T.C.

ANTALYA BILIM UNIVERSITY

INSTITUTE OF POSTGRADUATE EDUCATION

GRADUATE SCHOOL OF CIVIL ENGINEERING

MASTER'S THESIS

SUSTAINABILITY FACTORS EVALUATION OF PUBLIC TRANSPORTATION IN ISLAMABAD AND RAWALPINDI

Noman SHAUKAT

JANUARY 2023

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This thesis was accepted by the jury (with unanimous vote/majority vote) on the date 19/01/2023 in SUSTAINABILITY FACTORS EVALUATION OF PUBLIC TRANSPORTATION IN ISLAMABAD AND RAWALPINDI of INSTITUTE OF POSTGRADUATE CIVIL ENGINEERING.

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DECLARATION

Master Thesis of this study named “Sustainability factors Evaluation of Public Transportation in Islamabad and Rawalpindi” which I presented, I declare that scientific moral principles were followed in the preparation of this study, in case of benefiting from the works of others, reference is made following scientific norms, no falsification has been made in the data used, and that any part of this study is not presented as another academic study.

19 / 01/ 2023

Noman Shaukat

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ABSTRACT

SUSTAINABILITY FACTORS EVALUATION OF PUBLIC TRANSPORTATION IN ISLAMABAD AND RAWALPINDI

Noman SHAUKAT

MSc Thesis in Civil Engineering

Supervisor: Assistant Prof. Dr. Emre DEMİR
Co-Supervisor: Assistant Prof. Dr. Şenay SADIÇ

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A sustainable Transportation system for public transport in cities needs to evaluate the importance of economic, environmental, and social sustainability. This research evaluates the sustainability factors and prioritizes these factors for achieving sustainability in the public transportation of Islamabad and Rawalpindi. Appropriate factors of sustainability were identified based on literature studies. A total of 15 factors of sustainability were taken into the account, and cause and effect factors among these factors and their relationship were predicted by applying the decision-making trial and evaluation laboratory (DEMATEL) approach. The overall objective is to rank the sustainability factors in the transportation system to identify the key factors of sustainability in Islamabad and Rawalpindi. Results show that air pollution and traffic congestion are important factors of sustainability for transportation in the twin cities of Pakistan.

KEYWORDS: Factor evaluation, Public Transportation, Sustainability, Twin cities

COMMITTEE: Assistant Prof. Dr. Emre DEMİR

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ÖZET

İSLAMABAD VE RAWALPİNDİ'DE KAMU ULAŞIMININ SÜRDÜRÜLEBİLİRLİK FAKTÖRLERİNİN DEĞERLENDİRİLMESİ

Noman SHAUKAT

İNŞAAT MÜHENDİSLİĞİ ALANINDA YÜKSEK LİSANS TEZİ

Danışman: Dr. Öğr. Üyesi Emre DEMİR
Eş Danışman: Dr. Öğr. Üyesi Şenay SADIÇ

Ocak 2023; 107 Sayfa

Toplu taşıma için sürdürülebilir bir ulaşım sistemi için ekonomik, çevresel ve sosyal sürdürülebilirlik faktörlerinin önemi değerlendirilmelidir. Bu araştırma, sürdürülebilirlik faktörlerini neden-sonuç bağlantıları içinde değerlendirir ve İslamabad ve Rawalpindi'de sürdürülebilir toplu taşımacılık için bu faktörlere öncelik verilir. Literatür çalışmaları temel alınarak, sürdürülebilirliğin uygun faktörleri belirlenmiştir. Toplam 15 sürdürülebilirlik faktörü dikkate alınmış ve bu faktörler arasındaki neden-sonuç ilişkileri ve faktörleri karar verme analizi ve değerlendirme laboratuvarı (DEMATEL) yaklaşımları uygulanarak tespit edilmiştir. Genel amaç, İslamabad ve Rawalpindi'deki sürdürülebilirliğin temel faktörlerini belirlemek için ulaşım sistemindeki sürdürülebilirlik faktörlerini sıralamaktır. Sonuçlar, hava kirliliği ve trafik sıkışıklığının İslamabad ve Rawalpindi'deki ulaşım açısından sürdürülebilirliğin önemli faktörleri olduğunu gösterir.

