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Noise Mapping of an Educational Environment: A Case Study of South Dakota State University

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NOISE MAPPING OF AN EDUCATIONAL ENVIRONMENT:

A CASE STUDY OF SOUTH DAKOTA STATE UNIVERSITY

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science in Geography degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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TABLE OF CONTENTS

ACRONYMS

2D	two-dimensional
ArcGIS	Trademark name of ESRI GIS software
CDC	Centre for Disease Control and Prevention
dB	decibel
dBA	A-weighted decibel
DND	Daily Noise Decibel
DNM	Digital Noise Meter
EEA	European Environment Agency
END	European Noise Directive
EPA	Environmental Protection Agency
ESRI	Environmental Systems Research Institute
EU	European Union
GIS	Geographic Information Systems or Science
GPS	Global Positioning System
MSE	Mean Squared Error
NIOSH	National Institute for Occupational Safety and Health
NOAA	National Oceanic and Atmospheric Administration
OSHA	Occupational Safety and Health Administration
OSM	Open Street Map
PEL	Permissible Exposure Limit
RMSE	Root Mean Squared Error
SDDOT	South Dakota Department of Transportation
SDSU	South Dakota State University
SPA	Smartphone Application
TWA	Time Weighted Average
U.S.	United States
USGS	United States Geological Survey
WHO	World Health Organization
WSP	World Soundscape Project

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

NOISE MAPPING OF AN EDUCATIONAL ENVIRONMENT:

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Sound is the subjective dimension of what we hear when vibrations reach our ears. Noise, or unwanted sound (mostly human caused), is an objective function of the pressure of those vibrations and is often measured using decibels (dB). Noise is a type of pollution that has both direct and indirect negative impacts on humans, with significant implications for public health plus social, economic, and environmental well-being. Mapping the acoustic landscape (i.e., soundscape) using noise and sound data provides important insights for evaluating, interpreting, understanding, and managing environmental noise. The objectives of this research are threefold; to map the spatial and temporal patterns of the SDSU campus' soundscape, to identify the dominant sound sources at various locations, especially "problem areas", and to compare the quality of noise data collected from a smartphone application (SPA) and a traditional digital noise meter (DNM).

A SPA and DNM were used to simultaneously collect noise level data at the same collection sites in the field. A digital audio recorder was also used to collect sound data, which were subsequently classified based on their source into one of four different categories: mechanical; natural; human; and, communications. Ordinary kriging was used to interpolate both noise and sound data. A t-test was used to compare the mean noise levels across different time periods and test for significant differences between noise data collected using the SPA and the DNM.

Results clearly indicate that mechanical sound sources dominate SDSU's soundscape. The noise levels captured by the DNM ranged between 43-67, 44-69, and 43-61 dBA during the morning, afternoon, and evening, respectively. Similarly, noise levels captured by the SPA ranged between 44-71, 38-65, and 41-64 dBA during the morning, afternoon, and evening, respectively. The t-test results indicate that mean noise levels measured from these two devices did not exhibit statistically significant differences. Mapping the noisescape and the soundscape allowed the identification of problem areas and it also provided important insights that can be used to mitigate environmental noise issues. The results could also be used to raise awareness of the social, economic, environmental, and public health implications of noise pollution.

Keywords: noise mapping; sound mapping; soundscape; GIS; noise pollution

CHAPTER ONE: INTRODUCTION

Sound is the subjective dimension of what we hear when vibrations reach our ears. Noise, or unwanted sound (Berglund, Lindvall, & Schwela, 1999), is mostly created by human activities (Environmental Noise Directive, 2002) and is a type of pollution that affects people's health plus their social, economic, and environmental wellbeing. Noise pollution is one of the growing environmental concerns in the United States; every year, tens of millions of Americans suffer from a range of adverse health outcomes because of noise exposure (Hammer, Swinburn, & Neitzel, 2014). Noise pollution can negatively affect humans both directly and indirectly (European Environment Agency, 2014). The negative health effects include sleep disturbance, hearing impairment, annoyance, cardiovascular effects, and cognitive functioning, especially in school children (Aziz et al., 2012; Basner et al., 2014), and it negatively impacts wildlife (Barber, Crooks, & Fristrup, 2010; Laiolo, 2010).

It appears that decision makers have for too long overlooked noise pollution in environmental planning, apparently in favor of air and water pollution. Leading the way, many European countries have passed laws to mitigate rising noise levels. Regionally, the Environmental Noise Directive (END) was passed in 2002 and is used across the European Union to identify noise pollution and trigger necessary action at Member State and EU levels. The END requires member states to develop noise maps and noise management action plans for larger cities and along transportation nodes and corridors. In urban areas, educational institutions are among the main targets to reduce noise levels. The United States (U.S.), however, lags behind on the development of noise maps and implementation of noise management action plans. In fact, the U.S. Congress has not seriously brought this topic up for discussion in the senate for more than three decades (Hammer et al., 2014). Despite political inaction, noise pollution remains a topic of concern for many American citizens.

The U.S. does have a national noise policy; the Noise Control Act of 1972. This Act directed the U.S. Environmental Protection Agency (EPA) to conduct research on noise exposure and its effects, and to document acceptable level of noise levels under various environments. The EPA "Levels Document", published by U.S. Noise Abatement and Control office (1974), later became a hallmark to protect public health by describing sound exposure, identifying human related noise exposure impacts, and establishing noise exposure criteria for various effects. These actions led to the development of guidelines for environmental noise, which has been applied widely to road traffic and aviation noise, but noise pollution surrounding educational institutions has not been adequately considered.

Strategic noise mapping can help identify "problem areas" and provide the information necessary for decision makers about the social, economic, environmental, and public health impacts of noise. This research project employed Geographic Information System (GIS) capabilities to store, analyze, and communicate the results from an integrated data collection campaign to map both noise and sound. The results should provide useful information to the campus community in general and campus planners particularly. This research aims to map the soundscape of South Dakota State University's campus using acoustic intensity (noise) and acoustic quality (sound) to investigate spatial and temporal patterns of noise and sound. The results can be used to identify problem areas and propose workable solutions.

1.1 Problem Identification and Description

South Dakota State University (SDSU) aims to increase its student population to exceed 14,000 by 2018. The campus has adopted four different strategic goals; academic excellence, research and innovation, outreach, and a high performing university (SDSU, 2018). The first goal aims to promote academic excellence through quality programs, engaged learners, innovative teaching, and learning environment to attract more students (SDSU, 2018).

There are internal and external factors that determine the quality of learning quality or the quality of the learning environment. Internal factors include an instructor's performance, management, materials, and so forth. External factors, on the other hand, encompass environmental factors that can affect a student's accomplishment. The general ambience of a school, especially psychosocial ambience, is an important component of a student's success. Educational areas, thus, need a tranquil environment, because long-term and repeated noise exposure or disturbance may lead to psychological health complications and reduce students' learning ability or motivation.

Apart from well-equipped infrastructure, skilled teachers, and logistics, a quality learning environment should also include freedom from noise pollution or noise disturbance as a key factor. This research seeks to determine whether SDSU has any "problem areas" with noise pollution, or if SDSU's entire sonic landscape aligns with the mission, vision, and strategic goals of creating a "quality learning environment". This research aims to measure and map noise and sound for SDSU's exterior acoustic environment to identify any possible problem areas. Given the widespread use of external fans and air conditioners across the campus, as well as other mechanical sources of noise, it is reasonable to suspect there are many places across campus that negatively affects SDSU's quality learning environment.

1.2 Research Objectives

This research developed noise maps and sound maps for SDSU's campus. The resulting strategic noise maps could prove useful in identifying problem areas and preparing noise management action plans for the university campus, and perhaps other campuses across the state. The specific research objectives of this thesis are: (1) prepare two-dimensional (2D) outdoor noise maps of the SDSU campus at different spatial and temporal resolutions; (2) classify and map sound of the SDSU campus; and, (3) compare the relative advantages of using a traditional digital noise meter device compared to a smart phone application to collect noise data.

This thesis also aims to answer several research questions, which are listed as follows.

- Does the campus soundscape align with SDSU's mission, vision, and strategic goals of a "quality learning environment"?
- Do noise levels vary significantly across SDSU's campus at different locations in space; where are the most noisy and quiet places?
- Do noise levels vary significantly across SDSU's campus at different times of the day; what are the most noisy and quiet times?
- What are the prominent sources of sound across SDSU's exterior educational environment, and which sound source is most prominent?
- Are there any significant differences in the quality of noise data collected by a

smart phone application compared to a digital noise level meter?

1.3 Study Significance

GIS can be used as a tool to store, analyze, and visualize noise pollution through its built-in geostatistical and spatial analysis capabilities. Dating back almost a century, community planners have been using noise maps to communicate the spatial distribution of noise (Glück, 1973). Noise maps within GIS have been prepared for most European countries (Bellucci, Peruzzi, & Zambon, 2017; Murphy & King, 2016), but such maps are far less common in the United States, and virtually non-existent in South Dakota. Noise studies in the US, unfortunately, are almost exclusively limited to highway, railway, or airport noise (Khoo, 2013).

To the best of the author's knowledge, this research is the first of its kind conducted at the scale of a university campus in South Dakota. The results from the study could help improve noise management and inform the development of a strategic noise plan for the university campus, and potentially for other locations across the state. This soundscape mapping could also help faculty, students, and residents understand the acoustic environment across the campus. The noise and sound maps generated by this research can provide a tool to study spatial and temporal distribution of noise, to identify noisy "problem areas", to inform noise reduction measures, and so forth. Moreover, the resulting noise and sound maps for SDSU enable exploratory analysis that can provide information to help identify problem areas and specific undesirable sources of sound. The results also aid in the overall understanding of the outdoor acoustic environment of the SDSU campus.

1.4 Geographic Context

The study area for this research project was South Dakota State University campus (Figure 1), which is located in the City of Brookings, South Dakota (SD) at approximately 44.3189°N latitude and 96.7870°W longitude. The SDSU campus has a total area of over 250 acres and in 2017 was home to over 12,500 students (SDSU, 2018). The monthly daily average temperature ranges from 12.9°F (-10.6°C) in January to 70.3°F (21.3°C) in July (NOAA, 2017). The average relative humidity in midafternoon is about 60 percent, but it is usually higher at night with 81% (Schaefer, 2005). The wind direction is usually from the south, and average windspeed is 10-12 mph (Schaefer, 2005).

