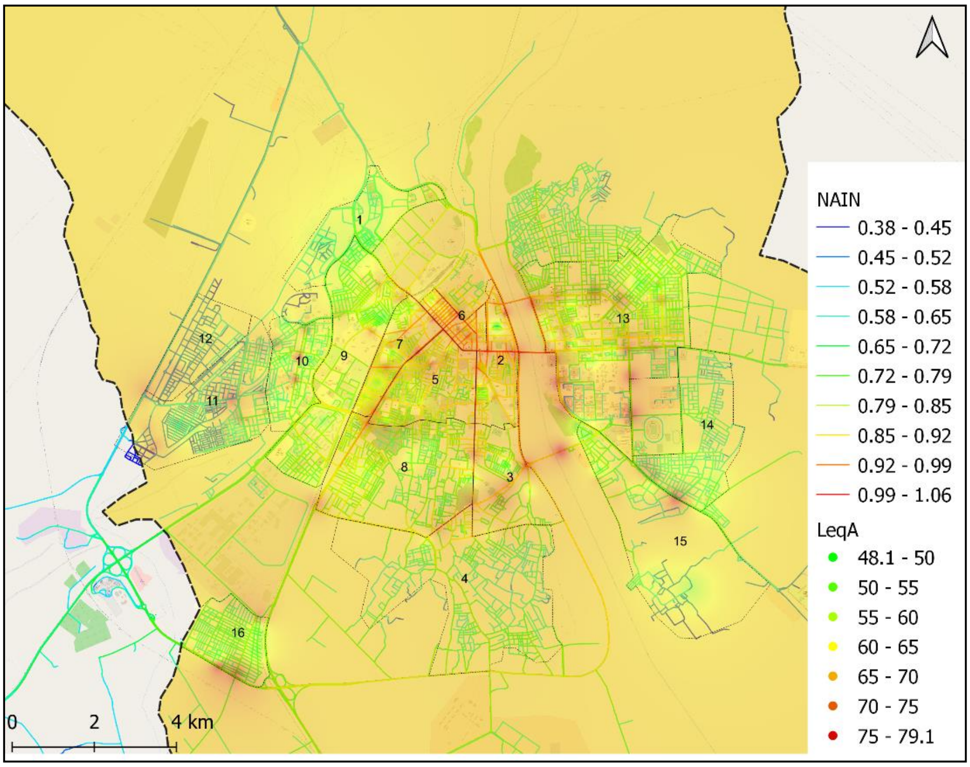

Fig. 6. 5. Visualization of the NAIN radius n values with the IDW Power 2

The southern part of the 14th zone represents a recently urbanized residential area, and the northern part (behind the city's Olympic Stadium) constitutes an open construction site, a fact noticed during the data collection process (see Fig. 6. 5). The desegregated nature of this area, and noise observations, would explain the resulting strong inverse correlations at local radii 800 m and 1200 m.

Feliache is a residential area connected to the national road leading to the "*Sidi-Okba Municipality*" which remains the principal noise source. Thus, it's evidenced by the high Pearson's value of 0.752 at a 2400 m radius, with a significant p-value at 0.01 level.

As previously mentioned, Sidi Ghezal is an isolated and autonomous area discarded from the city's urban network. However, it illustrates easy accessibility, considering its proximity to highways, with a thoroughfare stretching from the mosque to a central square hosting a local marketplace. Thus, it displays highly positive correlations that exceed 0.8 at all choice and integration radii.

In general, the results of this research have shown that the noise environment is intricately related to the spatial parameter of space syntax. However, a thorough analysis is required to comprehend the distinct variations that may emerge at the local scale of each neighborhood.

6.4 Correlation of Acoustic and Spatial Measures at 90°-100° Deciles

The Angular Segment Analysis depicts an aggregated urban fabric. It is feasible to identify the city's local core and get a sense of where local and global road circulation networks converge. These would be pertinent when Normalized Angular Integration (NAIN) values are limited to their highest ten percent values—90° and 100° deciles—which reflect the city's central core or the locations with the loftiest accessibility (Fig. 6. 6. B). Likewise, applying this rule for Normalized Angular Choice (NACH) displays the internal hierarchies of preferred paths inside the system (Fig. 6. 6. A).

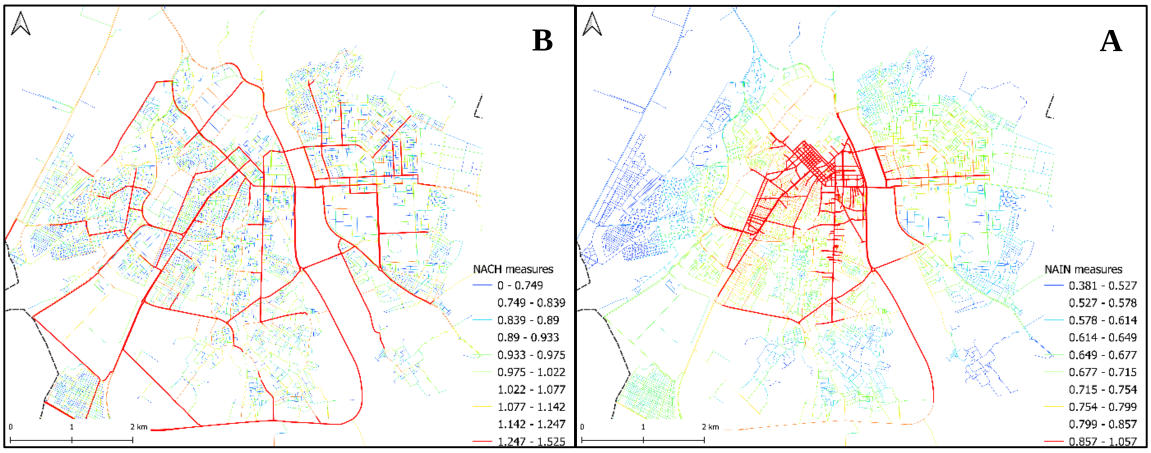

Fig. 6. 6. Highest Normalized Angular Integration (NAIN) and Normalized Angular Choice (NACH) values—90° and 100° deciles

Accordingly, these highest measures are mapped onto noise classes to demonstrate the impact of movement potentials on the identified noise levels (Fig. 6. 7).

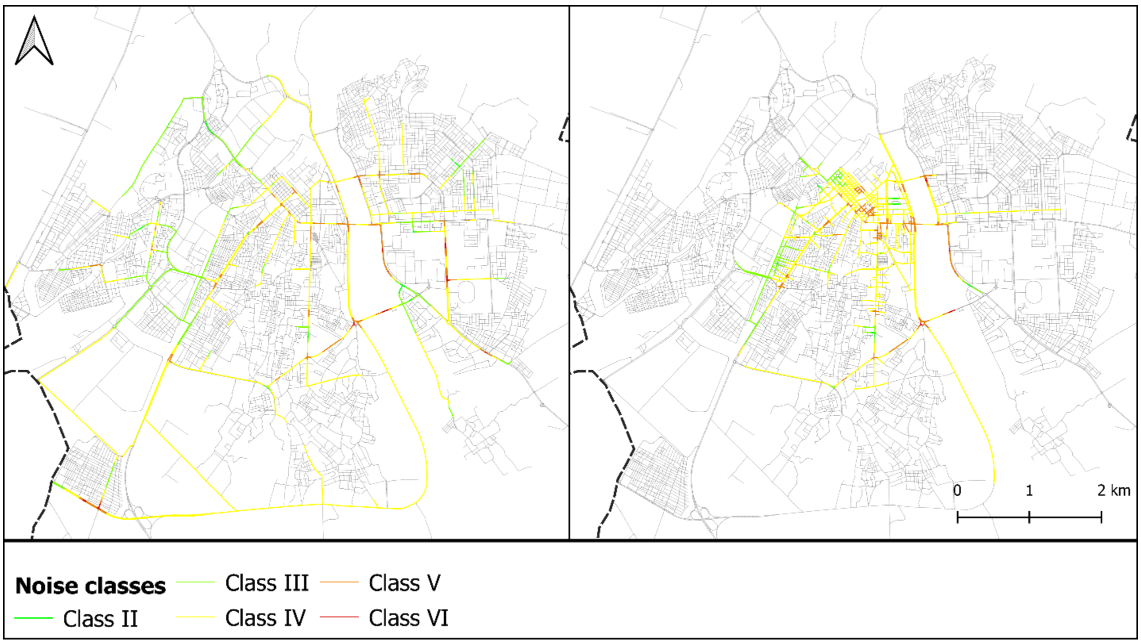

Fig. 6. 7. Visualization of noise classes according to global (NACH) and (NAIN) values—90° and 100° deciles

The correlations revealed a significant direct relationship between movement patterns and noise levels. Noting approximately 52.68% of the most popular preferred routes (NACH) and 60.49% of road segments exhibiting the highest NAIN values (integrated kernels) corresponding to Class IV (see Fig. 6. 8).

