URBAN SOUNDSCAPE QUALITY RATING USING GIS DATA AND REMOTE SENSING: A CASE STUDY OF AL-SAFA DISTRICT, JEDDAH, SAUDI ARABIA

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Abstract

The economic life of an urban area can significantly benefit from a good living environment, making this an essential part of any effective regeneration plan. As cities progressively compete with one another to invite investment, the existence of tranquil spaces, such as gardens and squares, becomes an important business and marketing tool. Managing noise is a major consideration for enhancing citizen's quality of life, since excessive noise levels have adverse effects on both human health and urban biodiversity. Soundscape evaluation is usually determined by approximating the monetary costs due to exposure to noise, such as hospital expenses, decreased productivity and returns from tourism or measured changes in biodiversity. The major objective of this study is establishing noise maps showing the areas with the highest noise level in order to propose and proposing urban solutions can control such nose level to enhance the quality of life for the residents and visitors of Al-Safa District in Jeddah, Saudi Arabia, using live monitoring of noise. Methods previously used to evaluate the impact of the urban soundscape measure urban noise level include hedonic pricing, a surveying technique, and choice experiment to evaluate individuals' preference of neighborhood. However, such studies lack real data, as they provide virtually no information on the way buildings or natural green walls can act as sound barriers or insulation, do not consider properties' proximity to noise zones, lack detail on the impact of contextual factors, such as weather, on the soundscape.

Furthermore, methodologies used to evaluate sound barriers do not differentiate between noise pitch and vibration. Moreover, noise reduction also has economic impact. One of the most important strategic goals of the Saudi Arabia's national Vision 2030 is focused on improving the quality of life of the Kingdom's citizens and residents. This plan will be implemented by creating an environmental system that contributes to increasing the level of economic, social, and development of the Kingdom's cities. The program uses six international indicators to assess the quality of life, with improving individuals' living conditions for a satisfied and healthy life through enhancing the urban environment prevailing as one of the overarching goals. Numerous studies have demonstrated the negative effect of noise pollution in cities on residents' health in cities by increasing risk of high blood pressure and cardiovascular disease, hearing loss, anxiety, and depression. Therefore, monitoring and managing noise pollution in cities is crucial to improving the quality of life in any urban environment. In the present study, remote sensing and GIS data were obtained to derive environmental and urban factors that may influence the soundscape quality. The smartphone application YOPELO was used to measure noise levels in the Al-Safa district of Jeddah. More than 25 distributed roadside spots in the study area were evaluated based on the traffic volume and mixed land use. The results of the study demonstrate noise levels ranging from 50-82 dB in the areas examined. The modeled high noise levels were significantly associated with commercial areas and higher traffic volume zones. The results of the current research can serve in assisting the government and policy makers in city planning with accordance to social, environmental and urban requirements. In addition, this research contributes to implementing Saudi Vision 2030 by providing pertinent data and interactive maps to determine city locations with lowest level of noise to create optimal public spaces. Moreover, the present research will contribute key information regarding areas with high noise pollution rates to facilitate planning and implementation of intervention strategies to make the areas more livable.

Key words: Soundscape Quality; GIS; Remote Sensing; Quality of Life

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1. Introduction

Rapid economical and societal development has led to high levels of environmental pollution, posing a major challenge to the sustainability of cities. In recent decades, there have been significant increases in various types of environmental pollution due to accelerated rapid urban and industrial growth, threatening the quality of the surrounding ecosystems. Most common types of pollution in cities include noise pollution, water pollution, soil pollution and air pollution (Jhanwar, 2016). Recently, research studies have begun to uncover the significant detrimental effects of noise pollution on health and productivity (Stansfeld, & Matheson, 2003). Therefore, assessing noise levels originating from sources including industry, traffic and transportation, as well as urban and population density is key to mitigating its consequences on human health (World Health Organization, 2009). Research studies have demonstrated that exposure to low noise levels for extended periods can result in number of health problems, including insomnia, memory disturbances, anxiety, and depression. Moreover, long-term exposure to noise pollution can result in learning abilities in children (Münzel, et al., 2018). In addition, previous studies have demonstrated that transportation is among the most common sources of noise pollution which contribute to sleep disturbances of residents of urban environments (Khan, et al., 2018). For instance, it has been estimated that in Europe, environment noise is responsible for over 900,000 cases of hypertension, 8 million cases of sleep disturbances and 43,000 cases of hospital admission due to associated conditions (Zuo, et al., 2016).