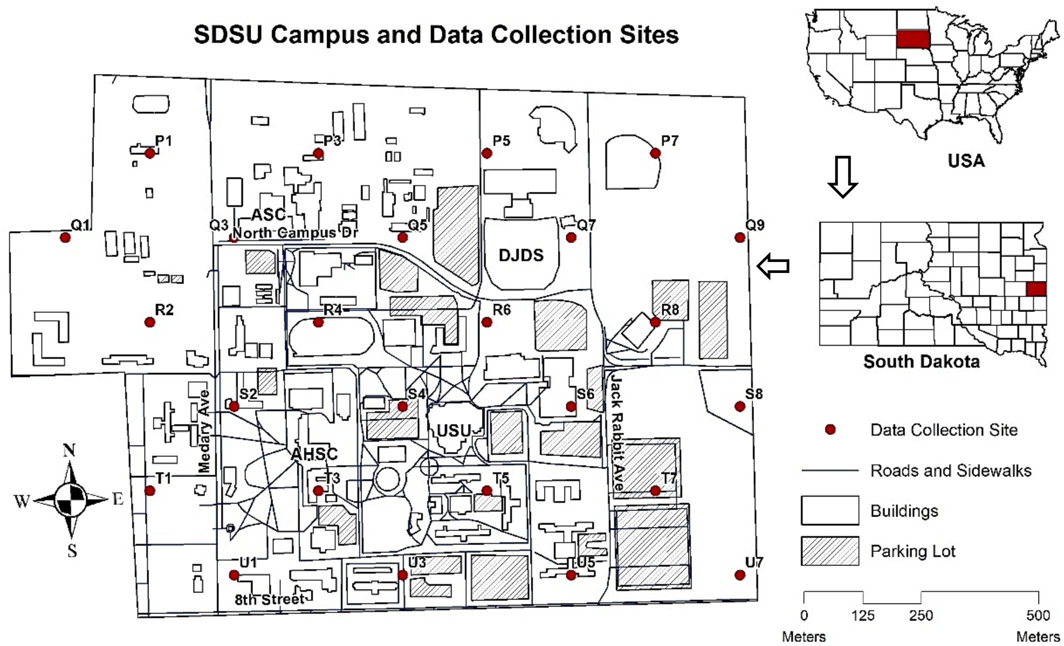


Figure 1. Study area and data collection sites.

Figure 1 illustrates the distribution of data collection sites across SDSU's campus. The systematic (i.e., bishop's case) sampling of data collection sites used the centroids

200m grid cells, which resulted in 25 data collection sites. Non-edge data collection sites are each surrounded by four other sample sites within 400 meters. SDSU's campus is exposed to different sources of sound, which are classified for this thesis into four categories; mechanical, natural, human, and communications. Mechanical sources include sound from traffic, exhaust fans, lawnmower, air conditioners, and so forth. Natural sources include sound from wildlife, pets, wind, running water, and so forth. Human sources include sound from steps, eating, background (inaudible) voices, cellphone ringing, and so forth. Communications sources include sound from intelligible conversation, talking on cell phone, music, radio, TV, iPod, and so forth.

The main roads surrounding SDSU's campus (Figure 1) include Medary Ave, North Campus Dr, 8th Street, and Jack Rabbit Ave, where the flow of vehicles is heaviest. The study area has also many sidewalks and smaller roads, where the movement of students and bicycles occur, that are tree-lined for safety and as a minor sound barrier. However, when the trees shed their leaves during winter, they are less effective as a noise buffer. The trees also provide habitat for birds and tree squirrels, which add to the campus' soundscape. There is a large garden around Medary Ave, on the south west side of the campus near in between data collection site S2 and T1, where the flow of students is particularly high. The campus has many parking lots (about 10, including three large, and other smaller ones) that are mostly located on the periphery of campus. The capacity of these parking lots ranges from 20 to 2,000 vehicles. Classes normally start at 8:00 AM in the morning and continue until 6:00 PM. The flow of students (and their relative contribution to the soundscape) is typically much higher when they are transitioning between classes.

Figure 1 also indicates the location of particular streets, buildings, and parking lots that provide landmarks, or reference locations that will be used to help explain the spatial distribution of noise and sound. The buildings chosen as landmarks include animal science complex (ASC), Avera health and science center (AHSC), Dana J. Dyke Stadium (DJDS), and University Student Union (USU). The major streets used for reference purposes are Medary Ave, 8th Street, North Campus Dr, and Jack Rabbit Ave. Also, the parking lots are highlighted in Figure 1, because they tend to generate traffic and associated impacts on the soundscape.

CHAPTER TWO: LITERATURE REVIEW

This research reviewed literature from multiple disciplines to gain a better understanding of the meaning and significance of both sound and noise, the existence of relevant guidelines or legislation pertaining to the source and volume of sound, and tools and techniques used to measure noise and sound.

2.1 Understanding Sound

Raymond Murray Schafer, a composer and a professor at Simon Fraser University, first introduced the concept of a soundscape through his 1977 book called "The Soundscape: Our Sonic Environment and the Tuning of the World". In his book, he tried to answer two major questions related to the relationship between humans and the sound of their environment. The first pertained to the consequences that can occur when those sounds change. The second question pertained to the sounds that humans want to preserve, encourage, or multiply. Schafer (1977) further argued in his book that over time humans' sound environments, which he calls "soundscapes", have moved from hi-fi to lo-fi. In a hi-fi soundscape, distinct sounds can be heard more clearly due to the low ambient noise level. However, in lo-fi soundscape, even powerful acoustic signals are obscured due to an overpopulation of sounds. Thus, he defined soundscapes based on tonality (sound quality), signal, and the sound print. He also advanced categorization of sound sources based on function and the meaning of the sounds. He taught many people from different disciplines to listen and somehow become more present in their everyday environment, and about how to listen. He emphasized walking through the world with our ears open to emphasize the importance of listening. He believed that listening gives a presence in our environment and a sense of being in a place.

Several people (e.g., Barry Truax, Bruce Davis, Peter Huse, and Hildegard Westerkamp), through their “World Soundscape (WS) Project”, have built upon Schafer’s work. For example, Truax (2001) focused on the ways of listening. For instance, he stressed that we should listen to the environment consciously and attentively as if it were music. Truax later focused on sounds that are antique, ephemeral, or disappearing, such as sound of a landline telephone’s bell ringing, and so forth. It is noteworthy that Brown (2004) also posits that soundscape is about the preferred sound sources and desired acoustic environment.

Guyot, Nathanail, Montignies, & Masson (2005) upgraded the existing databases on sound sources experienced in urban environments to understand how urban noise was perceived. The method was based on the physical description of urban spaces and sound sources, and on the perceptive evaluation of principal sources. They conducted both linguistic descriptions and field surveys in France and Greece, where they classified sound sources into four categories: nature (animals, elements), human (people, shopkeepers, children), activities (performances, road traffic, shops, deliveries, works, street cleaning), and objects (autonomous sound objects, epiphenomenon, background).

Guastavino (2006, 2007) categorized sounds based on the extent of human intervention. The three categories were: first, sounds that are directly related to human presence such as voice, steps, and so forth; second, sounds that are indirectly related to human presence such as vehicles, music, and so forth; and third are sounds that are not related to humans at all, such as natural sounds. She also discussed the relevance of situational factors in sound categorization; people categorize sounds into meaningful categories to make sense of their environment. A similar sentiment is posited by Foale (2014), who focuses on a phenomenological perspective whereby the only thing that truly matters is how the listener feels about the soundscape, which thereby defies objective measurement.

2.2 Understanding Noise

Noise, physically speaking, is a random signal with no spectrum or pattern. There are multiple approaches to define and to quantify noise, but most of them focus on the physical attributes and the subjective perceptions. The physical attributes of noise include amplitude (loudness), frequency (spectrum, pitch), and rate (intermittent, impulsive). On the other hand, the perceptual properties of noise are based on whether noise is wanted or unwanted or how annoying the noise is. Most people consider the perceptual dimension of noise, but Berglund et al. (1999) argue that environmental or community noise assessments should consider both the physical and perceptual properties of noise. However, Kinsler, Frey, Coppens, & Sanders (1999) warn that since the human ear has limited range, and it is less sensitive to lower frequencies than to higher frequencies, sound pressure levels need to be made the priority for policy and practice. The standard unit of measurement for sound pressure levels is the decibel (dB). One decibel is an exponent to the reference point of 20 micro Pascals or about 0.000000003 pounds per square inch. For these reasons, several different weighting systems have been proposed, such as daily noise dose (DND), time weighted average (TWA), permissible exposure limit (PEL), exchange rate, equivalent sound level (L_{eq}), day/night level (L_{dn}), and impulse noise. Among the different weighting systems, the “A” weighting (dBA) is the most commonly used for all noise levels.

The daily noise dose (DND) is defined as the percentage of admissible noise exposure experienced by a worker over a given point of time (Occupational Safety and Health Administration [OSHA], 2013). It is often thought as a “mid-point” descriptor that considers the peaks and the valleys during an 8-hour time than reflection of individual’s point in time. OSHA (2013) describe DND mathematically in Equation 1.

$$D = \frac{C(1)}{T(1)} + \frac{C(2)}{T(2)} + \cdots + \frac{C(n)}{T(n)} \qquad \text{(Equation 1)}$$

Where C(n) equals total time of exposure at a specific noise level and T(n) equals the reference duration for that level.

The DND formula considers an eight-hour workday, even if it is not measured for the full eight hours. The average exposure for the day is computed by adding the amount of time the workers spend in each noise levels. This time-weighted average is the mean exposure to occupational noise by workers without experiencing significant adverse health effects over the standardized work period (8-hour a day) (OSHA, 2013). It is the sum of average of concentration expressed over time (Equation 2).

$$\mathrm{TWA} = \frac{t_1 c_1 + t_2 c_2 + \cdots + t_n c_n}{t_1 + t_2 + \cdots + t_n} \qquad \text{(Equation 2)}$$

Where, t equals duration, and c equals concentration.

The permissible exposure limit (PEL) is the maximum permissible noise level that an employee/worker can be exposed to for a specific duration (eight-hour work day) (OSHA 2013). The PEL is 90 dBA for eight hours in the U.S. (Table 1). The DND for a worker exposed to 90 dBA for eight hours is 100%. Anything equal to or less than 100% is tolerable and will not exceed daily limits.

Table 1. Daily permissible exposure limits for the U.S.

Sound Level (dBA)	Permissible Daily Exposure (hours)
90	8
95	4
100	2
105	1
110	0.5
115	0.25

Source: Occupational Safety & Health Administration (OSHA) 2013

The exchange rate is the rate at which sound exposure level changes with a collateral change in the PEL (OSHA, 2013). OSHA set the exchange rate as 5 dB, which means an increase of 5 dBA is equivalent to the doubling of an exposure duration to any sound source. If the daily PEL for 90 dBA is eight hours, then the daily PEL for 95 dBA would be four hours. The exchange rate, however, in Europe, U.S. Department of Defense, and EPA is only 3 dBA, making it as a historically contested subject.