However, only 22.81% of the highest Choice values belong to class III, intending for residential areas. It is also crucial to emphasize that classes V and VI are designated for industrial regions. Although the results reported 22.92% and 20.16% for NAIN and NACH, respectively, belong to class V, despite the lack of industrial infrastructure in the Biskra city center. It further confirms the noisy character trait of the town center and the surrounding area.

Besides, the first class shows no existing values, due to the aggregation of the network system at this scale, on the one hand, and the high acoustic measures occurred on the other.

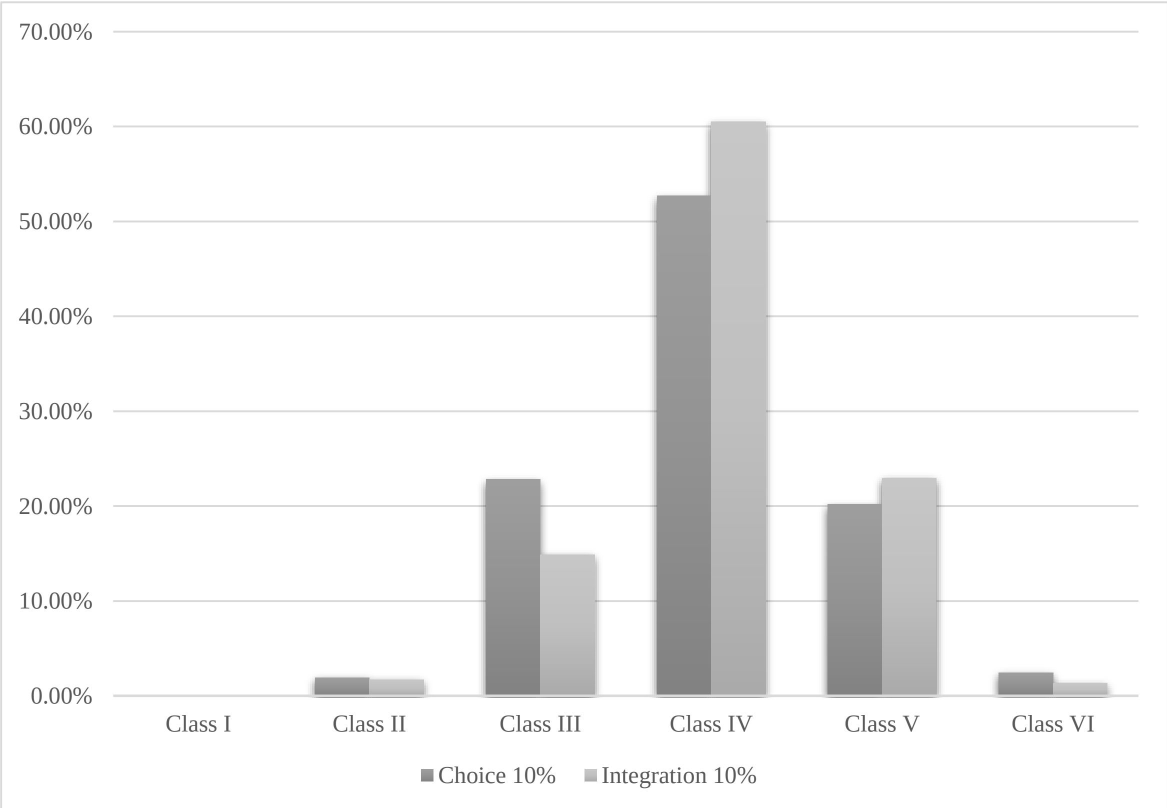

Fig. 6. 8. Restricted Normalized Angular Integration (NAIN) and Normalized Angular Choice (NACH)—90° and 100° deciles—distribution in relation to acoustic classes

6.5 Acoustic Patterns and Spatial Configuration in Different Urban Contexts

Parallel investigations were conducted, the first published in a scientific paper for the 50th edition of the "INTER-NOISE" congress. This comparative analysis aimed to assess the relationship between soundscape and spatial configuration in a different urban context. More precisely, we considered an area of 1.5 km square for the two city centers of Biskra and Pisa, performing two series of on-site synchronized measurements. Thirty stations were appointed in each location during the same winter season to overcome the influences of weather conditions.

The experimental process was carried out throughout the daytime and repeated on several weekdays for 15 minutes. Thus, we measured the equivalent sound pressure level (weighted A), employing a Brüel & Kjaer model 2260 sound level meter.

Afterward, these observations were modeled on QGIS software to enhance the data visualization. Meanwhile, the spatial assessment merely incorporates NAIN and NACH measures at the global scale (radius n).

An insightful analysis process has been implemented. Fig. 6. 9 depicts the summary of the main findings.

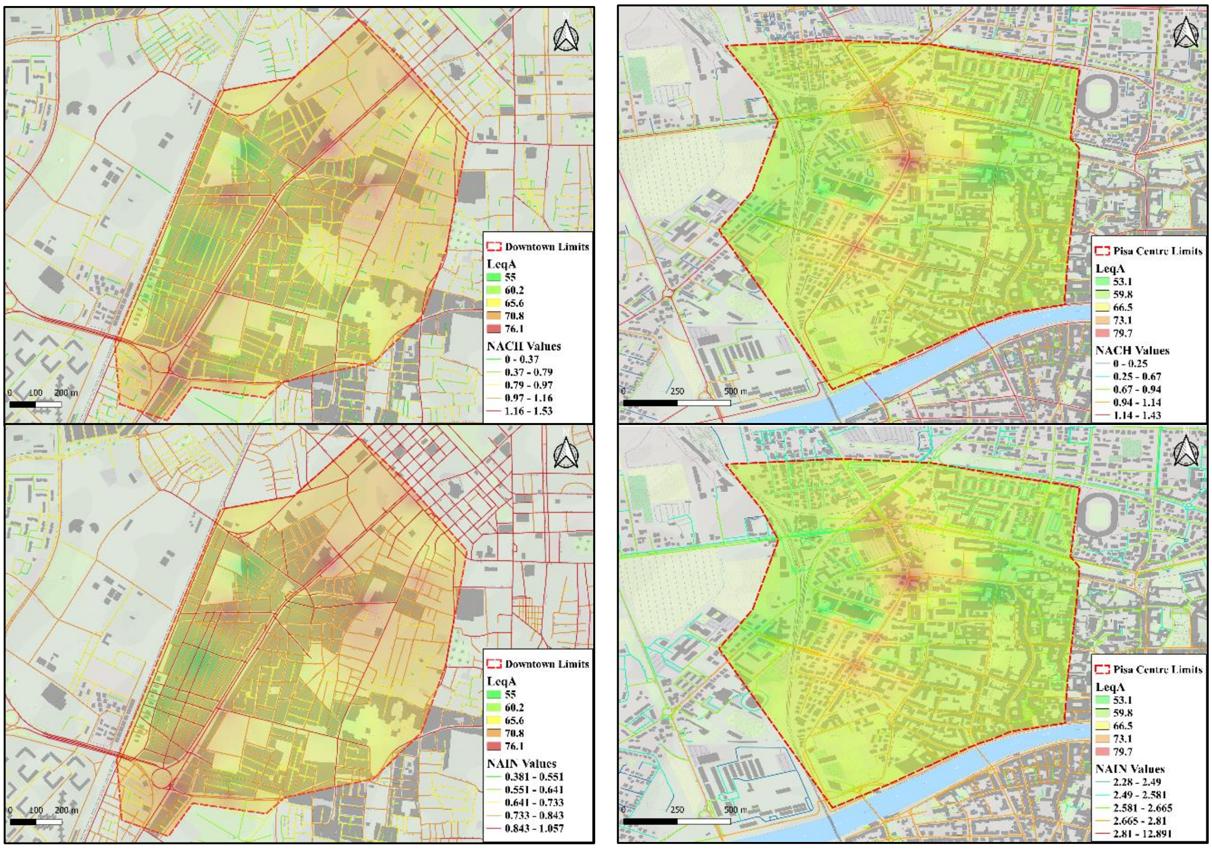

Fig. 6. 9. Acoustic patterns and spatial configurations of Biskra and Pisa downtowns (Source: Benameur, Cutini, et al., 2021)

The results demonstrate that the soundscape environment of the Pisa historic center was mainly associated with NACH values. Nevertheless, Biskra downtown shows a moderate positive correlation for both variables. These conclusions were further discussed based on spatial, social, and cultural dimensions and confirmed the relationship between spatial configuration and the soundscape environment (Benameur, Cutini, et al., 2021).