To date, several agencies have identified the limits for acceptable levels of noise pollution to minimise associated risks based on the noise level and the duration of exposure. For example, according to the United States Environmental Protection Agency (EPA), indoor noise levels should not exceed 45 dB indoors and 55dB outdoors Lee, & Fleming, 2002). Some agencies also take into consideration the proportion of land use and population density to determine the acceptable noise pollution limits. In cities that are continuously growing, the noise pollution limits are directly proportional to the level of economic development, posing a challenge in implementing policies aimed to regulate noise production.

Despite noise monitoring becoming more prevalent, studies involving accurate assessment of noise pollution levels in large urban centers are still lacking. Creating a city's soundscape is an accurate method of assessing noise pollution in urban areas (Hong, & Jeon, 2014). Noise mapping, combined with the use of geographical information systems, computational modeling, acoustic and remote sensing, is an effective and useful assessment method to visualize various areas' exposure to noise, noise source contribution and statistical data pertaining to the affected population (Zuo et al., 2016). The use of noise mapping can facilitate creation of noise control plans by the government and relevant policy makers. Accordingly, the use of noise maps in urban areas has gained increasing attention in Europe. Specifically, each European state is required to prepare, publish and manage noise maps of its major cities every five years, which become incorporated into the European Environment Agency's Report Net system (Zuo et al., 2016). The noise map report includes information such as noise composition and indicators, regions affected, techniques used to collect data, as well as the noise-mapping method used and time of the day when the data were collected. Recently, data obtained from social media sources has been used to integrate the obtained soundscape with noise mapping (Radicchi, 2018). Moreover, different mobile apps have been developed to collect user feedback and noise levels. Although different types of data sources for noise measurements are available, there are some persisting methodological problems present, including lack of consistency and

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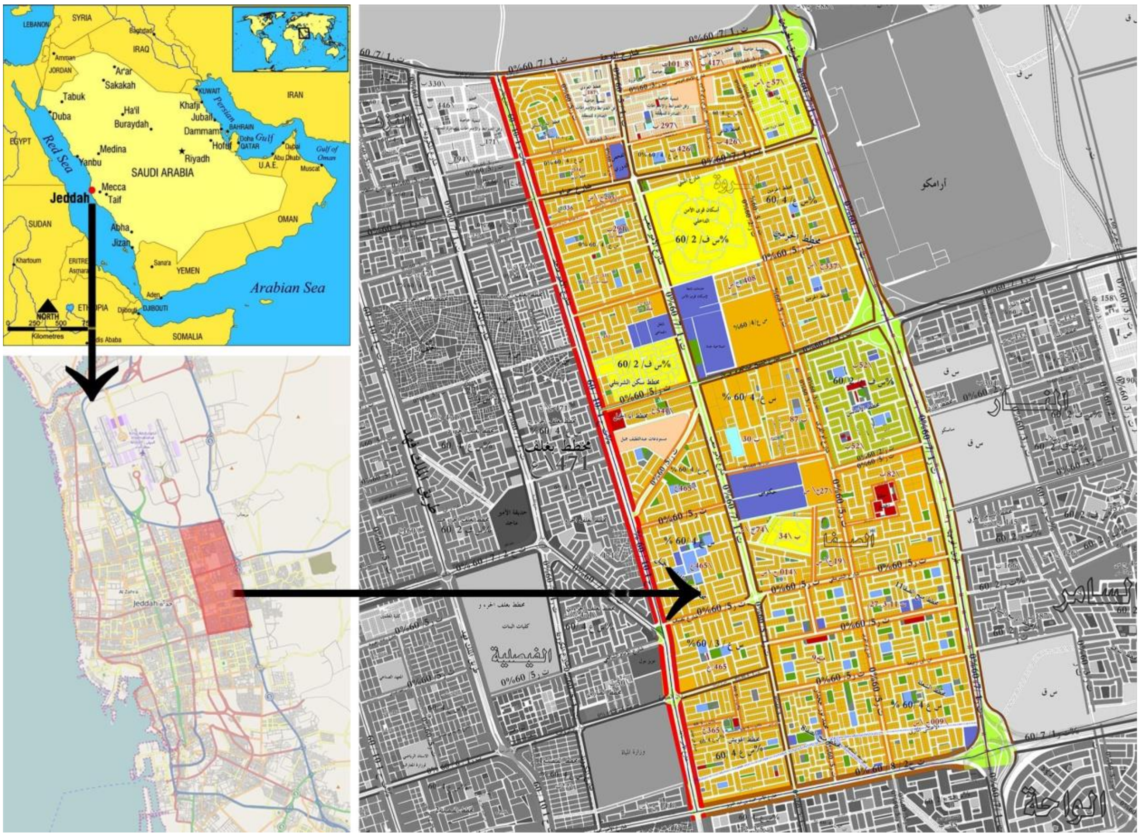
unavailability of live data. Jeddah other additional problems facing the collection of consistent and accurate soundscape data include high costs and the time-consuming nature of such research, and practical issues such as sound propagation influence by public facilities and buildings. The main objective of the present study is to establish noise maps and proposing solutions to enhance the quality of life for the residents of the Al-Safa district of Jeddah, Saudi Arabia, using live monitoring of noise. Additional study objectives include: a) Evaluation of the requirements of the present research project; B) Determination of the monitoring areas based on specified criteria; C) Evaluation of the noise data extracted from the applications used and generation of a noise map; D) Establishment of recommendations to minimize noise levels.