The equivalent sound level descriptor (L_{eq}) is a time weighted average representing total sound energy felt over a period as if it were continuous (OSHA, 2013). For instance, if a $L_{eq}(1) = 80$, it means that all sound energy integrated over a one-hour period is presented by the same energy as an unvarying 80 dBA sound. L_{eq} is the preferred noise descriptor by the U.S. government. The calculation of L_{eq} is based on Equation 3

$$L_{eq}=L_i + 10 \log X_i \qquad \text{(Equation 3)}$$

Where L_i equals level experienced for a period of time and $10 \log X_i$ equals the proportion of time L_i with respect to total time (8 or 10- hour work day).

The day/night level (L_{dn}) was started because unwanted sounds become more detectable during late nights (after 10 PM) and very early mornings (before 7 AM) (OSHA, 2013). L_{dn} is used for land-use planning and community noise assessment.

Impulse noise is computed differently than steady state noise; it is assessed by counting the number of repetitions of any noise greater than 100 dB that a worker is exposed to during their work day (Table 2). This count is then compared to number of allowable repetitions per day for a noise of that intensity.

Table 2. Impulsive sound pressure levels allowed for repetitions during a day

Range (DB SPL)	Allowable Repetitions/Day
> 140	0
140	100
130-139	1,000
120-129	10,000
110-119	100,000
100-109	1,000,000

Source: Occupational Safety & Health Administration (OSHA) 2013

2.3 Noise Guidelines

Berglund et al. (1999), in accordance with WHO, suggested that guidelines for community noise (also called environmental noise, residential noise, or domestic noise) should consider various environments, all noise levels, noise impacts, and sound sources except for industrial workplaces. For instance, in the case of schools, outdoor environmental noise levels above 55 dBA are considered annoying during play, and indoor noise levels above 35 dBA can impact communication (Table 3). South Dakota, however, uses 67 dBA as its noise abatement criteria (NAC B) for exterior school environments, and 52 dBA for interior school environments (Noise 2010) (Table 4).

Table 3. Guideline values for community noise in specific environments.

Specific environment	**Critical health effects**	**LAeq (dB)**	**Timing (hours)**	**LAmax fast (dB)**
School class rooms and preschools, indoors	Speech intelligibility, disturbance of information extraction, message, communication	35	During class	60
School, playground, outdoor	Annoyance (external source)	55	During play	-

Source: Extracted from WHO 1999, Community Noise Guidelines, page 65.

Table 4. Noise abatement criteria (NAC) specific environments in South Dakota

Activity Category	**L_{eq}(h)**	**Description of Activity Category**
B	67-dBA (Exterior)	Picnic areas, recreation areas, playgrounds, active sports areas, Parks, residences, motels, hotels, **schools,** Churches, libraries, and hospitals
E	52-dBA (Interior)	Residences, motels, hotels, public meeting rooms, **schools,** churches, libraries, hospitals, and auditoriums.

Source: Extracted from Federal-Aid Highway Program Manual 7-7-3. "Procedures for Highway Traffic Noise and Construction Noise", dated August 1982.

According to Eason (2013), we should understand what sound is, how it is measured, and how it is perceived when designing a sound map, because only taking physical measurements will not accurately represent the sonic landscape.

2.4 Measuring Noise

Many factors should be considered in the process of mapping noise. These factors include the data collection strategy, which includes the attributes to be measured, and the classification of sound sources. The data collection strategy must also reflect the different spatial and temporal dimensions of the study area, so data must be collected at different times of the day and at various locations. The optimum size of the mapping grid depends upon the characteristics of the study area and the desired outcome (Merchan & Balteiro, 2013). This research used a regular grid to generate a systematic sample of data collection points. A few conditions were developed to accommodate situations when, for example, a sampling point fell inside a building footprint. In such an instance, choices must be made whether to take the measurement from the roof in the correct location, or to move the location to the nearest possible spot on the ground, or to eliminate the point altogether (Arana, Martin, Martin, & Aramendía, 2010). The choice was made for this research to move the data collection site to the nearest possible spot on the ground. For larger areas, such as a community, Yilmaz and Hocanli (2006) suggests taking measurements at major intersections instead of using a geometric grid. Another principal factor to consider is the sound's source, which can be abstracted and represented as either a point or a line. Arana et al. (2010) and Eason (2013) suggests that a true evaluation of sound sources requires the use of both points and lines. However, only point-source measurements were collected for this study.

The mapping and spatial analysis of point-based field measurements should be converted into continuous space (e.g., grid or raster form) using an interpolation method to estimate the values in unsampled locations (Siska & Hung 2001). There are many interpolation methods available, such as inverse distance-weighting methods, Kriging, spline interpolation, polynomials, and others (see Lam, 1983). However, many researchers have found Kriging as most accurate prediction model for noise mapping purposes (Karakula et al., 2007; Eason, 2013). Another advantage of Kriging is that it offers minimum error variance (Siska & Hung, 2001), which is useful for preparing maps for practical applications.

In recent years, several researchers have used smartphone apps to collect decibel measurements required to create noise maps. For example, Murphy and King (2016) used smartphones to map noise and compared their maps to traditional noise mapping methods. They concluded that smartphone-based mapping has potential, but smartphones underpredicted noise levels compared to traditional data collection devices (Murphy & King 2016). Similarly, Shim, Kim, Woo, and Cho (2016) constructed noise maps based on sound pressure information measured by smartphones, while Zuo, Xia, Liu, and Qiao (2016) conclude that smart phones are a quick and inexpensive method to measure noise levels.

CHAPTER THREE: METHODS

This chapter provides a description of the data collection and data analysis procedures employed in this research.

3.1 Data Collection

This section describes the methods used to compile GIS data for the study area, followed by the methods used to collect noise data with two types of technology; a smartphone app (SPA) and a digital noise meter (DNM). This section also describes the technology and field methods used to collect sound data, classify it by source, and quantify its attributes.

Figure 2. High-resolution orthoimage of South Dakota State Campus.

3.1.1 Compiling GIS Data for the Study Area

The GIS data for SDSU's buildings, roads, and parking lots were obtained on-line from OpenStreetMap (http://www.openstreetmap.org), which is built by an on-line community that contribute and maintain geospatial data all over the world. OpenStreetMap (OSM) emphasizes local knowledge, where contributors use aerial imagery, GPS devices, and low-tech field maps to verify that OSM is accurate and up to date. The remaining base data for the campus were digitized by the author using a high-resolution orthoimage photo (50 cm spatial resolution) of the SDSU campus (Figure 2). The imagery was obtained from the U.S. Geologic Survey (USGS) website and was used to extract spatial information about campus facilities such as roads, buildings, parking lots, and so forth. These features were digitized manually using ArcGIS software.

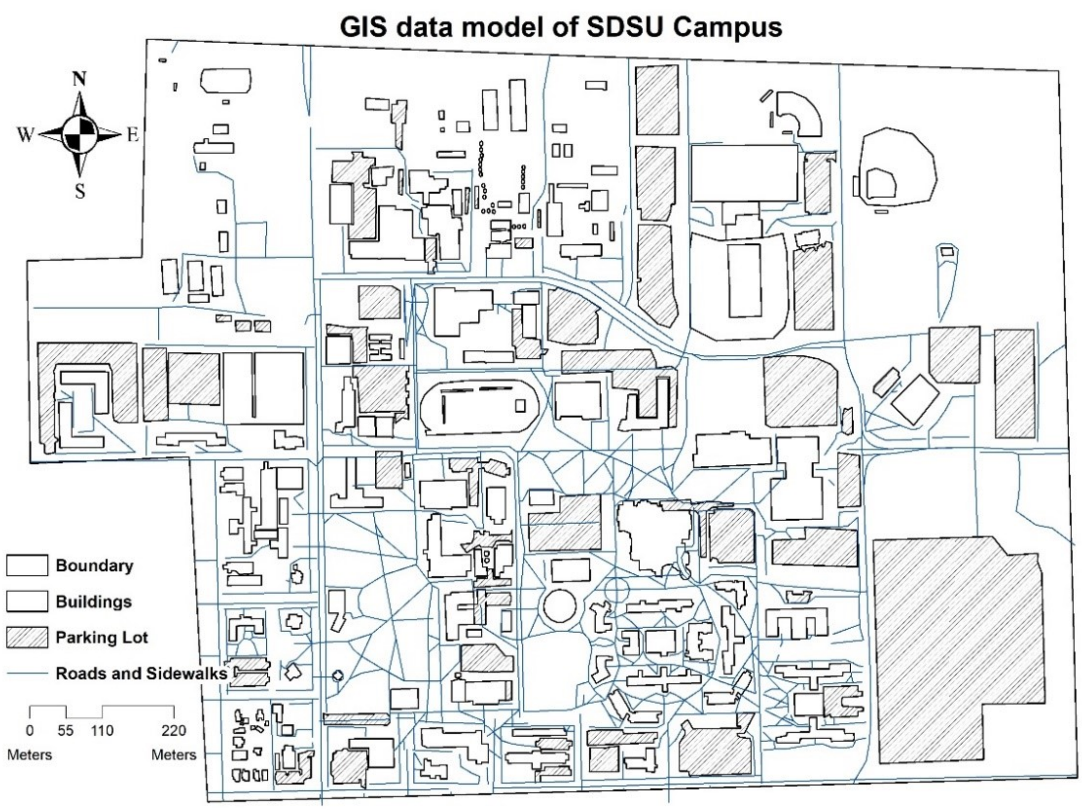


Figure 3. Map of the GIS data model of the SDSU campus.

Figure 3 shows the complete GIS data model of the SDSU campus. It includes the major buildings and structures (e.g. parking lots), which are outlined in black. The map also illustrates the vehicular and pedestrian transportation network (i.e., road and sidewalks), which are outlined in blue.

3.1.2 Noise Data Collection: Technology

3.1.2.1 NIOSH App

The National Institute for Occupational Safety and Health (NIOSH), part of the Centers for Disease Control and Prevention (CDC), developed a smartphone application (SPA) for iOS devices to gather sound pressure, or noise, data (in dB). The NIOSH interface is illustrated in Figure 4. NIOSH, in collaboration with an app developer, EA LAB, created this SPA especially for measuring noise at worksites. However, the SPA can be used to measure noise levels anywhere, including concerts, sporting events, and outdoor school environments. The NIOSH SLM SPA was installed on an iPhone 6s using an external microphone with a wind-muffling foam windscreen.