The second research, published in the Lecture Notes in Computer Science book series (LNCS), aims to validate the engaged methodological approach. The case study targets the metropolitan area of Florence and Prato provinces, given the availability of a large amount of data, such as the Municipal Acoustic Classification Plans (*Piani Comunali di Classificazione Acustica* - *PCCA*) for the Tuscany Region, built infrastructure and road-circulation network. Accordingly, this study examines the relationship between three variables at once: form, function, and acoustics (Benameur, Altafini, et al., 2021).

Similarly, the spatial analysis involves the Space Syntax theory; meanwhile, a GIS-based environment processes the data exploration.

The key outcomes highlight that the form, function, and spatial layouts significantly impact the acoustic environment. Moreover, the angular segment analysis's highest values can provide an accurate insight into the acoustic patterns, as illustrated in Fig. 6. 10.

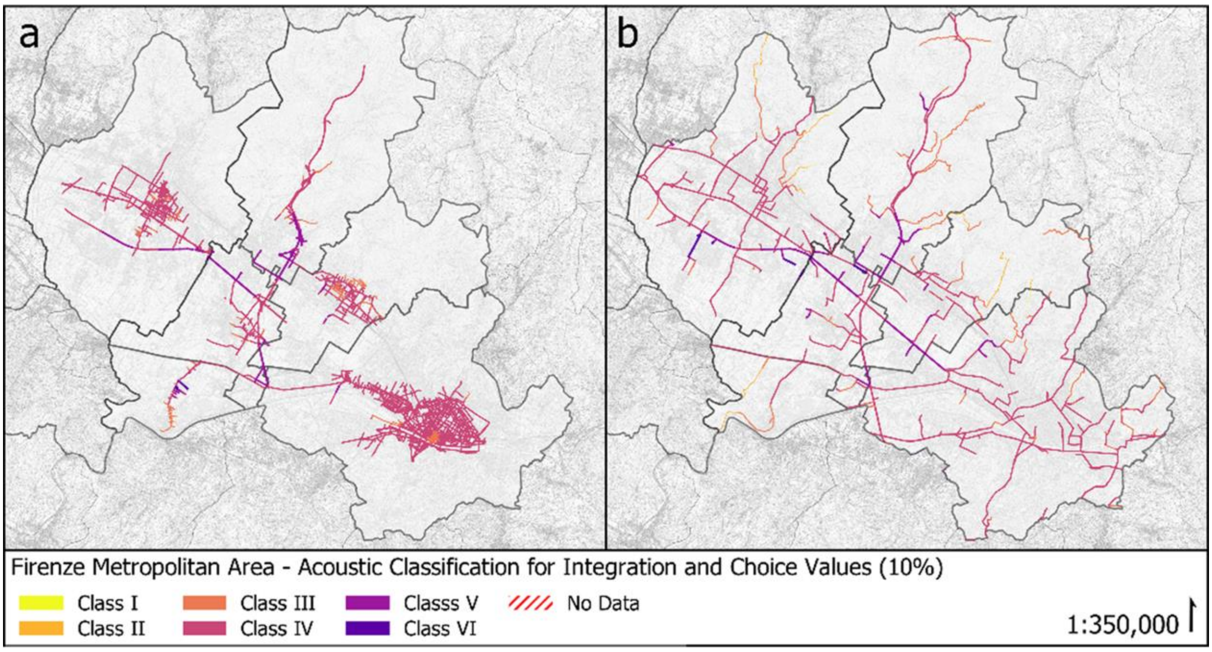

Fig. 6. 10. Acoustic classifications for the highest NAIN and NACH (10%) in the Metropolitan area of Firenze

The relationship between movement potentials and built structures might be a valuable planning tool for revising the Municipal Acoustic Classification Plan since it includes components that could yield finer information about environmental noise and its propagation.

Furthermore, the results obtained for Biskra City and the Florence metropolitan area show a very high degree of similarity, specifically at the highest 10 percent of the syntactic measures. Nevertheless, the correlations developed in the Tuscan region appear more significant and reliable, probably due to the amount of input data involved in each study. Given the extension of the study area, the introduction of additional measurement stations and supplementary acoustic variables could further refine the results.

6.6 Conclusion to this chapter

The developments presented in this chapter involved an array of statistical methods and variables, including Pearson correlation, R squared, explanatory matrices, principal component analysis (PCA) within NAIN, and NACH at 90°-100° deciles.

The exploration of the acoustic and syntactic measures was divided into two distinct levels. The first stage randomly tackles the correlation between variables globally. Hence, the combined by-product of NAIN and NACH illustrates a positive significant correlation within all radii at 0.05 level of p-values, implying that their relationship tends to be moderate and occasionally assertive. Moreover, we may infer by comparing the metric radii that the 2000 m radius displays the strongest linear relationship as it combines a high movement flow within an intense activity throughout the City.

Generally, the acoustic environment of Biskra City is directly related to the choice measures on both global and local scales, more precisely with high metric distances related to vehicular movement. Besides, the correlation maps highlighted a moderate relationship within the integration measures.

The second explanatory stage considers the location of the observations corresponding to the analyzed network system and clustered according to the urban zones. Accordingly, the correlations show three distinctive groups of neighborhoods:

- Six regions surrounding the city center reported highly significant correlations at small and large radii, such as the Wadi zone, star Melouk, colonial fabric, the western zone, and its first extension.
- Four peripherical areas only correspond to the large radii, namely M'cid region, the sixth area, El Alia and Sidi Ghezal. Hence, Feliache zone is associated with the medium radii 800 m, 1200 m, and 1600 m, conversely to the highest radius that shows no significance.

- Five discarded areas have reported non-significant correlation values, as is the case for the northern area, the old core, the second and third western extension, and the southern part of El Alia.

Furthermore, Principal Component Analysis consolidates these correlation outcomes and supplies further insights by generating centroids for each urban area. This feature provides a convenient clustering scheme among neighborhoods sharing similar spatial and acoustic patterns.

Therefore, the obtained findings can be influenced by the characteristics of each region and its socio-economic activities.

The correlations at 90°-100° deciles revealed a significant direct relationship between movement patterns and noise levels. Noting approximately 52.68% of the most preferred routes (NACH) and 60.49% of road segments exhibiting the highest NAIN values corresponding to Class IV.

Albeit, only 22.81% of the highest Choice values belong to class III, intending for residential areas. It is also crucial to emphasize that classes V and VI are designated for industrial regions. Although the findings reported 22.92% and 20.16% for the highest NAIN and NACH, respectively, belong to class V. These rates further confirm the noisy character trait of the city center and its surrounding areas, where the high correlations occur.

Throughout various urban contexts in Algeria and Italy, we may deduce that the ASA measures at the global and local scales are relevant to elucidate both urban layouts and acoustic patterns. However, a further diagnosis of land use and cognitive, social, and cultural properties is required. Likewise, it’s noteworthy to consider the other extraneous variables that may considerably impact sound and noise fluctuation.

The main conclusions demonstrate the effectiveness of the established methodology in highlighting the strength of the relationship between the environmental noise and the spatial layouts variables, and corroborate the hypothesis previously outlined for this research project.

Finally, in such regions lacking a municipal acoustic map the present strategy might be employed as a decision-making tool for urban planning and acoustic improvement measures.

CHAPTER 7:

CONCLUSION AND PROSPECT

Chapter 7: Conclusion and Prospect

During the last few decades, the tremendous urban growth rate of Saharan settlements has increased as much as the continuous demand for space production. Particularly in Biskra City, due to the inevitability of urban densification. Addressing such an environmental issue remain challenging during the planning process. This crucial process, however, has significant effects on the urban environment, sustainability, and resilience. Additionally, inhabitants are seeking better conditions for the surrounding environment.

Given all these elements, urban development today requires a sustainable strategic response that can comprehend and integrate the relationships between urban form, environmental factors, and quality of life.

Noise pollution remains one of the multiple external exposures associated with the residential location and urban form. This environmental factor represents a principal cause of adverse health effects, as reporting the World Health Organization in 2018.