1.1 Case Study

The case study was carried out in the Al-Safa District. This residential district in Jeddah, Saudi Arabia is considered as one of the most densely populated districts, with a population of 188,027. The western side of the district is bordered by the Prince Maged Bin Abdul-Aziz "Al-Sab'een," while its eastern side is limited by the highway "Al-Harameen Street." The district's northern side is bound by the Sheikh Abdul-Aziz Bin Baz Street and by the Prince Mohammad Bin Abdul-Aziz "Al-Tahlia" Street from the southern side. Moreover, several of the district's main streets pass through the Prince Met'eb "Al-Arba'een" Street and the "Om Al-Qura" Street. In addition, the district itself is divided into 12 smaller subdivisions, the largest being the Al-Safa District 1, followed by the Al-Safa District 3 and then Al-Safa District 2 (Figure 1).

Figure 1. **Map of Al-Safa District Location**



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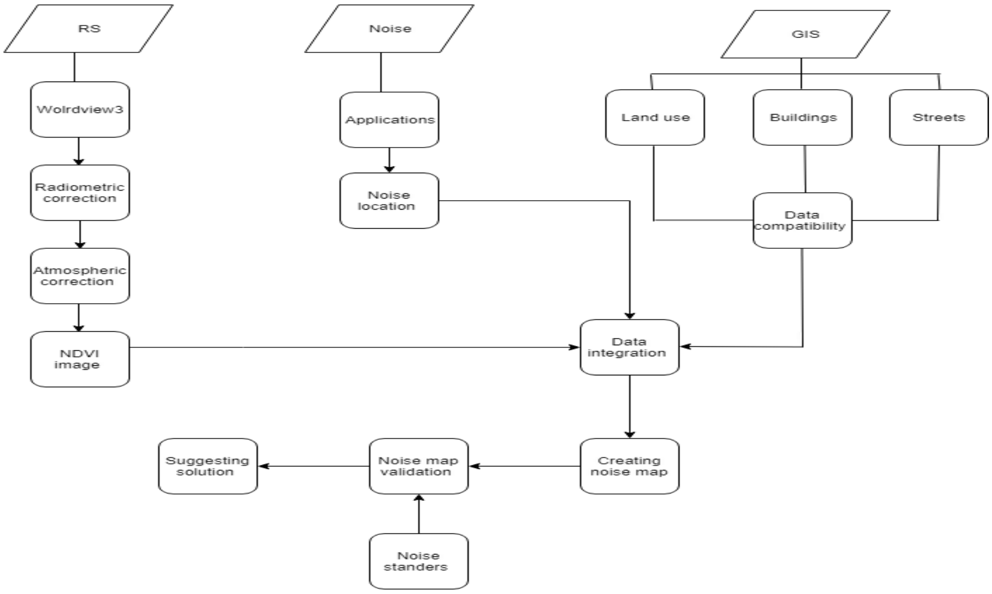
1.2 Procedure

Several study procedures are necessary in achieving an accurate rating of sound scope quality in urban areas. The first stage of this process involves collecting various data from remote-sensing and GIS. Sound data was collected using the YOPELO application and the Noise Capture application. The remote-sensing data was processed to generate the normalized difference vegetation index (NDVI) image to evaluate the presence of plants, since vegetation can contribute to reducing noise pollution. The data obtained from different sources were then merged to generate a map showing the areas with the highest noise levels. Finally, a proposal with recommendations to minimize noise pollution and improve the quality of life for inhabitants of Al-Safa District was created (Figure 2).

Figure 2. **Procedure Flowchart**



Source: Edited by Author.

1.3 Material Used

1.3.1 ENVI Program

This is one of the most widely used programs for satellite image analysis. ENVI was designed to fulfill the needs of the satellite and remote-sensing image users, providing high-accuracy results and allowing for analysis of images of various size and type. The software also allows simultaneous display of several images, enabling comparison.

1.3.2 ArcGIS program

This program has several functionalities, including processing, editing, and display of maps and digital data, as well as data display and analysis in layers. The software also allows adding items such as scale bars and legends. Moreover, this program permits organizing and managing GIS files, as well as recording and displaying documentary data. Finally, the software also includes tools for browsing and searching geographic information related to GIS files.