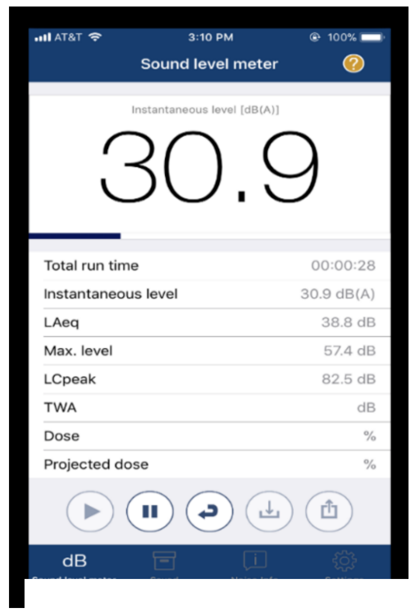


Figure 4. NIOSH interface

Figure 5. Dual-head lavalier microphone with foam windscreen

To increase the accuracy of measurements, NIOSH endorses using an external calibrated microphone whenever measuring sound pressure, based on recent work by Roberts et al (2016) and Kardous and Shaw (2016). The external microphone used for this research was the Pop voice-1.96" dual-head lavalier microphone, which is illustrated in Figure 5. The foam windscreen is an omnidirectional condenser microphone specially designed for iPhone/iPad, iPod touch, and it also works on most Android devices.

3.1.2.2 Noise Level Meter

The T Tocas SL 1361 Digital Noise Meter (DNM) is an affordably-priced noise level meter that is designed to meet the requirement of safety engineers, health, industrial safety, office and sound quality control in various environments (Figure 6). The range of its recording capability is 30 to 130 dB. This device is mostly appropriate if the job involves taking measurements of noise levels to make a printed report. The T Tocas SL 1361 DNM must be connected to a laptop/PC to transfer the data (using a software companion), and it saves the recordings in text or Excel format. According to the product details (Toscas, n.d.), the frequency range of the device is 31.5Hz to 8.5 KHz, it has an accuracy of +/- 1.5dB, and a sampling rate of 2 times per second. It can operate under temperatures from 0 to 40 °C (32 to 104 °F) and relative humidity of ≤ 80% (Toscas, n.d.).

Figure 6. T Tocas SL 1361 Digital Noise Meter

3.1.3 Noise Data Collection: Fieldwork

The noise data used in this study were obtained from field measurements in the study area using a T Tocas DNM and the NIOSH SLM SPA. Digital noise measurements were collected at 25 data collection points spatially distributed across SDSU campus representing a Bishop's case systematic sampling of regular 400 x 400 m grid to reduce sampling bias compared to using, for example, major intersections as proposed by Yilmaz (2006). Points located on the top of buildings were moved to the nearest ground location. Noise data were collected between October 2017 and March 2018 for ten-minutes intervals at each of the 25 data collection sites during three different time intervals of the day; morning (8:00 to 11:59 am), afternoon (12:00 to 4:59pm), and evening (5:00-10:59pm). Data collection was limited to times when there was no precipitation (snow or rain), low wind speeds, and reduced traffic (e.g., excludes holidays and special events). The noise measuring equipment (DNM and SPA) was mounted to a tripod that was positioned approximately 1.25 meters above the ground surface with a wind-muffling foam cover windscreen for the microphone of both the DNM and SPA.

Sound pressure levels were collected by the T Tocas DNM in fast response setting and measured in one-second average noise levels (dBA L_{eq}), which were used to calculate average (dBA L_{eq}) and maximum (dBA L_{max}) readings. The values obtained from the DNM were converted to L_{eq} values using the formula illustrated in Equation 4.

$$L_{eq} = 10\log_{10}[\int_{Q}^{T,m} \frac{P(t)}{P_0} dt \qquad \text{(Equation 4)}$$

Where L_{eq} is the equivalent continuous linear weighted sound pressure level at 20µPa, determined over a measured time interval T_m(s), P(t) is the instantaneous sound pressure of the sound signal, and P_0 is the reference sound pressure of 20µPa.

Adding L_{eq} values required taking an anti-log of each value. The process can be performed as shown in Equation 5.

$$\text{Total } L_{eq} = 10\log\left(\frac{10_{10}^{L_{eq1}} + 10_{10}^{L_{eq2}} + \cdots .. + 10_{10}^{L_{eqn}}}{n}\right) \qquad \text{(Equation 5)}$$

3.1.4 Sound Data Collection: Technology

Digital sound data were collected using a Tascam DR-05 is a 24-bit/96kHz Digital Stereo Recorder with Omnidirectional Microphones. This device records in MP3 or WAV format – including 96kHz/24-bit high-resolution audio – to microSD or microSDHC media (Tascam.com, 2018). The digital sound recordings were subsequently evaluated using sound classification instrument (Appendix A). The sound classification instrument was designed to categorize sound sources, which were further quantified using a 5-point Likert scale in terms of its pitch (background-low-high), volume (deep-high), and perception (peaceful-annoying). The categories used to classify sound sources were:

i. Mechanical – produced by machines or mechanical activities;
ii. Natural – produced by living organisms and natural phenomena;
iii. Human – produced by humans while doing their work; and,
iv. Communications – produced by technological devices (e.g. notifications, speaker phone) and by conversations.

3.1.5 Sound Data Collection: Fieldwork

Sound data were digitally recorded for 10-minute intervals at each of the 25 data collection sites. The Tascam DR-05 was mounted to a tripod that was positioned approximately 1.25 meters above the ground surface with a wind-muffling foam cover windscreen for the microphone. The researcher remained on the site for the 10-minute sampling period, maintaining silence, and the classification of the soundscape was reported at the end of the sampling period. The project did collect the weather data that includes temperature, relative humidity, and wind speed and direction that could affect the propagation of sound. The summary of those weather information collected in presented in the table below.

Table 5. Summary of weather data.

Weather Attribute	Morning			Afternoon			Evening		
	min	max	mean	min	max	mean	min	max	mean
Temperature (°C)	-4	4	1.0	5.6	13.9	9.2	-2	7	2.5
Relative Humidity (%)	62	89	74.6	31	60	45.8	49	84	70.2
Wind Speed (km/h)	2	7	6.7	0	12	4	3	8	5.2

The three measures of ambient atmospheric conditions suggest typical fall weather conditions for the study area. There are, however, some notable, and typical, differences in weather conditions between the three time periods. Some of these differences, particularly relative humidity and wind speed (and direction), which could impact on sound propagation across the study area.

3.2 Data Analysis

The noise and sound data were used to map several different dimensions of

SDSU's soundscape and subsequently used to identify "problem areas". Finally, this thesis compared the quality of the noise data collected by the DNM and SPA for any significant differences.

3.2.1 Mapping Noise and Sound

The spatial interpolation of collected values was conducted using R software's "gstat" package (Pebesma, 2001) that provides a wide range of univariate and multivariate geostatistical modeling, prediction, and simulation capabilities (Pebesma, 2001). In gstat, geostatistical modeling involves calculating sample variograms and cross variograms and then fitting a model to them (Pebesma, 2001).

The noise data (sound pressure in decibels) were initially compiled in .csv file format and imported into gstat. Descriptive statistics were used to assess whether the data met the assumptions of Kriging. A grid was created to store and visualize the surface of predicted values. The model was then defined from the sample variogram. The default parameter values were chosen from the sample variogram for the range, nugget, and partial sill. More specifically, the default settings were: the range parameter was taken as one-third of the maximum sample variogram distance; the nugget parameter was taken as the mean of the first three sample variogram values; and, the partial sill was taken as the mean of the last five sample variogram values. In this case, a spherical variogram model (most cases) or exponential variogram model were used (Table 6). The mean standardized error (MSE) and the Root-Mean-Square-Standardized-Error (RMSSE) were used to check the bias and uncertainty in the data.

Table 6: Summary of variogram models for Kriging the noise data

Parameters	Digital Noise Meter			NIOSH SPA		
	Morning	Afternoon	Evening	Morning	Afternoon	Evening
Sill	46	14	82	62	186	19
Range	320	500	11067	779	11121	991
Nugget	70	50	29	6	50	18
Model	Exp	Exp	Exp	Sph	Sph	Sph
MAE	4.168	5.43E+00	4.576	5.113	6.812	4.3253
RMSE	5.123	7.00E+00	5.301	6.476	7.835	5.190

The interpolated noise values (dBA) were extracted as a raster from R software and then imported into ArcGIS to visualize the noise maps. Data analysis also included the preparation of thematic sound maps to help illustrate the origins of the recorded sounds. The sound intensity scores for volume, pitch, and perception were used to create a series of thematic maps reflecting the accumulated acoustic experience at different times of the day.

3.2.2 Identifying "Problem Areas"

Noise problem areas are the areas that have maximum allowable noise level limits and have sensible receptors – a place where the occupants are more susceptible to the adverse effects of exposure. The problem areas for this study were identified based on whether noise level reach their maximum allowable limits in or around sensitive (high student density) areas. The WHO guidelines were generally used to determine whether SDSU's campus has any noise pollution problem areas. In South Dakota, however, 51 dBA is considered a quiet urban daytime noise level, and 66 dBA or higher is considered noisy enough to create an impact at various times and at different locations. The noise maps were used to identify problem areas that have higher noise exposure and require mitigation measures.

3.2.3 Comparing DNM and SPA Data Quality

Mean noise levels from the DNM were compared with those collected by the SPA to test for significant differences between the two devices. The t-test comparison provides valuable insights regarding the quality of noise level readings (decibels) and allow some general recommendations whether the devices collect data of equal quality. A t-test compares the means from two groups (when $n < 30$) and computes a p-value, which is the probability of committing a Type I error or “the probability under the assumption of no effect or no difference (null hypothesis), of obtaining a result equal to or more extreme than what was actually observed” (Dahiru, 2008). It measures how likely any observed difference between groups is due to chance. The null hypothesis was that the means of the datasets (both DNM and SPA) are not statistically different. If the p-value is less than the Alpha value (at 0.05 for a 95% confidence interval), the null hypothesis must be rejected. When the null hypothesis is rejected, the conclusion is a statistically significant difference between these two datasets.

CHAPTER FOUR: RESULTS

The results include a series of interpolated surfaces of noise levels (decibels) for the morning, afternoon, and evening time intervals using data collected from the digital noise meter (DNM) that are aligned beside the corresponding series of maps using data collected from the NIOSH smartphone app (SPA). The results also include a series of interpolated surfaces are used to illustrate the mean values for volume, pitch, and perception for each of the four sound origins (i.e., mechanical, natural, human, and communications). The noise and sound data, in conjunction with the GIS data to provide context, problem areas are identified, and mitigation measures suggested. Finally, the results present a comparison of mean values from the DNM and SPA to test for statistically significant differences.