Since 2002, European countries have established an effective strategy for assessing the acoustic environment and controlling noise pollution through the Environmental Noise Directive (END). This directive is constantly being improved and refined by developing a set of action plans, including the implementation of decision-making tools. Nevertheless, developing countries like Algeria remain in the preliminary phase of diagnostics and analysis of environmental issues.

Correspondingly, this dissertation aimed to analyze the acoustic environment over the urban configurations of Biskra City. Thus, it encompasses several objectives, including an insightful spatial assessment of the urban fabrics, a noise mapping prototype, and a diagnostic of the interconnection between the surrounding acoustic environment and the current urban structure.

In other words, it provides a detailed synthesis of the soundscape regarding all the spatial, social, economic, and psychological components. The latter serves as a starting point for further research and specialized interventions.

The epistemological positioning according to the literature review on the main concepts and dimensions induced to delineate a research design based on two facets, an objective and subjective approach. The objective assessment diagnoses the spatial analysis of the urban zones using the angular segment analysis method, on the one hand, since there is a direct relationship between urban morphology and traffic noise through mobility patterns.

On the other hand, the evaluation of the physical acoustic environment ventured an experimental approach based on 240 stations of measures within a soundscape modeling process using interpolation models.

This phase was achieved on the SAGA GIS module and included Inverse Distance Weighted (IDW) and Kriging models. Moreover, it is vital to mention that the main correlations between spatial and acoustic data were committed to the Geographical Information System software QGIS (*QGIS, Białowieża*, 2022).

Furthermore, the subjective approach encompasses a psychoacoustical assessment process and addresses several topics, such as soundscape perceptions, sonic mind mapping, and sound preferences.

The spatial assessment highlights two main conclusions:

1) From a macro perspective: the normalized angular choice map exhibits an organic and hierarchical network pattern distinguished by the prevalence of many anchored segments connecting the city parts.

On the integration map, a non-edge effect is evident, emphasized by the segregated nature of the boundaries. Consequently, the most integrated neighborhoods consolidated principally around the city center. The same map highlights considerable variations across distinct areas according to land use categories.

Typically, central locations are inherently the most frequented as they reflect the most intensive social coexistence.

These determinations might be further dissected before standardizing the two syntactic measures by implementing an aggregated map combining integration and choice values and providing a global overview of the current layouts. Hence, it denotes the locations integration level and their interest in estimating movement and occupancy.

Furthermore, the four-pointed star model demonstrated the strength of the examined urban pattern on the background network structure compared to its foreground. Thus, it revealed the effectiveness of a fully connected background network in maintaining a consistent design.

The model endorsed the drawn inferences of the irregular form, apart from the colonial urban fabric. Predominantly, the foreground network of Biskra city comprises an organic grid, indicating specific sociocultural priorities and moderate ease of access.

2) From a micro perspective: the ring of highways around the city, the four bridges, and the primary boulevards indicate a high trend of vehicular movement. This statement portrays the high local choice values at the tallest distances throughout the analyzed area.

Moreover, small radii choice measures reflecting pedestrian movement remain identical over the entire system. Also, at 1600 and 2000 m radii, we may identify the appearance of the most preferential routes around the downtown, Eastern, and Western regions.

Besides, local integration from low to high metric distances illustrated the progressive emergence of six urban areas, including Wadi Zone, Colonial fabric, Star Melouk, Dalaa & Dalia, El Alia, and Sidi Ghezal owing to the ease of access and the congestion of diverse social and economic activities.

Finally, the main correlations between higher and smaller radii (3200 m and 400 m) reveal an average value on the city scale. Therefore, some high values reached 0.8 for downtown zones and adjacent areas. It indicates highly integrated routes on a city scale. Conversely, the other peripheral districts reported lower correlations.

Likewise, the intelligibility exhibited a high correlation roughly to the city center. This culmination signifies that their built environment is more orientable at varying degrees, conversely to the whole network.

The second objective assessment dealing with the acoustic modeling process demonstrated the effectiveness of the "Inverse Distance Weighting k2" model for simulating the acoustic environment over a wide area. Although, its visualization remained granular and considered the nearest locations to measurement stations (most immediate radius). However, the Kriging models, namely the universal model, enable a more fluid visualization, and smooth representation, albeit with a significantly diverse variety (Benameur et al., 2022).

Nevertheless, few studies reported that spatial interpolation methods perform poorly, first because they focus mainly on sound measurements and then because they fail when dealing with a small number of monitoring stations. Therefore, they suggested several alternative inputs to enhance these interpolations. Land use regression models (LUR), for instance, provide more sophisticated acoustic maps by carefully considering the realistic aspect and classifications of land use (Xie et al., 2011).

Aumond et al. (2018) also compared the performance of ordinary Kriging and universal Kriging while the semivariograms were calculated based on the Euclidean distance between stations and the distance through road network typologies for both interpolation methods. The authors highlighted that incorporating the road distance can increase performance accuracy, particularly for ordinary Kriging. Conversely, Universal Kriging yielded satisfactory results due to the linear regression already included in the computing process. This research also outlined the importance of establishing a wide range of observations to obtain a more realistic interpolation (Aumond et al., 2018).

Likewise, a recent study aimed to enhance the interpolation models based on IoT attributes to generate dynamic and practical noise maps by optimizing the empirical formulas (Middya & Roy, 2021).

Additionally, QGIS software aids in exploring the internal characteristics of each urban zone through the use of a zonal analysis toolbox feature. The outcome of this step offers meaningful graphs and enables an overview of the frequency and disparity of the simulated data.

Despite the inadequacy of local standards relating to outdoor acoustics and urban noise, the incorporation of international standards and regulations has made it possible to assess the acoustic environment in the Algerian context. It consists in clustering the outcomes in their specified noise classes.

This analytical phase demonstrates that the residential area of the North zone and Hai el Moudjahidine represent the quietest district of the scrutinized urban sample.

The first extension west zone, El Alia South, and Feliache's middle quartiles are all categorized as Class III, indicating that these areas have reported moderate noise levels.

Downtown (Dalia & Dalaa), West Zone (extension 2), and East Zone (El Alia) display a noisy character within multifarious values as a consequence of significant functional diversity.

The highest noise values refer to the Wadi zone, Ancient City (M'cid), Downtown (Star Melouk and Colonial Fabric), and the East zone (El Alia). Likewise, several parts of the sixth zone roughly belong to class V.

Thus, the global overview of the acoustic environment of the city highlights 60.01% of the urban system falls within the fourth noise Class (Class IV) and exceeds 65 dB. Moreover, 30.31% were classified as Class III, ranging from 60 dB to 65 dB. Hence, this highlights a potentially vulnerable acoustic environment, particularly for areas close to the city center, El Alia, and the city's historic urban fabric. This an alarming circumstance that requires a focused strategy to address the noise pollution issue.

The relationship between the acoustic measures and the spatial syntactic variables, according to an array of statistical analysis, displays the following conclusive remarks:

First, the combined product of NAIN and NACH illustrate a positive correlation within all radii, meaning that this relationship tends to be moderate to strong.

In general, the acoustic environment of Biskra City is directly related to the choice measure on both global and local scales, more precisely with high metric distances related to vehicular movement.

On the other hand, the acoustic environment is highly related to the integration parameters and highlighted in several districts located near the downtown.

Across varying urban contexts, we may conclude that ASA measures at both global and local scales play a significant role in explaining urban development and acoustic phenomena (Benameur, Altafini, et al., 2021; Benameur, Cutini, et al., 2021). However, further diagnosis of land use and cognitive, social, and cultural properties are required.

In regions lacking a municipal acoustic map, the angular segment analysis remains an effective predictive tool to assess acoustic patterns. This methodology might be applied as a decision-making tool for urban planning and acoustic improvement measures.

From a subjective point of view, affective responses through a graphical representation model of eventfulness and pleasantness provide an insightful analysis of the soundscape perceptions. The results showed that the closest areas to the city center, including dense urban centers with congested buildings, are the most susceptible to the problem of noise pollution. Subjective results confirm the accordance of perceptual attributes with the objective assessment.

Beyond the harsh climate conditions and the challenge of ensuring adequate thermal comfort, noise control should be considered as part of a sustainable development strategy for Saharan areas. Thus, establishing a detailed noise map within the framework of an action plan is vital due to the alarming situation.

Finally, the efficient management of road traffic, the inclusion of material properties, and the integration of natural elements can improve the current noisy environment and enhance the quality of life and well-being of the inhabitants of Biskra city.