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1.3.3 Noise Capture application

This is a free software available for download to android devices, which allows the user to measure and share noise levels. Every acquired measurement is connected to the GPS to provide accurate results pertaining to the monitored locations.

1.3.4 YOBELO application

This application is privet software developed by Visibird Company and used to measure sound intensity and provides coordinates indicating the location of each measurement.

2. Literature Review

2.1 Background

Soundscape evaluation is a multidisciplinary process involving scientists from fields such as anthropology and psychology among others. Notably, some of the ongoing research is aimed at evaluating users' interactions with various private and public urban spaces, as well as the influence of visual and auditory factors on the quality of their experiences (Bild et al., 2018). Previous studies were aimed to determine soundscape indicators and descriptors that can assist in describing or predicting the space users. Soundscape competence is determined by the users' expectations and familiarity (Bild et al., 2018). Sound analysis can permit identification of its sources, as well as to deduce its complexity and pleasantness. The evaluation of sounds in the cities is then determined using soundscape, which allows the noise cause to become accepted or rejected. Such researches can Jeddah help to determine the allowable limit of noise pollution and the duration of exposure, in addition to its acceptable sources. Moreover, soundscape evaluation can determine the most common locations exposed to noise pollution using various geomatics applications, including geographical information and high-resolution satellite images. Finally, the data collected as part of the current study can help to contribute to implementing necessary changes in the Saudi Vision 2030 by providing necessary recommendations to decrease noise pollution and increase the quality of urban spaces.

2.2 Noise Pollution

Noise pollution can be defined as any undesired sound which is perceived as a nuisance when carrying out daily activities such as sleep, work or even a carrying a conversation (Goines, & Hagler, 2007) Noise pollution has been an undervalued problem since its effects on human health are cumulative; however, the World Health Organization (WHO) has declared noise pollution as one of serious threats to human health (Berglund et al., 1999).

2.3 Sound Levels and Unit of Measurement

The effects of noise pollution differ can differ between individuals. Some individuals are more sensitive to loud sounds, while others can be more sensitive to high frequency sounds. In general, any loud sound that is continuous for an extended period of time can be damaging to human health (Glorig, 1961). The intensity of sound is measured in decibels (Db). The sound intensity of normal conversation is approximately 60 Db. Generally, any sound higher than 85 Db in intensity is considered harmful based on the duration of exposure and whether ear

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protection is used or not (Berglund et al., 1999). Table 1 below demonstrates the intensities of various sound sources.

Table 1. **Harmful Noise Levels**

Sound	Level in decibels
Rustling of leaves	30 dB
Domestic sounds	40 dB
Casual conversation	60 dB
Office sounds	70 Db
Vacuum cleaner	75 dB
Traffic jam	80-89 Db (sounds over 85 Db are considered harmful)
Audience at sports events	120 – 129 dB
Jet aircrafts	140 dB

Source: HealthLink BC

2.4 Sources of Noise Pollution

2.4.1 Traffic jams

In Cities, the source of noise in traffic jams mainly originates from cars and car exhaust, as well as from trucks and buses. This type of pollution has been increasing due to narrow streets and larger numbers of vehicles as a result of population growth.

2.4.2 Planes

Military and commercials planes flying at low altitudes have added a new source of noise pollution in recent decades, now affecting new environments such as gardens and spaces inhabited by wildlife.

2.4.3 Trains

Sounds generated from engines, horns, and whistles originating from trains traveling on railways can affect nearby residential areas. For example, a train car can generate high-frequency noise that may reach 120 Db, affecting nearby houses and individuals working on the train and in the nearby areas (Berglund et al., 1999). Rail traffic, air traffic, and road traffic are some of the main causes of environmental pollution.

2.4.4 Construction

Sounds generated by construction work either on highways or in the cities are considered to be a major source of noise pollution. Construction includes the use of air hammers, bulldozers, cranes and other noise-producing instruments, increasing noise pollution in cities (Berglund et al., 1999). Wearing hearing protection devices (HPD) by construction workers can help to reduce health problems related to noise.

2.4.5 Factories

Factory noise is less common in large cities, as factories are usually present in areas that are relatively far away from residential districts. However, there are some cases where houses are located close in proximity to factories. In these cases, residents living close to the factories often suffer from noise exposure. Operating tools and large machines used in the industry generate

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high-intensity sounds that can have significant health consequences for both workers and residents alike.