ANAHTAR KELİMELER: Faktör değerlendirmesi, Toplu Taşıma, Sürdürülebilirlik, İkiz şehirler

JÜRİ: Dr. Öğr. Üyesi Dr. Emre DEMİR

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SYMBOLS AND ABBREVIATIONS

APHA	: American public health association
AQI	: Air Quality Index
BRT	: Bus rapid transit
CDA	: Capital Development Authority
$\bar{C}$	: Average of covariance between items
$\bar{V}$	: Variance of an item
CFU	: Colony forming unit
CO	: Carbon monoxide
Db	: Decibel
DEMATEL	: Decision-Making Trail and Evaluation Laboratory
GHG	: Greenhouse gases
HCs	: Hydrocarbons
Hz	: Hertz
ITS	: Intelligent transportation system
K	: Number of scale items
KRTC	: Karachi Road transport corporation
ML	: Milliliters
NCS	: National conservation strategy
NDWQS	: National Drinking Water Quality Standard
NEQS	: National environmental quality standards
NESPAK	: National engineering services Pakistan
NOx	: Nitrogen oxides

NTRC	: National Transport Research Centre
NUST	: National University of Sciences and Technology
OECD	: Organization for economic and development
PCRWR	: Pakistan Council of Research in Water Resources
PM	: Particulate matter
PSDP	: Panjab Sector Development program
PT	: Public transportation
RTA	: Regional transport authority
SMEDA	: Small and Medium Enterprise Development Authority

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PREFACE

First of All, thanks to Allah Almighty who give me the strength and resources to complete my master's thesis in a better manner.

To my supervisors – Emre DEMİR and Şenay SADIÇ – I am very thankful to you for your ongoing mentorship, support, insightful comments, and advice over the past few months. Without your support, the research and learning that went into this thesis would not have been possible. Your guidance and mentoring have helped me think more clearly, scientifically, and critically about transportation and my research as a professional Civil Engineer. Even if I wrote another thesis on everything, I've learned in the past year working with you two, it might not cover everything. I appreciate each of you for sharing your special knowledge with me and assisting me in realizing my full potential, exploring new opportunities, and overcoming obstacles.

Mom, Dad, and my family since I can remember, you have been a loving family that has motivated me to pursue my goals regardless of what they are. You gave me the resources I needed to achieve my goals, whether I wanted to fly or be in the sky. I appreciate you always being there for me and supporting me as I struggled with my health to complete this thesis.

Thanks to all of you who helped me to achieve my goals.

1. INTRODUCTION

This section starts with the importance of the transportation sector followed by sustainable Transportation which explains the sustainability in the transportation sector in a better manner and moves towards key challenges for sustainability in transportation. After that sustainable public transportation and the need of transforming the transportation sector are discussed and after that barrier to sustainable transformation in the transportation sector is presented. The section is concluded with research area information and the problem statement of the thesis.

"The car is now the defining technology of our built environment. It sets the form of our cities and towns. It dictates the scale of streets, the relationship between buildings, the need for vast parking areas, and the speed at which we experience our environment. Somewhere between convenience and congestion, the automobile dominates what were once diverse streets shared by pedestrians, cyclists, trolleys, and the community at large." (Shoup, 2018)

Transportation is a vital part of the country's economy, and it is regarded as the country's backbone. However, transportation is one of the leading sources of death and injury all around the world. It is difficult to survive without a backbone, and it is much more difficult to survive with a damaged backbone, therefore to develop the country's economy, We must make transportation both affordable and safe. Concerns about the condition of our globe and the environment have grown significantly as a result of the broad adoption of an auto-centric lifestyle. The rise of the automobile over the past century has largely been a result of transportation planning methods. Aimed to provide more road infrastructure to meet anticipated traffic volumes (Hanson et al., 2004) in many urban locations, air pollution and traffic congestion are the two biggest problems. Transportation refers to the movement of people, goods, and resources from one location to another. It is an integral component of modern society, facilitating the exchange of goods, services, and ideas and promoting economic growth and development (Hall and Hay, 2003).

Transportation plays a crucial role in shaping urban development, by providing access to employment, services, and recreation (Cervero and Kockelman, 1997). Additionally, transportation can impact the quality of life of individuals and communities, influencing factors such as air quality, energy use, and social equity (Brownstone and Levinson, 2000).