4.1 Mapping the Noisescape

Kriging analysis was used to generate a series of interpolated surfaces of mean noise levels for the morning, afternoon, and evening (arranged by rows in Figure 7) using data collected by the DNM device in the left column and the SPA device in the right-hand column. During the morning, the DNM and SPA recorded the highest dBA values on the northwest side of SDSU that have exceeded SDDOT recommended noise levels (> 66 dBA), followed by areas that have exceeded WHO recommended noise levels (> 55 dBA), mostly around south east and south west part of SDSU. On the other hand, most of the open and green spaces, especially along the eastern, southern, and western edges of campus are the quietest and exhibit the lowest decibel readings. Both the DNM and the SPA recorded similar values during the morning.

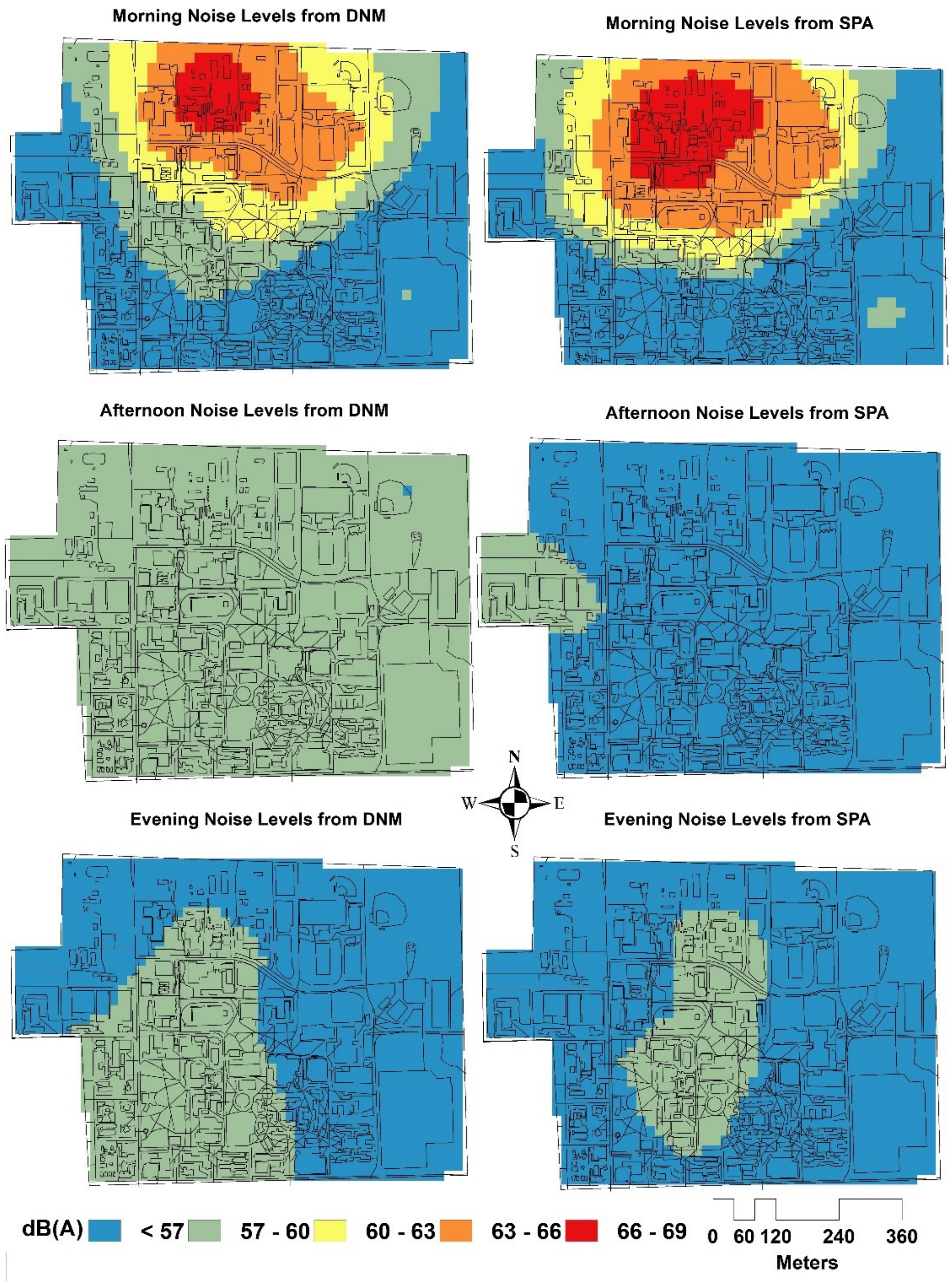


Figure 7. Kriged mean noise levels by time of day and by measurement device.

The DNM and the SPA appear to have recorded dissimilar values during the afternoon. Figure 7 shows all parts of SDSU have exceeded WHO recommended noise though slightly, but none have exceeded SDDOT recommended noise levels. Only the western central part, on the west side of Medary Ave. seems to have exceeded WHO recommended noise levels.

During evening, both the DNM and SPA exhibit similar patterns and they both recorded the highest values on the south-west and south-central side of SDSU campus. Similarly, noise values are very high near the intersection of Medary Ave. and North Campus Dr., extending toward the Avera and Student Union buildings; an area that appears to have exceeded WHO recommended noise levels.

Table 7. Summary statistics for noise levels from DNM and SPA devices.

	Digital Noise Meter (DNM)					Smartphone App (SPA)				
Outcome	n	M	SD	Min	Max	n	M	SD	Min	Max
Morning dBA	25	58.0	6.1	49.5	72.8	25	57.1	7.6	38.0	65.0
Afternoon dBA	25	57.5	6.9	46.2	73.2	25	52.6	8.3	38.0	65.0
Evening dBA	25	56.5	5.2	47.5	67.8	25	54.2	5.8	41.6	65.0

According to the results in Table 7, the DNM recorded a mean value of 58.0 dBA for the morning (7:00 – 11:59), which is 3 dBA greater than WHO recommended noise levels. An increase of 3 dBA is barely perceptible to human ear, but the range of noise levels collected during morning from DNM and SPA exceed 20 dBA, indicating that there are areas inside SDSU that are 4 times as loud as from the quietest areas of campus. The DNM recorded mean values of 57.5 dBA during the afternoon (12:00 – 16:59) and no areas on campus exceeded the SDDOT recommended noise level during this time. The noise levels measured from SPA has the highest deviation among all time periods and this may be the reason in dissimilar noise level distribution on that time. The DNM recorded mean values of 56.0 dBA during the evening (17:00 – 23:00), which is the lowest among all time periods.

4.2 Mapping the Soundscape

The next objective was to map different sound sources across the SDSU campus. Soundscape maps were interpolated using volume, pitch, and perception for each of the time intervals (i.e., morning, afternoon, evening), each of the sound sources (i.e., mechanical, natural, human, and communications). However, given the similarities between human and communication sound sources, they were merged, using mean values, into a single category for illustration purposes only. Consequently, the following soundscape maps will only illustrate mechanical, natural, and human sources of sound.

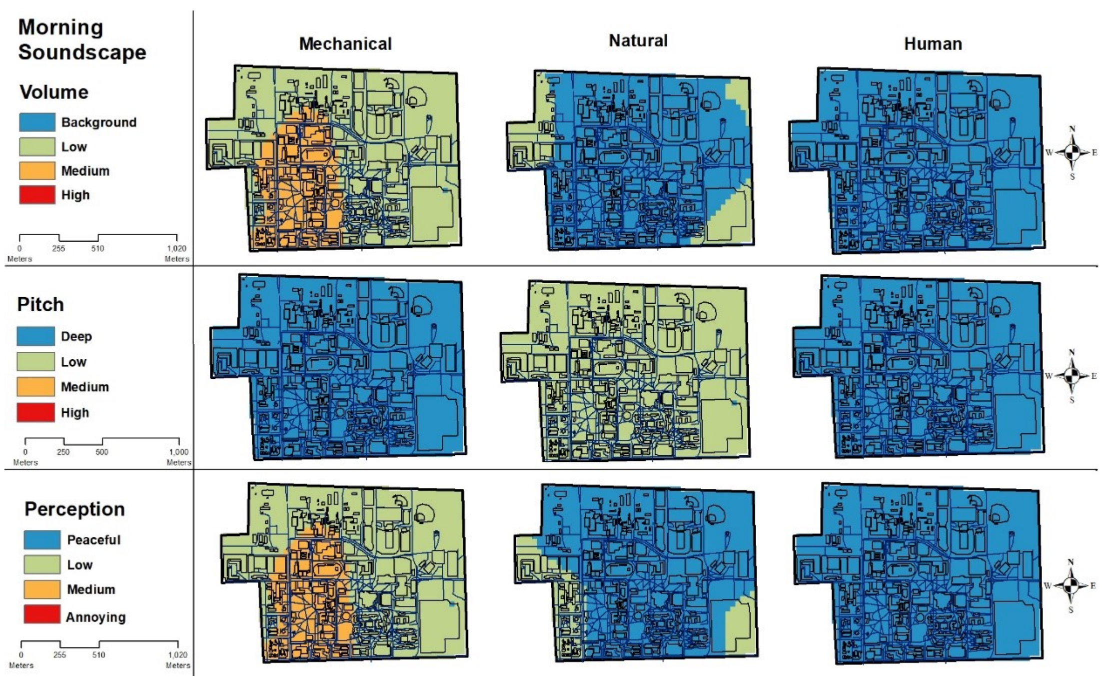


Figure 8. Volume, pitch, and perception for sound sources during the morning

Mechanical sound sources seem to dominate SDSU's sonic landscape in terms of volume and pitch during morning (Figure 8), but they are not considered annoying during that time. Natural sources of sound are low yet dominant across SDSU's campus, in terms of pitch, during the afternoon (Figure 8). Human sources of sound remain low in volume during morning, afternoon, and evening. The primary sources of mechanical sounds include air conditioners, fans, and traffic, while the primary natural sound sources include birds, squirrels, and leaves rustling in the wind.