2.5 Harmful Effect of Noise Pollution

Continuous exposure to noise is a major cause of many health problems such as anxiety, lack of concentration, reduced productivity and insomnia (Berglund et al.,1999). The negative health effects experienced can develop into more serious health issues, including cardiovascular problems and/or hearing loss. Hearing is one of the five essential human senses. Continuous exposure to loud sounds causes damage to the ear structure, which can result in hearing loss, especially upon exposure to sound levels of over 85 dB for extended periods of time (Basner et al., 2014). Noise prevents city residents from enjoying calm sleep, causing insomnia and related health issues. Lack of sleep also causes fatigue and mood disturbances (Goines, & Hagler, 2007). Based on scientific studies, exposure to high-intensity noise for prolonged time periods results in decreased cognitive awareness, causing reduced problem-solving abilities (Davies, 1968). High levels of noise result in release of stress hormones, including adrenaline and cortisol (Andren et al., 1982). Accordingly, long-term exposure to high-intensity sounds can cause chronic stress, resulting in increased blood pressure and cardiovascular disease (Davies et al., 2009).

2.6 Application of GIS on Noise Pollution

Geospatial Information Systems (GIS) can conveniently be adapted to gather, analyze and present noise information. GIS can also be extended to answer to user-specific problems through deterministic and statistical models. There are many studies have applied the use of technologies and GIS to present noise information in many cities. A study has done to develop day and night road traffic noise maps for Guangzhou using Geographical Information Systems (GIS) and Global Positioning Systems (GPS). First, as speed-density relation is used to estimate the traffic volume from GPS data collected from floating cars. Meanwhile, the attributes of the roads and buildings are automatically exported from GIS. Second, a single vehicle noise emission model is combined with a noise propagation model to formulate a regional traffic noise calculation model that accounts for the traffic noise attenuation in an urban area. The results show that the average error between the estimated and measured values is below 2.0 dB (Yilmaz & Hocanli, 2006). Continually, A GIS-based noise assessment was carried out to study the noise pollution scenario of Guwahati city at various locations, i.e. commercial zones, residential zones and silence zones (educational institutions and hospitals and nursing homes). Sound Level Meter (SLM) was used for assessment of noise levels and noise mapping was done using Geographic Information System (GIS) technique. From the study, it was observed that noise environment of the Guwahati city is deteriorating and unsafe in various locations for human and it exceeds the noise standards suggested by the Central Pollution Control Board (CPCB) and Bureau of Indian Standards (BIS). This study also highlighted the noise polluted and vulnerable areas through diurnal noise mapping. It was also observed from the study that, places with high traffic congestion, narrow roads, heavy constructional activities, and poor traffic management areas are more vulnerable to high noise levels (Alam, 2011). Subsequently, a detailed method used for assessing and mapping noise pollution levels in Ota metropolis, Nigeria using ArcGIS 10.5 Software is presented in this paper. Noise readings were measured at a time interval of 30 min for each site considered using a precision grade sound level meter. The noise map was developed based on the computed values of average equivalent noise

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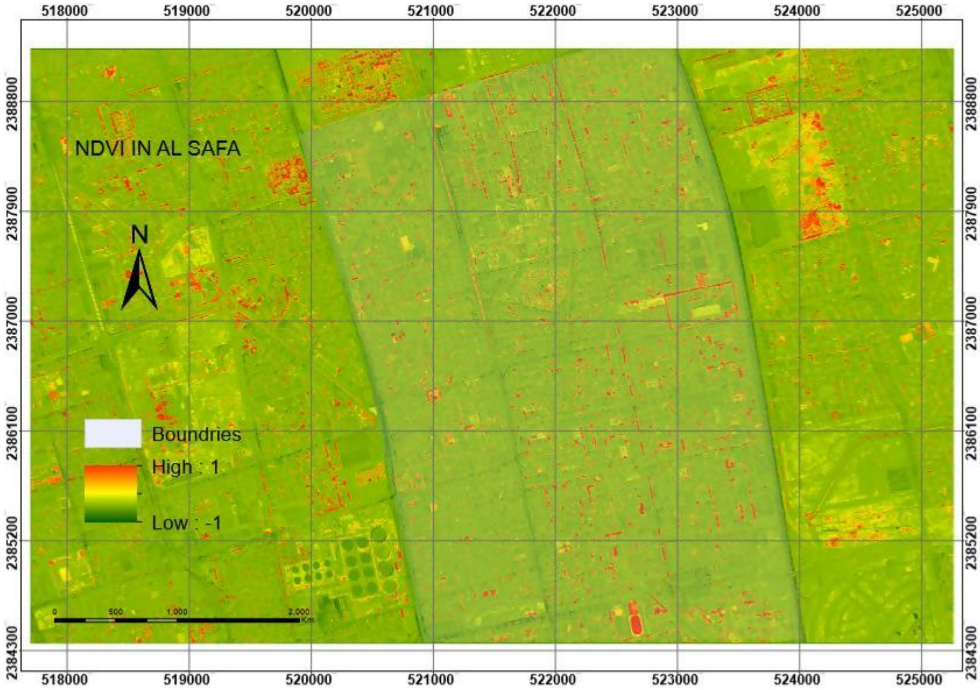
(LAeq) for the selected locations. Results of this study show that the A-weighted sound level (LAeq), the background noise level (L10) and the peak noise level (L90) vary with location and period of the day due to traffic characteristics especially traffic volume, vehicle horns, vehicle-mounted speakers, and unmuffled vehicles at road Junctions, major roads, motor parks and commercial centers (Oyedepo et al,. 2019). Many other studies have been reviewed in order understand, analyze and applied similar methods within our research.