7.1 Scientific and Technical Barriers

The main scientific and technical barriers preventing the fulfillment of this doctoral thesis are related to numerous logistical, computational, and normative impediments.

The literature review, which can provide a foundation for further research, is lacking in addressing the urban acoustic theme at the national and provincial levels. Even fewer studies examine the relationship between the urban fabric and acoustics, where the originality and novelty of our methodological approach lies.

Additionally, we should emphasize several issues related to the invalidity, scarcity, and accessibility of raw data. Specifically, that information related to urban planning, such as (built environment in 2D and 3D), demographic statistics (population density by occupied area), and road traffic properties (number of vehicles and motorcycles, asphalt properties).

Likewise, building facades characteristics, building type or age, and location of services are currently inferred from external related sources of information. Alternatively, such information could be made available via open data portals, notably high-quality scientific journals that allow for data reuse, exemplified by the journal Data in Brief, and through community databases such as OpenStreetMap. In fact, over the past few years, the scientific community has witnessed a widespread shift toward open-access data.

Besides, the limited number of available data for the Algerian context is less accurate and obsolete, representing simply some tabular statistics. However, introducing a detailed and updated database to Geographic Information Systems is highly recommended to address many issues. The latter should include multi-information related to urban planning and environmental assessment (Leghrib et al., 2021).

Regarding logistical constraints, it lacked a sophisticated acoustic lab, enabling various physical acoustic variables such as frequency and amplitude of spectral peak, spectral energy, sharpness roughness, loudness, judged energy variation, judged pitch and variance explained (Hall et al., 2013). The limitation to performing simultaneous measurements in different areas, or even several constraints related to accessibility and security preventing the experimental protocol of measurements during the night-time or in isolated urban sectors. Moreover, the measured sound levels and temporal fluctuations remain other contributing factors to noise annoyance. The implication of more sophisticated indicators and adjusted mapping representations are thus indispensable for noise dynamics assessment.

Lastly, in terms of standards compliance, the misfit of the international standards by the local norms and policies on acoustics and noise control prevents the performance of some insightful computational methods via several powerful software such as LIMA, CadnaA, and Soundplan.

7.2 Future Prospect

This study provides novel insights for potential research targeting:

- Consideration of the sound temporal variation in both objective and subjective facets. Firstly, by elaborating measurement stations during different parts of the day, based on the mathematical formula of LDEN (Level sound pressure during Day, Evening, and Night).

  Secondly, introducing a multiple-choice question in a survey form that indicates the occurrence of the dominant noise sources.
- The combination of GIS interpolation results within parametric approaches tools such as Rhino software and Pachyderm plugin to analyze urban and landscape design features at an inner-complex scale.
- The introduction of supplementary inputs such as traffic loads is of paramount relevance to generate more sophisticated maps.
- The consideration of the physical properties of building materials in a thorough investigation. Nevertheless, such an approach will only be possible after a remarkable shift in urban planning tools, namely the application of geographic information systems, while discarding the existing conventional methods.
- The implementation of further research dealing with the psychological and physiological noise pollution effects involving annoyance, irritability, insomnia, cardiovascular problems, and hearing loss.
- Under the license of the publication journal, these datasets can be reused in comparative investigations that associate many fields, including soundscape, noise pollution, urban planning, computational and applied sciences, social and psychological sciences, health and well-being of inhabitants, and sustainable development challenges.

Finally, we emphasize the necessity of implementing a robust sound mapping strategy for Saharan settlements and other regional provinces.

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Appendix A: Measured Dataset Details

Table 1: Level sound measured Data

Station ID	LeqA	Date	Time	Longitude	Latitude
A1	66.9	8-Nov-20	8:02:50 AM	5.722301	34.85128
A2	71	8-Nov-20	8:13:22 AM	5.722265	34.85169
A3	63.9	8-Nov-20	8:22:07 AM	5.721576	34.85108
A4	68.7	8-Nov-20	8:31:21 AM	5.720654	34.84997
A5	71.3	8-Nov-20	8:43:25 AM	5.718434	34.84742
A6	72.1	8-Nov-20	8:56:25 AM	5.717112	34.84601
A7	74.3	8-Nov-20	9:05:03 AM	5.716235	34.84475
A8	73.2	8-Nov-20	9:17:22 AM	5.718541	34.84437
A9	61.3	8-Nov-20	9:26:04 AM	5.71865	34.84487
A10	64.1	8-Nov-20	9:38:50 AM	5.721151	34.84713
A11	62.9	8-Nov-20	9:48:56 AM	5.723358	34.84693
A12	64.3	8-Nov-20	9:59:34 AM	5.721809	34.84881
A13	71.7	8-Nov-20	10:10:48 AM	5.724349	34.84992
A14	75.5	8-Nov-20	10:20:20 AM	5.724844	34.85097
A15	67	8-Nov-20	10:29:00 AM	5.724735	34.85176
A16	67.4	8-Nov-20	10:37:41 AM	5.725862	34.85172
A17	73.7	8-Nov-20	10:48:56 AM	5.726876	34.85176
A18	64.2	8-Nov-20	10:58:23 AM	5.727347	34.85273
A19	67.8	8-Nov-20	11:06:00 AM	5.72746	34.85325
A20	73.8	8-Nov-20	11:26:02 AM	5.726814	34.85456
A21	66.8	8-Nov-20	11:33:04 AM	5.726776	34.85383
A22	69.7	8-Nov-20	11:42:06 AM	5.725202	34.85336
A23	70.5	8-Nov-20	11:51:13 AM	5.723918	34.85237
A24	76.2	8-Nov-20	12:03:36 PM	5.723209	34.85234
A25	70.2	8-Nov-20	1:57:03 PM	5.721505	34.85457
A26	69.7	8-Nov-20	2:05:50 PM	5.719608	34.85316
A27	71.6	8-Nov-20	2:17:15 PM	5.717025	34.85475
A28	55.9	8-Nov-20	2:25:23 PM	5.717931	34.85583
A29	63	8-Nov-20	2:37:12 PM	5.718977	34.85445
A30	70	8-Nov-20	2:41:06 PM	5.723722	34.8553
B1	66.3	10-Nov-20	7:53:15 AM	5.724074	34.85534
B2	66.5	10-Nov-20	8:01:34 AM	5.723753	34.85571
B3	67.4	10-Nov-20	8:07:44 AM	5.723898	34.85628
B4	75	10-Nov-20	8:16:05 AM	5.725419	34.85589
B5	69.5	10-Nov-20	8:25:56 AM	5.724171	34.8571
B6	62.3	10-Nov-20	8:33:14 AM	5.723955	34.85805
B7	60.2	10-Nov-20	8:41:40 AM	5.725036	34.85776
B8	66	10-Nov-20	8:50:54 AM	5.725753	34.85916
B9	70.8	10-Nov-20	8:59:12 AM	5.726798	34.85818