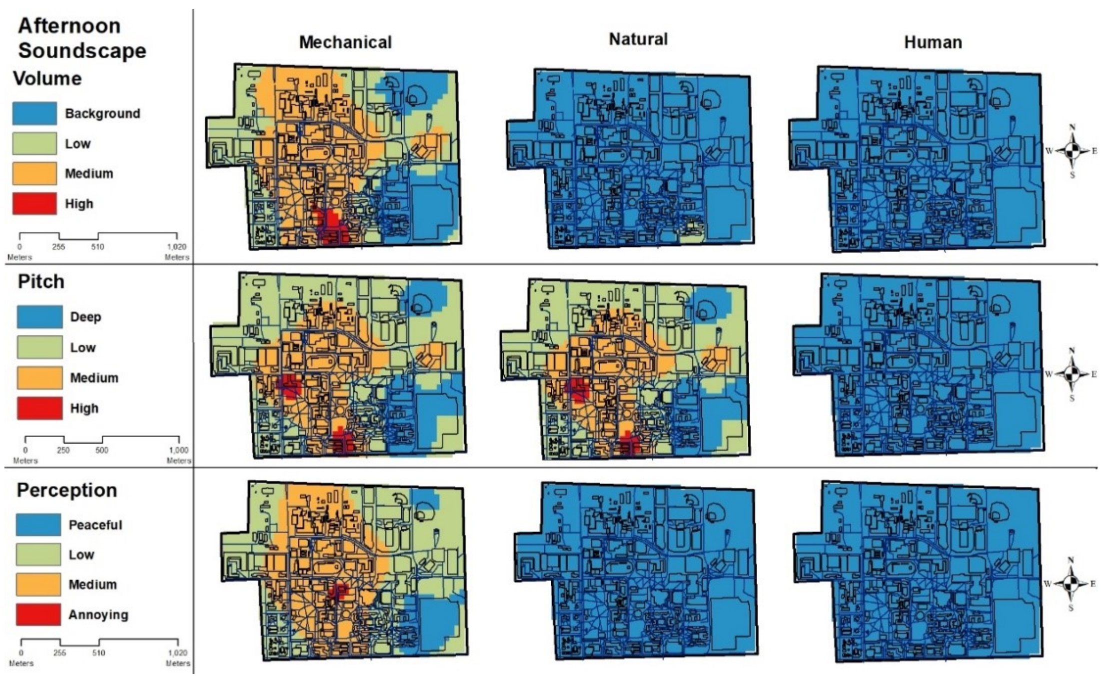


Figure 9. Volume,pitch, and perception level for sound sources during the afteroon.

Mechanical sources of sound seem to remain dominant across SDSU's campus in terms of volume, pitch, and perception during afternoon (Figure 9). These sources of sound are high in volume, mostly on south west and south-central part of SDSU, close to the 8th Street. This location is near the road leading to the Student Union Building. On the central part of SDSU's campus, mechanical sound sources are high in volume, mostly near the Student Union Building, and its associated parking lot. There is a frequent movement of vehicles in the parking lot of SDSU's Student Union Building as this is the main gathering location for the students. On the other side of the Student Union Building, there is a parking lot that may also significantly contribute to the mechanical sounds. Other sources of sound remain in low volume and perception during afternoon, presumably overwhelmed by air conditioners, fans, and traffic.

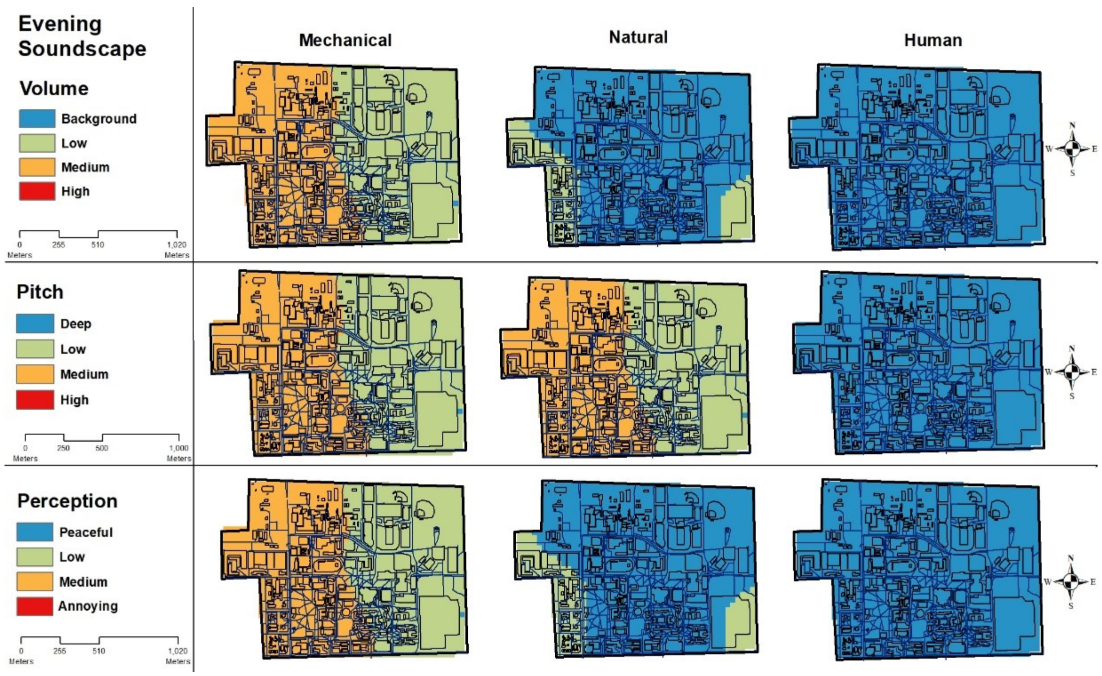


Figure 10. Pitch level for different sound sources during the evening

Mechanical and natural sources of sound appear to dominate the soundscape in terms of pitch during evening (Figure 10), and they are medium in volume along both sides of Medary Ave. However, there is a similar pattern for pitch emanating from both mechanical and natural sound sources, while the former is largely due to the high traffic volumes, the latter is due to the presence of a relatively high concentration of trees, open areas, and residential gardens, which provide shelter and habitat for several bird species and squirrels that are particularly noticeable during the afternoon and evening. Other sources of sound, namely human, and communication, remain in comparatively low in volume during the afternoon (Figure 10).

The soundscape maps are supplemented by summary statistics for sound sources that are stratified by their attributes time of day in Table 8.

Table 8. Summary statistics for sound sources (five-point scale) by time interval.

Source	Attribute	Measures	Morning	Afternoon	Evening
Mechanical	Volume	Mode (Range)	3 (2-4)	3 (1-5)	3 (2-4)
	Pitch	Mode (Range)	3 (2-4)	3 (1-5)	3 (2-4)
	Perception	Mode (Range)	3 (2-4)	2 (1-5)	3 (2-4)
Natural	Volume	Mode (Range)	1 (1-3)	1 (0-3)	1 (1-3)
	Pitch	Mode (Range)	1 (1-3)	1 (0-2)	1 (1-3)
	Perception	Mode (Range)	1 (1-3)	1 (0-2)	1 (1-3)
Human	Volume	Mode (Range)	1 (0-2)	0 (0-1)	1 (0-2)
	Pitch	Mode (Range)	1 (0-2)	0 (0-2)	1 (0-2)
	Perception	Mode (Range)	1 (0-2)	0 (0-2)	1 (0-2)
Communication	Volume	Mode (Range)	0 (0-2)	0 (0-2)	0 (0-3)
	Pitch	Mode (Range)	0 (0-2)	0 (0-2)	0 (0-3)
	Perception	Mode (Range)	0 (0-2)	0 (0-2)	0 (0-3)

Mechanical sources seem to be the dominant sounds across the SDSU campus in terms of volume, pitch, and perception during evening. Mechanical sound sources are typically low in volume on the east half of campus and medium volume on the west side of campus. Results also indicate that volume levels decrease noticeably for all sound sources during the evening hours, which allow the train (several blocks away from campus) to become audible. Natural sounds, including birds, squirrels, and the rustling of tree leaves also becomes more prominent during the evening hours. Noticeably absent from the soundscape during the evening, perhaps due to the random nature of data collection periods, were human and communication sounds.

Mechanical sources of sound appear to dominate SDSU's soundscape over all three time periods (mode = 3 on a 5-point Likert scale). Mean values from mechanical sound sources are moderate in volume, pitch, and perception, but the values exhibit considerable variability. For example, all three measures (i.e., volume, pitch, and perception) ranged from a low of 1 to the maximum value during the afternoon. On the other hand, natural sources of sound are typically very low across SDSU's soundscape, with modal value of 1 for all three measures and all three time periods. These results suggest that natural sound sources may not dominate the SDSU soundscape, mostly because it is overwhelmed by mechanical sound sources, yet it remains an integral component and adds an important dimension to the campus's soundscape. Human and communication sources of sound were barely audible at the data collection sites during all the different sampling periods. Of course, this depends on the limited data collection period (i.e., 10 minutes) at each location. It appears that class schedules have a strong influence on human (i.e., student) sound sources, which peak during change of classes, but are almost non-existent if collected during mid-class hours.

4.3 Identifying Problem Areas

The areas on campus with measured noise levels that exceed the recommended noise levels and/or unpleasant sounds were identified using the noisescape and soundscape maps. The problem areas are along Medary Ave., (one of primary roads that runs across SDSU), especially areas that are closer to the major intersection of Medary Ave. and North Campus Dr. There are also, however, some mechanical equipment (namely fans and air conditioners) that add to locally excessive noise levels across the SDSU campus. These sources of noise have no noise buffers, and it does not appear that proper areas attention has been paid to the negative impacts on the “quality learning environment” around SDSU’s campus. Some examples of these annoying sources of noise are illustrated in Figure 11.