3. Methods and Results

Different approaches were used to examine level of social interactions of users' expectations, familiarity, and activities that affected soundscape quality rating. The hardware and software used in the study have two subsystems: the processing core and the acquisition subsystem. The methods used in the study are described below:

3.1 Step 1: Extracting the NDVI

Figure 3. **Vegetation Cover (NDVI) of Al-Safa District**



Source: Edited by Author.

Initially, high-resolution images of the Al-Safa District were used, and radiometric calibration was achieved in order to calculate the spectral footprint, Afterward, the atmospheric correction was done, Finally, the NDVI was extracted from the images (Figure 3). The use of NDVI allows transforming multispectral data into a single image band representing vegetation distribution, as the amount of green vegetation present in the pixel. Therefore, NDVI values range from −1 to +1, where negative values correspond to an absence of vegetation (Imam et al., 2016). This analysis permits the detection of healthy plant cover present in the area studied.

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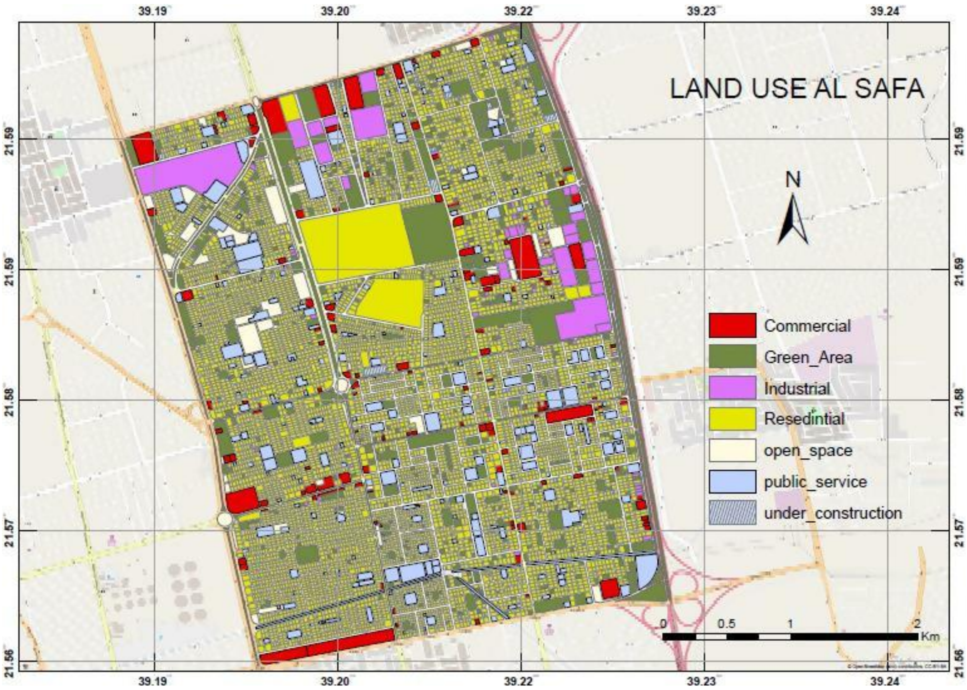
3.2 Step 2: Field Data Collection

The times for field monitoring and rush hours were determined using Google Maps. The software was also used to determine the most congested locations of the Al-Safa District, yielding 25 areas distributed over the district. Subsequently, the monitoring process was initiated using YOBELO and Noise Capture applications. Obtained data were exported in the form of Excel files containing the coordinates for the monitoring locations and the average of sound levels. The data were then processed, organized and converted into a text file to be entered into ArcGIS.

3.3 Step 3: Processing Using GIS

The data of land use in the Al-Safa district obtained from the Jeddah municipality required amendment and organization in order to be used in the study, which were carried out in order to generate the resultant map to indicate the district areas with the highest noise pollution (Figure 4).