B10	71	10-Nov-20	9:07:44 AM	5.726042	34.8578
B11	62.1	10-Nov-20	9:15:10 AM	5.726139	34.85722
B12	67	10-Nov-20	9:22:37 AM	5.726362	34.85646
B13	64.8	10-Nov-20	9:29:48 AM	5.727184	34.8564
B14	72.8	10-Nov-20	9:38:46 AM	5.727667	34.85649
B15	56.1	10-Nov-20	9:59:21 AM	5.725345	34.85817
B16	69.8	10-Nov-20	10:25:34 AM	5.727001	34.85509
B17	75.9	10-Nov-20	10:33:49 AM	5.728617	34.85642
B18	68.5	10-Nov-20	10:42:14 AM	5.729194	34.85545
B19	72.8	10-Nov-20	10:53:07 AM	5.728768	34.8544
B20	76.4	10-Nov-20	11:00:58 AM	5.729858	34.85393
B21	67.4	10-Nov-20	11:20:00 AM	5.731059	34.85586
B22	65.5	10-Nov-20	11:31:54 AM	5.732574	34.85724
B23	70.8	10-Nov-20	11:40:35 AM	5.733775	34.85739
B24	74.5	10-Nov-20	11:51:02 AM	5.735062	34.85642
B25	68.3	10-Nov-20	12:02:02 PM	5.734852	34.85523
B26	48.1	10-Nov-20	12:11:25 PM	5.733821	34.85494
B27	74.9	10-Nov-20	12:23:00 PM	5.735799	34.85206
B28	74.4	10-Nov-20	12:33:21 PM	5.732224	34.8522
B29	71.3	10-Nov-20	12:42:06 PM	5.7291	34.85241
B30	72.6	10-Nov-20	12:52:05 PM	5.727801	34.85364
C1	71.1	15-Nov-20	8:01:43 AM	5.730934	34.85146
C2	73.1	15-Nov-20	8:09:20 AM	5.730866	34.85047
C3	70.5	15-Nov-20	8:18:06 AM	5.730724	34.84834
C4	63.3	15-Nov-20	8:25:34 AM	5.731283	34.8485
C5	69	15-Nov-20	8:32:48 AM	5.732373	34.84911
C6	69.7	15-Nov-20	8:40:35 AM	5.731509	34.84806
C7	56.7	15-Nov-20	8:47:26 AM	5.731659	34.84767
C8	71.1	15-Nov-20	8:56:01 AM	5.733191	34.84705
C9	65.5	15-Nov-20	9:03:17 AM	5.732277	34.84699
C10	70	15-Nov-20	9:10:16 AM	5.730896	34.84656
C11	69.7	15-Nov-20	9:22:03 AM	5.73046	34.84469
C12	73.4	15-Nov-20	9:34:31 AM	5.730206	34.84098
C13	64.3	15-Nov-20	10:39:20 AM	5.729276	34.83979
C14	57.5	15-Nov-20	10:49:32 AM	5.729658	34.83832
C15	72	15-Nov-20	11:03:57 AM	5.729799	34.83564
C16	73.2	15-Nov-20	11:13:47 AM	5.732958	34.83636
C17	73.5	15-Nov-20	11:23:04 AM	5.733656	34.83576
C18	73	15-Nov-20	11:31:48 AM	5.734433	34.83736
C19	69.6	15-Nov-20	11:53:47 AM	5.735912	34.83999
C20	56.4	15-Nov-20	12:03:54 PM	5.734423	34.83971
C21	65.5	15-Nov-20	12:14:09 PM	5.733079	34.83992
C22	78	15-Nov-20	12:25:09 PM	5.737026	34.83947
C23	61.8	15-Nov-20	12:34:28 PM	5.737481	34.83673
C24	66.6	15-Nov-20	12:44:05 PM	5.736859	34.83405
C25	68.6	15-Nov-20	12:56:28 PM	5.734204	34.83274

C26	65.3	15-Nov-20	1:15:06 PM	5.731834	34.83203
C27	66	15-Nov-20	1:23:06 PM	5.728554	34.83232
C28	64.1	15-Nov-20	1:33:27 PM	5.723345	34.83159
C29	71.2	15-Nov-20	1:38:27 PM	5.725266	34.83297
C30	69.9	15-Nov-20	1:51:27 PM	5.727359	34.83436
D1	70.6	18-Nov-20	8:07:21 AM	5.708187	34.85523
D2	64.6	18-Nov-20	8:14:58 AM	5.707126	34.85467
D3	57.7	18-Nov-20	8:21:42 AM	5.705619	34.85598
D4	71.1	18-Nov-20	8:31:08 AM	5.704289	34.85374
D5	56	18-Nov-20	8:40:49 AM	5.705257	34.8521
D6	70	18-Nov-20	8:58:41 AM	5.702041	34.85344
D7	68.7	18-Nov-20	9:06:47 AM	5.700327	34.85334
D8	63.2	18-Nov-20	9:14:27 AM	5.698574	34.85356
D9	65.9	18-Nov-20	9:23:35 AM	5.69706	34.8533
D10	64.2	18-Nov-20	9:38:02 AM	5.695342	34.85503
D11	66.9	18-Nov-20	9:45:30 AM	5.692728	34.85434
D12	64	18-Nov-20	9:54:36 AM	5.692114	34.85246
D13	69.3	18-Nov-20	10:03:54 AM	5.690689	34.85123
D14	68.9	18-Nov-20	10:11:29 AM	5.688949	34.8503
D15	71.6	18-Nov-20	10:22:40 AM	5.686852	34.84902
D16	65.5	18-Nov-20	10:30:38 AM	5.687945	34.84726
D17	68.7	18-Nov-20	10:39:41 AM	5.686773	34.84484
D18	63.6	18-Nov-20	10:50:03 AM	5.685382	34.84358
D19	70.6	18-Nov-20	10:58:54 AM	5.687712	34.84308
D20	56.8	18-Nov-20	11:13:11 AM	5.691035	34.84517
D21	59	18-Nov-20	11:21:54 AM	5.692972	34.84491
D22	67	18-Nov-20	11:31:40 AM	5.69608	34.84482
D23	61.7	18-Nov-20	11:41:00 AM	5.69846	34.84461
D24	69	18-Nov-20	11:52:10 AM	5.699338	34.84575
D25	74.1	18-Nov-20	12:00:58 PM	5.698149	34.84784
D26	70.9	18-Nov-20	12:11:24 PM	5.702463	34.84845
D27	65.8	18-Nov-20	12:19:29 PM	5.704046	34.84972
D28	58.5	18-Nov-20	12:26:11 PM	5.704248	34.8478
D29	75	18-Nov-20	12:36:25 PM	5.706718	34.84981
D30	75.6	18-Nov-20	12:46:29 PM	5.707378	34.85223
E1	73.6	19-Nov-20	8:18:45 AM	5.736729	34.852
E2	71.7	19-Nov-20	8:30:11 AM	5.740234	34.85183
E3	62.4	19-Nov-20	8:39:31 AM	5.741268	34.8537
E4	69.7	19-Nov-20	8:48:15 AM	5.742872	34.8524
E5	69.9	19-Nov-20	8:57:12 AM	5.74254	34.85425
E6	63	19-Nov-20	9:07:27 AM	5.744378	34.85489
E7	66.2	19-Nov-20	9:21:43 AM	5.7454	34.85318
E8	59.4	19-Nov-20	9:29:48 AM	5.744164	34.85265
E9	65.5	19-Nov-20	9:41:16 AM	5.745247	34.852
E10	58.3	19-Nov-20	9:49:56 AM	5.746299	34.85079
E11	60.4	19-Nov-20	10:00:16 AM	5.74899	34.8516

E12	74.3	19-Nov-20	10:09:26 AM	5.750974	34.85203
E13	70.3	19-Nov-20	10:21:19 AM	5.751151	34.85309
E14	71.4	19-Nov-20	10:30:43 AM	5.753512	34.85212
E15	65.8	19-Nov-20	10:41:00 AM	5.75522	34.85314
E16	65.3	19-Nov-20	10:50:54 AM	5.755486	34.85527
E17	59.9	19-Nov-20	10:56:40 AM	5.755285	34.85607
E18	69.4	19-Nov-20	11:07:37 AM	5.755774	34.85727
E19	56.6	19-Nov-20	11:15:21 AM	5.75538	34.85871
E20	61.7	19-Nov-20	11:21:57 AM	5.755028	34.85987
E21	56.7	19-Nov-20	11:30:41 AM	5.753023	34.85918
E22	64.5	19-Nov-20	11:46:09 AM	5.750534	34.8614
E23	73.4	19-Nov-20	12:18:19 PM	5.750296	34.85745
E24	74	19-Nov-20	12:28:01 PM	5.746871	34.85815
E25	62.5	19-Nov-20	12:36:36 PM	5.743784	34.8569
E26	72.6	19-Nov-20	12:45:05 PM	5.741926	34.85802
E27	65.6	19-Nov-20	12:56:55 PM	5.738956	34.86006
E28	70.5	19-Nov-20	1:05:00 PM	5.736527	34.86109
E29	76.5	19-Nov-20	1:14:07 PM	5.738596	34.85737
E30	63.6	19-Nov-20	1:24:29 PM	5.740213	34.85524
F1	75.4	17-Jan-21	9:01:50 AM	5.74154	34.85111
F2	76.8	17-Jan-21	9:09:04 AM	5.741689	34.84869
F3	75.8	17-Jan-21	9:16:50 AM	5.742427	34.84589
F4	56.3	17-Jan-21	9:24:49 AM	5.744266	34.84372
F5	55.8	17-Jan-21	9:32:32 AM	5.745324	34.84268
F6	79.1	17-Jan-21	9:41:02 AM	5.741778	34.84099
F7	63.1	17-Jan-21	9:50:15 AM	5.74543	34.84126
F8	65.3	17-Jan-21	10:02:23 AM	5.748179	34.84122
F9	59.5	17-Jan-21	10:11:56 AM	5.746733	34.83867
F10	68.4	17-Jan-21	10:19:24 AM	5.746615	34.8376
F11	68	17-Jan-21	10:25:24 AM	5.748884	34.83592
F12	64.1	17-Jan-21	10:37:13 AM	5.751331	34.83681
F13	62	17-Jan-21	10:46:42 AM	5.753322	34.83674
F14	76.2	17-Jan-21	10:57:31 AM	5.75687	34.83536
F15	61.6	17-Jan-21	11:09:42 AM	5.753893	34.82711
F16	58.6	17-Jan-21	11:17:29 AM	5.758509	34.82552
F17	60.3	17-Jan-21	11:31:27 AM	5.760722	34.83462
F18	60.2	17-Jan-21	11:37:15 AM	5.761833	34.83715
F19	62.2	17-Jan-21	11:45:42 AM	5.757486	34.83849
F20	62.1	17-Jan-21	11:52:42 AM	5.756011	34.839
F21	60.8	17-Jan-21	12:01:44 PM	5.759344	34.8394
F22	66.1	17-Jan-21	12:07:40 PM	5.76078	34.84236
F23	66	17-Jan-21	12:14:40 PM	5.761861	34.84558
F24	64.7	17-Jan-21	12:23:58 PM	5.759497	34.84466
F25	72.4	17-Jan-21	12:41:34 PM	5.754611	34.85202
F26	67.1	17-Jan-21	12:52:39 PM	5.753292	34.85148
F27	77.4	17-Jan-21	1:02:09 PM	5.751321	34.84895