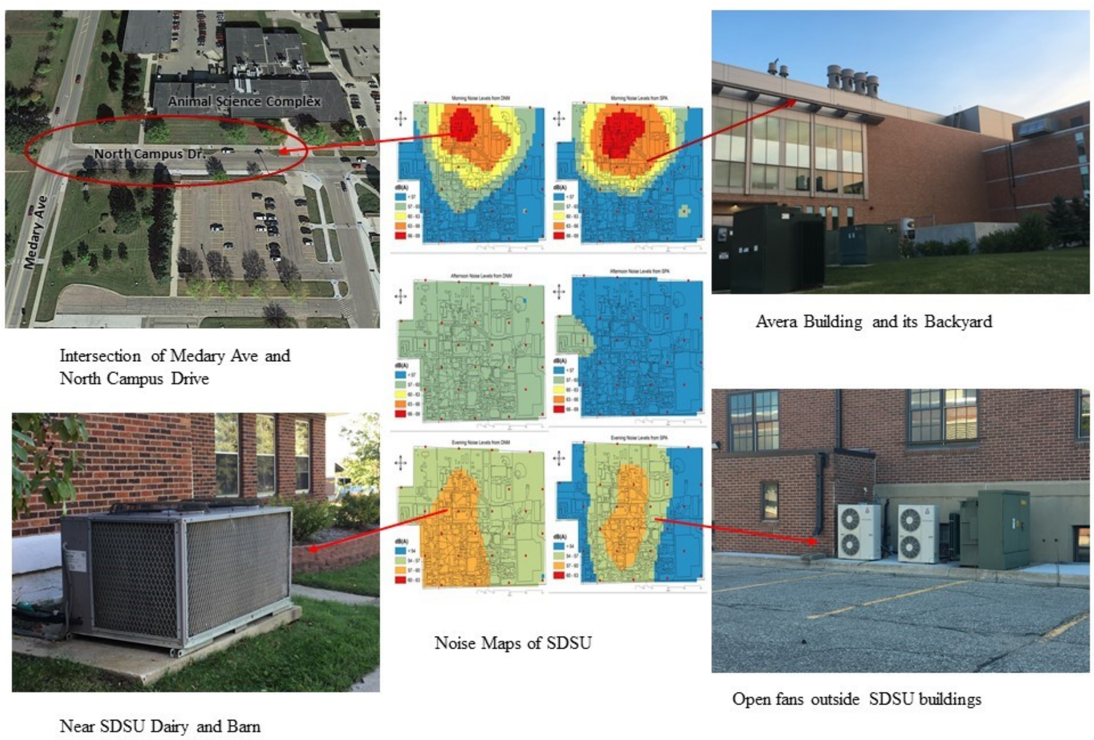
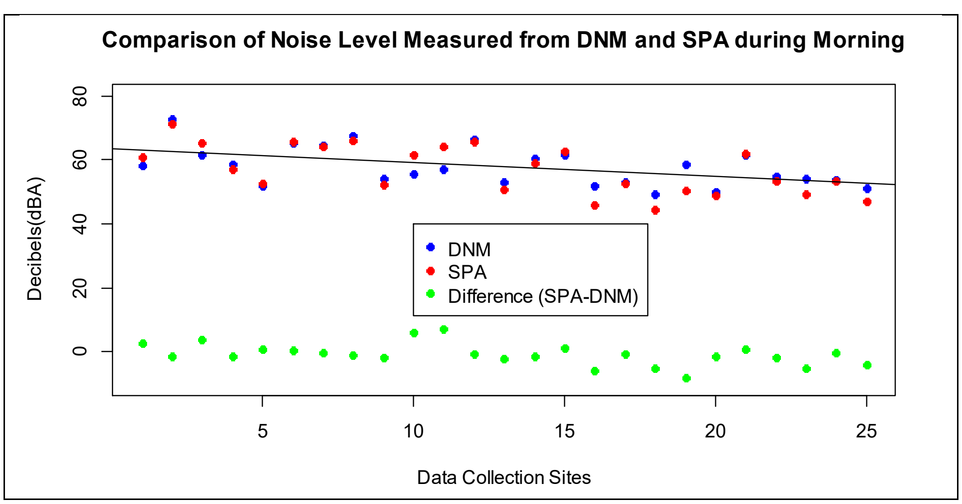


Figure 11. : Sources of noise in problem areas with their locations.

The intersection of the Medary Ave. and North Campus Dr. (Figure 11), near the Animal Science Complex have remarkably high noise levels, particularly during the morning. This may be because of the high traffic volumes on those areas at those times. The other problem area identified is proximate to the large mechanical equipment on the roof of Avera Health and Science Center. Although the noise levels were not in high in this vicinity, the location of the building (i.e., on the central part of the campus) had a noticeable impact on the soundscape of much of the surrounding area of campus. This area was also identified as problem area because of its proximity to a high density of pedestrian infrastructure that is frequently used by students to go to their respective class buildings, the Student Union, Administrative Building, and the Library. There are several other areas across the campus that have loud fans (not fenced) that dominate the soundscape for large surrounding areas. Many of these fans are in close proximity to the sidewalks, benches, and picnic tables, which negatively impacts the soundscape and, thus, the students' experience when they walk through those areas.

4.4 Comparing DNM and SPA Data Quality

This research sought to compare the noise data collected using a T Tocas digital noise meter (DNM) and the NIOSH smartphone app (SPA). Mean noise levels collected with the DNM and SPA are illustrated along with the difference (SPA minus DNM) between each paired measurement in Figure 18 using separate graphs for the morning, afternoon, and evening.



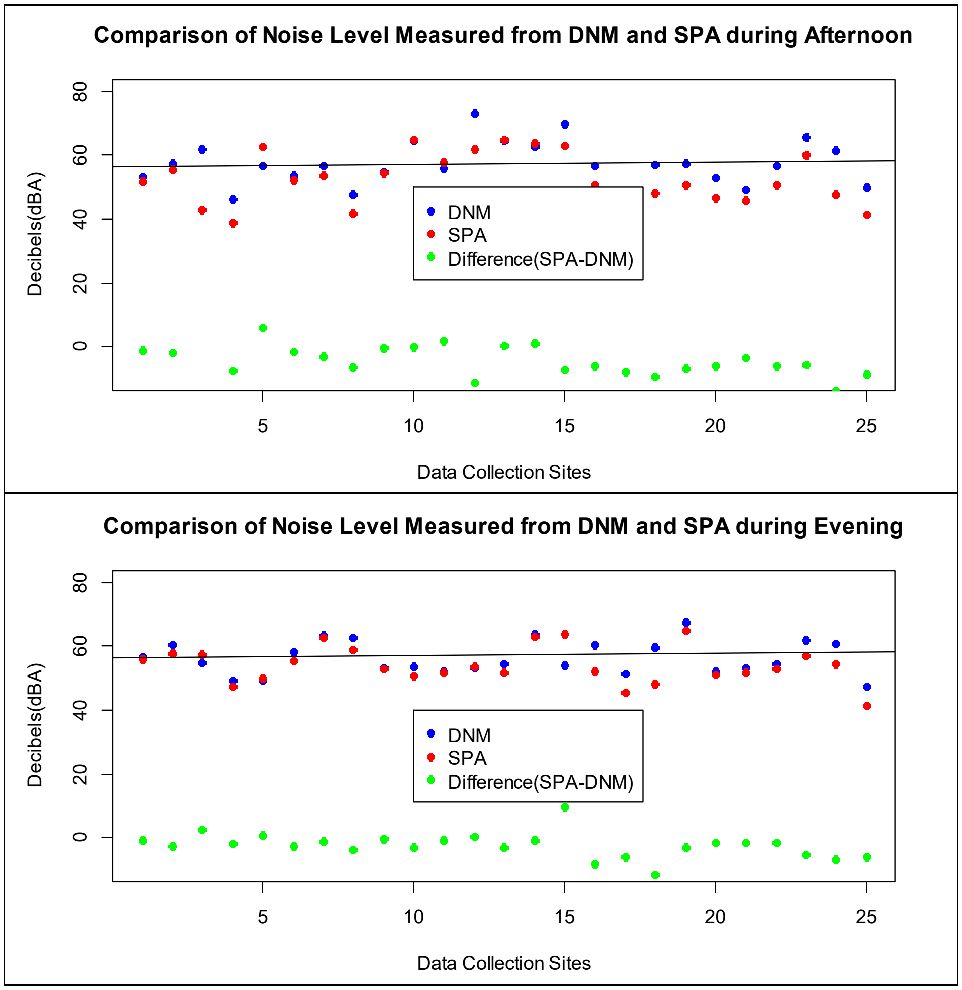


Figure 12. Comparison of noise level data collected from DNM and SPA devices.

Figure 12 shows the comparison of mean noise levels from two data collection devices (DNM and SPA) during the morning, afternoon, and evening. The bottom green points represent the differences, which range from -8.3 to 6.1 dBA (morning), -19.1 to 6.10 dBA (afternoon), and -11.5 to 9.8 dBA (evening). The differences are not considered large, because most have not exceeded 10 dBA, which would be twice as loud. In most cases, the mean noise levels from the DNM and SPA align closely, indicating there are limited differences between measurements taken from these two devices. However, most mean noise levels from the SPA are noticeably lower than those from the DNM, indicating either the SPA has underestimated noise levels of the DNM has underestimated them, or both. The consistently lower noise levels from SPA may be due to the additional wind muffling cover.

Table 9 shows summary statistics for the noise levels measured by the DNM and SPA for the morning, afternoon, and evening. Table 9 also illustrates the results for a paired sample t-test with unequal variances for noise levels measured from the DNM and SPA for the morning, afternoon, and evening.

Table 9. Comparison of mean noise levels from DNM and SPA devices.

	Digital Noise Meter (DNM)			Smartphone App (SPA)			Abs. Diff.	t	p-value
Outcome	n	$\bar{x}$	SD	n	$\bar{x}$	SD			
Morning dBA	25	58.0	6.1	25	57.1	7.6	0.9	0.434	0.665
Afternoon dBA	25	57.5	6.9	25	52.6	8.3	4.9	2.268	0.028
Evening dBA	25	56.5	5.2	25	54.2	5.8	2.3	1.453	0.153

The results illustrated in Table 9 show remarkable similarities between measures of central tendency and dispersion for both noise level measuring devices. Only the measurements collected during the afternoon time exhibit marginally significant (97% confidence) differences between the DNM and SPA mean noise level measurements.

CHAPTER FIVE: DISCUSSION

This research sought to map the soundscape of SDSU's campus using objective measures of noise and subjective (i.e., perceived) measures of sound to identify potential spatial and temporal patterns. In doing so, this research has addressed several questions, which are the subject of this chapter.

It seems that the campus soundscape tends to align with the SDSU's mission, vision, and strategic goals. There are not many "problem areas" that exceeded the threshold levels established by the South Dakota Department of Transportation (SDDOT). However, if we use the WHO thresholds, where noise levels exceeding 55 dBA in school areas are considered noisy, then there are many "problem areas" across SDSU's campus at different time of the day that threaten the quality of the university's learning environment. By quality learning environment here means the environment free of noise pollution or the areas that have not exceeded the recommended noise levels.

Morning hours appear to be the noisiest time of the day, despite the hypothesis that the afternoon would have been noisier. The results may reflect coincidence between data collection periods and time of higher traffic volumes or times when mechanical sources of sound were more prominent. The areas where the highest noise levels were measured tended to coincide with major road intersections, which significantly contributed to the high noise readings.

Among the different sources of sound, mechanical sources were the most prominent across the campus, followed by natural sounds, in all three time periods. Human and communication sounds were almost negligible, perhaps because these sounds were overwhelmed by mechanical or natural sources of sound. The author cannot rule out the researcher's error in coding the different sources of sound according to their volume, pitch, and perception.

Parking areas also had high noise levels. This may because the data were collected during school hours, and not during holidays, when the movement of vehicles is high. The parking areas that have high noise levels tend to be those areas that are closer to building where students movement (for classes) are higher.

Natural sounds also seemed to dominate during the afternoon time period, and mostly around Medary Ave. During the afternoon, the data were collected around 5:30 PM, when birds tended to be both active and vocal, perhaps owing in part to the high number of trees in the vicinity. However, mechanical sounds were also dominant adjacent to the Medary Ave. owing to the high volume and frequency of vehicular traffic. Human and communication sound sources remain low in these areas because most classrooms, plus the busy hubs of the library and Student Union, are on the other side of the campus, where increased number of students are expected.