Figure 4. **Amended Land Use Map of Al-Safa**



Source: Edited by Author

The map was divided into commercial buildings (highlighted in red), as well as green areas (highlighted in green), industrial areas (highlighted in pink), open areas (highlighted in white), public services as schools (highlighted in light blue) and buildings under construction (highlighted in grey). After data were amended, the data points were exported from monitoring programs, which included the X and Y coordinates and the average sound levels. The pathways for data monitoring involved the use of the applications Noise Capture and YOBELO (Figure 5 & Figure 6).

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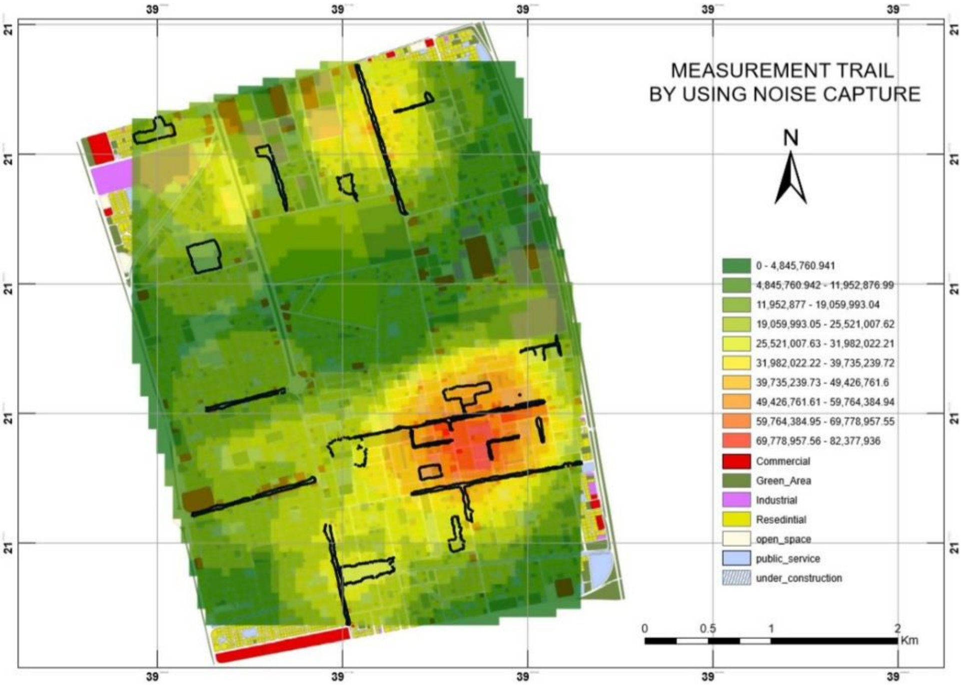
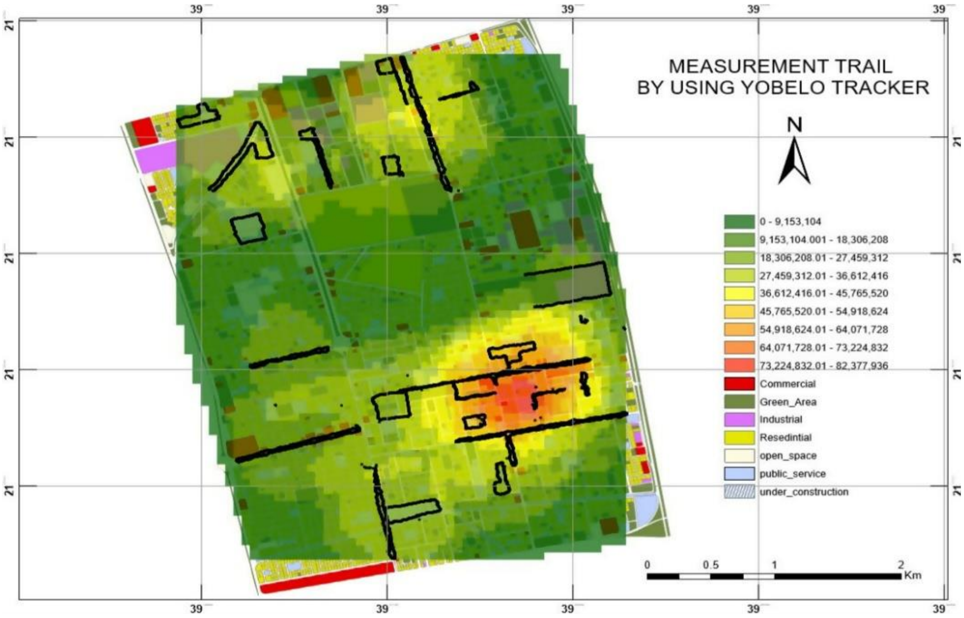
Figure 5. **Measurement Trail Using Noise Capture Application**



Source: Edited by Author.