F28	77.4	17-Jan-21	1:10:09 PM	5.751371	34.84483
F29	71.4	17-Jan-21	1:18:13 PM	5.753023	34.83896
F30	71.5	17-Jan-21	1:27:13 PM	5.753956	34.83804
G1	69.9	19-Jan-21	8:05:40 AM	5.699588	34.81636
G2	58.4	19-Jan-21	8:13:09 AM	5.700462	34.82004
G3	58	19-Jan-21	8:25:09 AM	5.700723	34.8222
G4	71.5	19-Jan-21	8:41:27 AM	5.700908	34.82385
G5	69	19-Jan-21	8:50:44 AM	5.699098	34.82496
G6	69.1	19-Jan-21	9:00:44 AM	5.697139	34.82547
G7	65.4	19-Jan-21	9:09:02 AM	5.69595	34.82394
G8	65.3	19-Jan-21	9:19:02 AM	5.694256	34.82505
G9	65.8	19-Jan-21	9:30:36 AM	5.692031	34.82271
G10	63.3	19-Jan-21	9:31:11 AM	5.692136	34.82164
G11	64.7	19-Jan-21	9:42:15 AM	5.694232	34.82125
G12	64.6	19-Jan-21	9:48:15 AM	5.696121	34.82143
G13	59.5	19-Jan-21	9:53:07 AM	5.695301	34.8198
G14	77	19-Jan-21	10:00:57 AM	5.69532	34.81846
G15	76.9	19-Jan-21	10:08:57 AM	5.697546	34.81767
G16	70.7	19-Jan-21	10:19:40 AM	5.72101	34.84414
G17	68.4	19-Jan-21	10:31:05 AM	5.724397	34.84413
G18	63.6	19-Jan-21	10:38:23 AM	5.72423	34.84203
G19	60.3	19-Jan-21	10:49:28 AM	5.721859	34.84076
G20	67	19-Jan-21	11:00:56 AM	5.717967	34.84121
G21	61	19-Jan-21	11:08:54 AM	5.715439	34.83932
G22	63.1	19-Jan-21	11:19:36 AM	5.713217	34.83763
G23	65.9	19-Jan-21	11:28:12 AM	5.71359	34.83459
G24	72.3	19-Jan-21	11:39:20 AM	5.709141	34.836
G25	61	19-Jan-21	11:51:34 AM	5.708939	34.83877
G26	65.5	19-Jan-21	12:02:36 PM	5.707913	34.84074
G27	62.7	19-Jan-21	12:11:59 PM	5.707318	34.8426
G28	65.5	19-Jan-21	12:19:23 PM	5.7075	34.84388
G29	57.1	19-Jan-21	12:30:16 PM	5.710236	34.84511
G30	60.3	19-Jan-21	12:37:34 PM	5.711913	34.84599
H1	58.7	21-Jan-21	8:42:37 AM	5.716363	34.85685
H2	52.4	21-Jan-21	8:51:33 AM	5.718722	34.85643
H3	58.9	21-Jan-21	8:59:37 AM	5.720053	34.85673
H4	57.6	21-Jan-21	9:07:55 AM	5.72222	34.8571
H5	69.2	21-Jan-21	9:15:20 AM	5.72121	34.85847
H6	63	21-Jan-21	9:23:17 AM	5.719508	34.85952
H7	68	21-Jan-21	9:29:52 AM	5.718131	34.85989
H8	65.7	21-Jan-21	9:37:24 AM	5.716127	34.86029
H9	61.5	21-Jan-21	9:46:52 AM	5.716458	34.86307
H10	54.2	21-Jan-21	9:54:53 AM	5.716954	34.86477
H11	61	21-Jan-21	10:07:00 AM	5.71684	34.86672
H12	59.3	21-Jan-21	10:16:05 AM	5.717841	34.86931
H13	56.8	21-Jan-21	10:30:51 AM	5.71477	34.8634

H14	57.1	21-Jan-21	10:40:49 AM	5.710962	34.86461
H15	58.6	21-Jan-21	10:48:36 AM	5.713656	34.86187
H16	60.7	21-Jan-21	10:57:42 AM	5.71435	34.86002
H17	59.9	21-Jan-21	11:06:09 AM	5.712781	34.85885
H18	67	21-Jan-21	11:13:31 AM	5.713034	34.85668
H19	62.2	21-Jan-21	11:21:50 AM	5.71133	34.85466
H20	57.7	21-Jan-21	11:31:49 AM	5.709145	34.85366
H21	56.9	21-Jan-21	11:39:34 AM	5.708493	34.85202
H22	60.1	21-Jan-21	11:47:25 AM	5.707695	34.85036
H23	61.9	21-Jan-21	11:54:03 AM	5.707319	34.84893
H24	61.3	21-Jan-21	12:03:56 PM	5.707011	34.8468
H25	60.1	21-Jan-21	12:17:10 PM	5.714023	34.84699
H26	59.6	21-Jan-21	12:26:31 PM	5.715635	34.84767
H27	65.2	21-Jan-21	12:34:48 PM	5.717914	34.84781
H28	57	21-Jan-21	12:43:52 PM	5.717636	34.84917
H29	72.1	21-Jan-21	12:50:53 PM	5.71884	34.85079
H30	56	21-Jan-21	12:58:27 PM	5.719652	34.85238

Table 2: Global descriptive statistics of measured data (ID 1 to 8)

Statistic	North Zone	Wadi Zone	Ancient City (M'cid)	Ancient City (Old Core)	Downtown (Star Melouk)	Downtown (Colonial Fabric)	Downtown (Dalia & Dalaa)	Sixth Zone
Nbr. of observations	4	19	11	6	22	20	14	13
Minimum	54.2	48.1	56.4	64.1	61.3	56.1	56.0	57.5
Maximum	61.0	74.9	78.0	71.2	76.2	76.4	72.1	74.3
1st Quartile	56.375	66.9	66.050	65.475	64.925	65.7	59.075	63.1
Median	58.2	70.0	72.0	67.3	68.250	69.650	65.750	65.9
3rd Quartile	59.725	72.1	73.300	69.575	71.6	72.650	69.125	70.7
Mean	57.900	68.411	69.364	67.517	68.673	68.615	64.250	66.277
Variance (n-1)	8.633	43.748	39.077	7.862	17.847	29.498	30.503	27.924
Standard deviation (n-1)	2.938	6.614	6.251	2.804	4.225	5.431	5.523	5.284
Variation coefficient	0.044	0.094	0.086	0.038	0.060	0.077	0.083	0.077
Skewness (Pearson)	-0.283	-1.803	-0.767	0.105	0.079	-0.603	-0.187	0.040
Standard error of the mean	1.469	1.517	1.885	1.145	0.901	1.214	1.476	1.466
Standard error of the variance	7.049	14.583	17.476	4.972	5.508	9.570	11.964	11.4
Standard error(Kurtosis (Fisher))	2.619	1.014	1.279	1.741	0.953	0.992	1.154	1.191
Mean absolute deviation	2.250	4.533	4.937	2.383	3.527	4.314	4.771	4.344
Median absolute deviation	1.950	3.100	2.400	2.300	3.650	3.150	4.350	4.800
Geometric mean	57.844	68.064	69.094	67.468	68.549	68.403	64.026	66.082
Geometric standard deviation	1.052	1.113	1.098	1.042	1.063	1.085	1.091	1.083
Harmonic mean	57.787	67.666	68.810	67.420	68.425	68.183	63.801	65.887