The results from analyzing the different sound sources mostly corroborate findings from the noise maps that have been prepared, and most of the problem areas are adjacent to areas where mechanical sound sources are dominant. The main sources of mechanical sounds are vehicular traffic and mechanical equipment outside the buildings, air conditioners, fans.

A 5-point Likert scale was used to code the volume, pitch, and perception of different sound sources. Most of the time, the researcher heard sounds from mechanical equipment or traffic, and this may help explain why mechanical sound sources dominated the soundscape across much of the campus. These data were collected with the knowledge of the author, and his perception of soundscape may be different from someone else. The author does not rule out the possibility that the results would be different if the same data collected done by another person. To reduce such discrepancies and variability, the author used the best knowledge about his theoretical knowledge and expert suggestions. This shows that SDSU's campus is quiet most of the time. Also, many times, human and communications sources of sound were not heard at all. This led to the merging of Human and Communication sources on the soundscape maps.

Morning mean noise levels (58 dBA) were less than SDDOT threshold noise levels. However, according to the WHO thresholds, environmental noise levels on SDSU's campus were slightly greater than the recommended noise level of 55 dBA (increases by 3 dBA). The morning seems to be more noisy than other time periods. Contrary to the original hypothesis, results indicated the morning to be noisier and afternoon had the highest variation. Mostly the north west and north central areas of campus were noisier during the morning. Perhaps because the data collected were from 8:00-12:00PM, with most of the data collected around 9:30-10:40AM, which is usually the time when students' movement for classes occur and vehicular movement tends to be higher. The evening also has similar noise level variation across SDSU. It has not however, exceed the recommended SDDOT noise level limits and suggests that the campus is peaceful during evening hours.

Mechanical sources of sound seemed to dominate in terms of volume, pitch, and perception across all time periods across SDSU's campus. The main sources of sound were mainly mechanical equipment, air conditioners, fans, and traffic. The second dominant source of sound were natural, followed by human sources. It is quite surprising to find that the human sound sources were barely audible across much of the study area, especially considering there are more than 12,000 students on campus. The students' exhibited higher levels of physical movement when classes started or ended, and the data collection times were disproportionately during the start or half time of the hour, which missed times of high pedestrian student traffic.

None of the sound sources were considered annoying. According to Hong and Jeon (2017), the perceptions of certain sounds depend on the context of the area, and it is reasonable to suspect that the sound sources were mostly mechanical because there were many machines operating outside SDSU and the limited number of trees. The data were collected during winter/fall season, so most of the trees, which are almost exclusively deciduous, lacked leaves and consequently also lacked the counds of wildlife.

The NIOSH app was used because it was approved after it was validated through a study with a number of devices and researches. The NIOSH application is not currently available for Android, so only an iPhone was used in this study. Also, to improve on the measurement, an external microphone with noise reduction was used, and it did improve the results. Eason (2013) compared the quality of measurements using a smart phone app and traditional sound level meter, and she concluded that those measurements were not comparable. On the contrary, this research indicates that those measurements are comparable when external wind shielding of the microphone is employed. The results of this study accord with research conducted by Zuo et al. (2016), who used mobile phones as a device to collect noise data and used external microphone to improve the measurements.

This research is not without its limitations. For example, the time intervals could have been improved, the range of time intervals may have been too coarse. For example, the results could have been improved if smaller time intervals of increased frequency were used. For example, the morning time interval could have been started at 6:00 AM, and the evening time could extend until 10:00 PM, or even later into the night. The main limitation was the time and weather conditions. South Dakota is a windy state, so the time and day when the wind speed was less than 12 mph was rarely found. This led to extending the time it took to collect the data required for this project, which required almost 5 months.

Scheduling the time for data collection and the number of volunteers for the data collection was another limitation. The data were collected by the researcher for all 25 locations. The average time for collecting the data for each location was 30-45 minutes, and there were 25 locations, and the data had to be collected for 3 time periods, so it took around 37.5 - 45 hours for collecting overall data. The DNM did not have data logging capabilities, which meant that it had to be attached to the computer to record the data. For each DNM, one laptop was required, which was not possible given the budget of the research project.

This research may also be subject to personal bias or error. Since the researcher was alone to perceive and record the sound sources, it can be suspected that there was some bias, and the ranking of the sound sources would have slightly been different if collected from another researcher. Since soundscape is a perception of sound, and differs from people to people based on context, it cannot be ruled out that possibility of bias and error. Karakula et al. (2007) indicate that the quality of a noise model can be improved with high density of observation points. Since this research had limited number of observation points, it can be suspected that the maps are of limited accuracy in noise distribution across the SDSU campus. Unlike Eason (2013), this research showed that the both SPA and DNM are of comparable quality. The author used SPA with noise reduction equipment, and that could have improved the measurement. Merchan and Diaz-Balterio (2013) find that noise map accuracy at different grid spaces depends on topographical factors and reducing grid resolution can reduce calculation time by more than 90%. This research project did the same for the same purpose, by compromising the accuracy in noise map.

Davies et al. (2013) posits that cognitive effects such as the meaning of the soundscape and its components influence perception of soundscape. This means that the soundscape is a perceptual feeling and may differ slightly if the data were collected by the other person. Hong (2016) finds that pleasant sound environment is closely related to overall impression of urban pedestrian streets. Visual impression also could have been played a role. For instance, the areas that are near/along the main road or nearby big machines could have been given more weightage for mechanical sounds for volume, pitch, and perception. Shim et al. (2016) indicates that there is a possibility of using the smartphones for noise mapping using citizen scientists or volunteers. This research used smartphones with external microphone to collect noise level data, and it did improve the measurements. Only afternoon time periods had slight difference in their measurements. This may be because of equipment error or human error.

Air conditioning and exhaust fans could be fenced and there are some places where such measures have been applied, but if more could be included that would significantly improve the overall soundscape of the campus. For example, the fans on top of the Avera building is the main source of mechanical sounds on the western portion of the SDSU campus, besides traffic. There is no fencing around that area. The research conducted by Den Boer (2007) concluded that the most cost-effective measures are those addressing the noise at-source. In SDSU campus too, machines- air conditioners, are the main source of mechanical noise, and that could be improved by addressing them at source, which is fencing around or using latest or new equipment.

In this study 25 sample locations were sampled at 10-minute intervals at three different times of the day to capture the spatial and temporal variations in noise and sound across SDSU's acoustic landscape. In retrospect, this may not have been a sufficiently large sample size to fully capture the spatial and temporal variations in SDSU's soundscape. Because of the dispersion of noise and sound at each sample location and time, it is reasonable to suspect that more sampling locations and longer sampling durations would have generated more robust data. However, this project did collect weather information such as temperature, relative humidity, wind speed and direction (Table 11) to help control for variability in sound propagation and intensity and showed there was not much variation in the weather conditions that could significantly affect the propagation of sound.

CHAPTER SIX: CONCLUSIONS

This study presented the results from a case study of mapping noise and sound for the campus of South Dakota State University for three time periods. The noise maps were generated from data, collected by two different devices, that were spatially interpolated to generate a continuous surface of noise levels across campus. The results show few places on SDSU's campus that exceeded the SDDOT noise recommendation levels, but the number of problem areas increase if we use the WHO thresholds. The morning, afternoon, and evening noise levels ranged between 43-67, 44-69, and 43-61 dBA, respectively using the DNM, and 44-71, 38-65, and 41-64 respectively for the SPA. The mean noise levels measured using the smartphone application (SPA) are comparable with those collected with the digital noise meter (DNM). These results highlight the potential for using cheap and portable smartphones for data collection, which may help pave way for increased use of citizen science projects in academic research. The results from this case study also indicate some "problem areas" across SDSU's soundscape that require attention.

Results from this research clearly demonstrate that mechanical sources of sound tend to dominate SDSU's soundscape. A possible approach to mitigate such problems could be fencing around the noisy machines that are outside the buildings and planting more trees along the sidewalks and the open areas (sound fencing, which could double as snow fencing during the winter months). Although SDSU is a "Tree Campus USA institution", there are not many evergreen trees that could offset the noise from the traffic, machines, and fans during fall and spring seasons. Thus, planting trees mostly evergreen such as pine and spruce trees, although not native to the ecoregion, could provide an inexpensive mitigation measure.

The methods employed in this study, especially soundscape mapping, can be applied to other educational environments as well. This approach could be extended to include data collection at a higher spatial and temporal resolution, and even the possibility of 3D and indoor mapping of noise and sound. Citizen science projects could be employed to gather noise and sound data using smartphones.

There are an increasing number of studies on noise mapping or soundscape mapping around the world, but few have used GIS to help map the noisescape and soundscape of an educational environment. Noise mapping using soundscape mapping can, thus, be an important tool for evaluating and interpreting environmental noise that can provide information to concerned authorities for mitigation of the noise pollution problems.

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APPENDICES

Appendix A. Sound Classification Instrument

Date =	**Weather =**	**Name =**
Location =	**Latitude =**	**Longitude =**
Site Description and other Important Contextual Information:		

Time	**Mechanical**			**Natural**			**Human**			**Communications**		
	<u>Examples</u>: traffic, lights, fans, lawnmower, air conditioner, etc.			*<u>Examples</u>: squirrels, birds, dogs, rain, wind, running water*			*<u>Examples</u>: steps, eating, background voices, washing dishes, cellphone ringing, etc.*			*<u>Examples</u>: intelligible conversation, talking on cell phone, music, radio, TV, iPod, etc.*		
	Enter 1 through 5			**Enter 1 through 5**			**Enter 1 through 5**			**Enter 1 through 5**		
Insert correct hour of the day	**Volume** (Background-Low-High)	**Pitch** (Deep-High)	**Perception** (Peaceful-Annoying)	**Volume** (Background-Low-High)	**Pitch** (Deep-High)	**Perception** (Peaceful-Annoying)	**Volume** (Background-Low-High)	**Pitch** (Deep-High)	**Perception** (Peaceful-Annoying)	**Volume** (Background-Low-High)	**Pitch** (Deep-High)	**Perception** (Peaceful-Annoying)
__ __:10												
	Description of Sound(s)			Description of Sound(s)			Description of Sound(s)			Description of Sound(s)		
__ __:20												
	Description of Sound(s)			Description of Sound(s)			Description of Sound(s)			Description of Sound(s)		
__ __:30												
	Description of Sound(s)			Description of Sound(s)			Description of Sound(s)			Description of Sound(s)		
__ __:40												
	Description of Sound(s)			Description of Sound(s)			Description of Sound(s)			Description of Sound(s)		