Figure 6. **Measurement Trail Using YOBELO Application**



Source: Edited by Author.

After completion of identification of the noise points on the map, the last step of the methods involved generating a map which demonstrated the district areas with the highest noise pollution based on the points entered using the spatial analyst toolbox on ArcGIS and then determining the areas with the highest noise pollution. Subsequently, noise maps were generated showing

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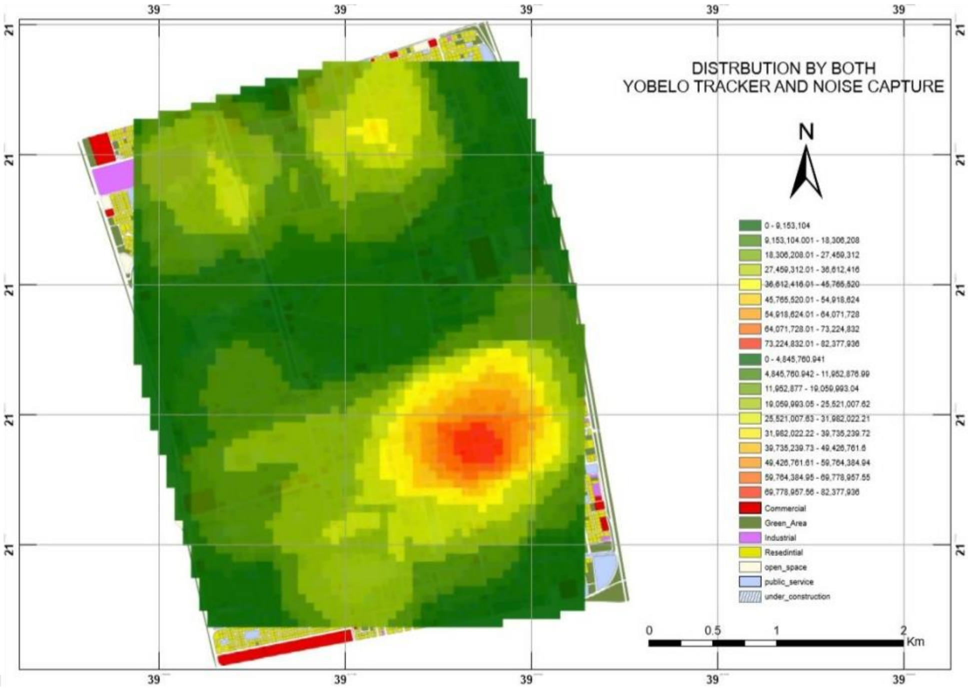
the areas with the highest level of noise pollution using the two applications, which were merged into one map (Figure 7).

Figure 7**. The map generated by Noise Capture and YOBELO**



Source: Edited by Author.

4. Conclusions and Recommendations

4.1 Conclusions

After determining sound levels and establishing the limit of what can be considered as noise pollution, as well as monitoring the level of noise in the Al-Safa District, we determined that the Abdul-Aziz Bin Ibrahim Street was the most affected area assessed. The average level of noise pollution recorded in this location was between 75-85 dB. This street is considered a commercial street with high traffic. Moreover, car horns are commonly used by cars in the passing traffic, which is itself poorly organized. Moreover, the study observations include lack of plant vegetation on the street, which would normally serve to absorb some of the noise produced.

4.2 Recommendations

As part of the Saudi Vision 2030, improving the quality of life for the Kingdom's residents and citizens one of the top aims of the program. Using the study results, the following recommendations can be made to contribute to achieving this aim, including the following:

1. Increased use of vegetation, including trees, in urban spaces for noise absorption purposes.
2. Better organization of urban spaces which experience crowding.
3. Relocation or re-organization of the district's informal markets.

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4. Raising awareness of the harmful effects of noise pollution among the city authorities.
5. Encouraging city residents to limit the use of car horns.
6. Improved maintenance of gardens in the residential districts.
7. Implementing additional taxes and fines for polluting entities.

Implementing these recommendations can help to reduce levels of noise pollution and improve the quality of life of residents of the Al-Safa District of Jeddah, while increasing the quality of urban spaces in the district. Finally, it should be noted that this piece of research is an initial part of a long-term project to create a noise map for the entire city of Jeddah. This part of research will be followed by other studies using additional methods and technique in order to achieve more accurate results. Furthermore, part of the continuing studies will focus on finding out the urban elements with the higher impact on urban noise levels positively and negatively which help to develop urban solutions that can be applied to many public spaces with the goal of the reduction of urban noise pollution.

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Conflict of Interest: The author declares no conflict of interests.

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