Table 2: Global descriptive statistics of measured data (ID 9 to 16)

Statistic	West Zone (Hai El Moudjahidine)	West Zone (Extension1)	West Zone (Extension2)	West Zone (Extension3)	East Zone (El Alia)	East Zone (El Alia South)	Feliache	Sidi Ghezal
Nbr. of observations	21	15	13	8	36	10	13	15
Minimum	52.4	56.0	56.8	63.2	56.6	60.2	55.8	58.0
Maximum	71.6	75.6	74.1	71.6	77.4	71.5	79.1	77.0
1st Quartile	58.7	58.1	63.6	64.150	62.875	61.125	59.5	63.950
Median	61.0	61.9	68.7	66.4	68.250	63.450	63.1	65.4
3rd Quartile	65.5	68.2	70.0	69.0	72.8	66.075	68.0	69.5
Mean	61.962	63.667	66.585	66.750	67.872	64.530	64.462	66.560
Variance (n-1)	23.068	43.261	25.421	8.866	39.063	18.036	49.804	33.930
Standard deviation (n-1)	4.803	6.577	5.042	2.978	6.250	4.247	7.057	5.825
Variation coefficient	0.076	0.100	0.073	0.042	0.091	0.062	0.105	0.085
Skewness (Pearson)	0.148	0.655	-0.592	0.335	-0.125	0.664	0.815	0.321
Standard error of the mean	1.048	1.698	1.398	1.053	1.042	1.343	1.957	1.504
Standard error of the variance	7.295	16.351	10.378	4.739	9.338	8.502	20.332	12.824
Standard error (Kurtosis (Fisher))	0.972	1.121	1.191	1.481	0.768	1.334	1.191	1.121
Mean absolute deviation	3.861	5.427	4.050	2.425	5.400	3.410	5.337	4.539
Median absolute deviation	3.900	4.200	2.200	2.450	5.200	2.650	4.500	3.700
Geometric mean	61.785	63.361	66.402	66.692	67.589	64.407	64.121	66.325
Geometric standard deviation	1.081	1.106	1.081	1.045	1.098	1.067	1.112	1.091
Harmonic mean	61.608	63.068	66.214	66.635	67.302	64.288	63.797	66.093

Appendix B: Descriptive Statistics of the Modelled Dataset

Table 1: Global descriptive statistics of the spatial interpolation models

	IDW	IDW GAUSSIAN	IDW EXPONENTIAL	OK	UK
Count	127576519	127576519	1.28E+08	1.28E+08	127576359
Sum	8444668493	8049119534	8.1E+09	8.02E+09	7947577503
Mean	66.19296842	63.09248439	63.46676	62.84322	62.2966321
Median	66.30621338	62.08335495	63.37327	61.97803	61.8720016
St.Dev	1.217374732	4.310959834	3.458548	2.911299	3.90284912
Min	48.11786652	57.10000229	58.13979	58.38124	54.1226349
Max	79.09683228	77.09075928	73.04282	71.71288	71.718605
Range	30.97896576	19.99075699	14.90303	13.33163	17.5959702
Minority	48.11786652	57.29286957	58.13979	58.38127	54.1226349
Majority	66.50491333	59.29999924	59.14066	59.96442	66.0540848
Variety	2569682	3440163	2572678	2467456	3560093
Variance	1.482001238	18.58437469	11.96156	8.475661	15.2322313

Appendix C: Questionnaire Design

I. General information

<table>
<tr><td colspan="2">المنطقة العمرانية
Urban Zone :</td><td colspan="4">..</td></tr>
<tr><td colspan="2">**Street :** الشارع/ الحي</td><td colspan="4">...</td></tr>
<tr><td>الجنس:
Gender:</td><td>......</td><td>السن:
Age :</td><td>............</td><td>المهنة:
Profession :</td><td>.............................
.</td></tr>
<tr><td colspan="3">**Academic level**
المستوى التعليمي</td><td colspan="3">☐ Preschool أمي
☐ Primary إبتدائي
☐ Intermediate متوسط
☐ Secondary ثانوي
☐ Tertiary جامعي</td></tr>
<tr><td colspan="3">**What is the type of your residence**
ما نوع مسكنك الحالي</td><td colspan="3">☐ Individual فردي
☐ Collective جماعي
☐ Semi Collective شبه جماعي</td></tr>
<tr><td colspan="3">**Which floor do you live on?**
في أي طابق توجد غرفتك</td><td colspan="3">☐ Ground floor الأرضي
☐ First floor الأول
☐ Second floor الثاني
Autre :.........</td></tr>
<tr><td colspan="3">**What is the location of your room regarding the principal facade?**
ما موقع غرفتك نسبة للواجهة الرئيسية</td><td colspan="3">☐ Near قريبة
☐ Far بعيدة</td></tr>
<tr><td colspan="3">**How long have you lived in this neighborhood?**
منذ متى تقطن بهذا الحي</td><td colspan="3">☐ Less than 2 years أقل من سنتين
☐ From 2 to 5 years من 2 إلى 5 سنوات
☐ More than 5 years أكثر من 5 سنوات</td></tr>
</table>

II. Soundscape environment:

1. How do you find your neighborhood and its immediate surroundings?

1. كيف تجد حيك و محيطه المباشر ؟

	Strongly Disagree غير موافق بشدة	Disagree غير موافق	Neutral لا هذا ولا ذاك	Agree موافق	Strongly Agree موافق بشدة
Calm هادئ	☐	☐	☐	☐	☐
Chaotic صاخب	☐	☐	☐	☐	☐
Monotonous ممل	☐	☐	☐	☐	☐
Vibrant حماسي	☐	☐	☐	☐	☐
Eventful مزدحم	☐	☐	☐	☐	☐
Uneventful مهجور	☐	☐	☐	☐	☐
Pleasant ممتع	☐	☐	☐	☐	☐
Annoying مزعج	☐	☐	☐	☐	☐

2. How satisfied are you with the sound environment in your neighborhood?

2. ما مدى رضاك على البيئة الصوتية داخل حيك ؟

☐ Highly Dissatisfied ساخط جدا ☐ Dissatisfied ساخط ☐ Neither/Nor لا هذا ولا ذاك ☐ Satisfied راض ☐ Highly Satisfied راض جدا

III. Sonic Mind mapping:

3. Please describe with a drawing how do you see your neighborhood in terms of noise pollution: **4. هل يمكنك أن توضح برسم مبسط كيف ترى حيك من ناحية الازعاج الصوتي:**

4. Does noise interfere with your regular activities and job?

5. هل تعتبر الضجيج مشكلة تعيقك إلى حد ما في حياتك اليومية أو العملية؟

☐ Yes
نعم

☐ No
لا

5. Will you change your residence because of its acoustic environment?

6. هل مستعد أن تغير مسكنك بسبب محيطه الصوتي؟

☐ Yes
نعم

☐ No
لا

If "Yes", please answer the following questions:

إن كانت إجابتك نعم، يرجى الإجابة على الأسئلة التالية :

5.2. Prioritize your criteria for choosing a new home (from 1 to 6) :

2.5. رتب من 1 إلى 6 حسب الأولية، معايير انتقاءك لمنزل جديد:

O	Area المساحة	O	Several facades تعدد الواجهات	O	Thermal comfort الرفاهية الحرارية
O	Good neighbours حسن الجوار	O	Equipped area القرب من المرافق العامة	O	Acoustic comfort الرفاهية الصوتية

5.3. In which neighborhood do you prefer to live in Biskra?

3.5. في أي حي من أحياء مدينة بسكرة تفضل العيش؟

....

....

6. Rank the following sound sources by preference:

6. رتب مصادر الصوت التالية بحسب الأفضلية:

		1	2	3	4	5
Vehicle engines	محركات السيارات					
Motorcycles engines	محركات الدراجات النارية					
Surrounding speech	دردشة					
Silence	سكون					
Children playing	لعب أطفال					
Tree leaves	أوراق أشجار					
Water flow	جريان المياه					
Hiss of air	صفير هواء					
Rain	أمطار					
Purring cats	مواء قطط					
Birds	زقزقة عصافير					
Music	موسيقى					
Adhan	آذان					