Therefore, it is important to carefully consider the various options and impacts of transportation systems and solutions. A range of alternative transportation solutions, such as public transit, active transportation, and ride-sharing, are available, each with its benefits and drawbacks (Ewing and Cervero, 2010).

Due to several human inventions, including transportation, life is getting easier every day. One of the more important needs of the modern world is mobility. Today's congested highways and city streets move slowly, and occasionally not at all. Cars, bikes, trucks, and other vehicles are primarily used as modes of transportation. The nation's economy is heavily

dependent on transportation.

1.1. Sustainable Transportation

The triple bottom line is a key idea in bringing sustainability to the transportation industry. Three dimensions—the environment, the economy, and society—are used by (Banister, 2005; Black, 2010; Falinski et al., 2018; Jeon, 2007; Kennedy, 2002; Newman, P. Kenworthy, 1999) to analyses sustainable development concerns. The phrase "triple bottom line" refers to these three factors. Low in 2013, defines them as follows:

- Environment: The environmental or ecological dimension takes into account how changes in local and global surroundings are impacted by human activities and advancements.
- Social: The social aspect of sustainability is frequently described as addressing concerns of justice and inclusion.
- Economic: development is the process of a community's growth or progress towards economic goals, such as increasing wealth, employment, productivity, or ultimately wellbeing.

For all urban people to have access to mobility and a safe, environmentally friendly form of transportation, a sustainable transportation system must be in place (Keeble, 1988). Any form of transportation that is "green" and has no influence on the environment is referred to as sustainable transportation (Litman & Burwell, 2006). To be sustainable, transportation must balance our present and future needs (Yigitcanlar & Dur, 2010). Walking, cycling, taking public transportation, carpooling, car sharing, and using green automobiles are some examples of sustainable mobility (Chandra & Kumar, 2020). It also includes indigenous fuels, electric and alternative fuel cars, and energy-efficient, low- and zero-emission modes of transportation. In discussions on sustainability, theories of sustainable development are frequently used. A definition of sustainability that is frequently used is found in the Brundtland Commission's report, Our Common Future - “Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Keeble, 1988)

Sustainable transportation and the development of any country are interlinked. For example, due to reliance on automobiles, cities around the world have congested roads, which results in pollution and societal costs like accidents (Moavenzadeh et al., 2002). Because of this, transportation networks can encourage urban expansion while also providing a variety of challenges. Impacts on the economy, society, and ecology are among these difficulties (Banister, 2005). These challenges can be considered sustainability challenges.

1.1.1. Challenges for Sustainability in Transportation

The tremendous economic growth due to modernization has resulted in major issues, one very important of them being traffic congestion (Profillidis et al., 2014). Designing an

efficient public transportation system is a global challenge but developing countries need to use the transportation system sustainably to avoid hurdles of constructing or expanding infrastructure in the future (Profillidis et al., 2014).

Transportation intersects with the environment and other social areas, which can improve people's quality of life (Awasthi et al., 2011). It can promote economic expansion and link people to essential services. But it can also lead to several difficulties. According to Litman & Burwell in 2006, current trends in automobile-oriented transportation are unsustainable because of significant negative effects on environmental, economic, and social factors.

Congestion is a major problem in auto-dependent cities that negatively affects their sustainability (Profillidis et al., 2014). Congestion is a major problem related to auto dependence and is characterized by poor traffic flow rates and excessive vehicle densities. Congestion has been deemed a worldwide phenomenon that is caused by increasing automobile dependence (Moavenzadeh et al., 2002). Environmental (increased pollution), economic productivity loss, and social effects are among the negative effects (human health and equity impacts).

Apart from energy production and industrial processing, transportation contribution to air pollution is comparatively high, and hence it is the main source of air pollution. The economic effects of congestion are examined by (Banister, 2005), who contends that a system is regarded unsustainable from an economic point of view when it is unable to provide sufficient mobility for a variety of travel reasons and modes. The health costs associated with a sedentary lifestyle and other social sustainability challenges can be attributed to auto-dependent transportation (Cidell, 2012). According to Schiller & Kenworthy in 2010, cities were able to develop significantly with fewer barriers than when cities were governed by other forms of transportation because of the lowered travel time and enhanced personal mobility provided by automobiles. Increased mobility was a result of this kind of growth, but it also brought up the sustainability issues detailed in table 1. According to some evidence, the development of motorways and increased emissions for transportation have harmed the environment.

According to Newman, P. Kenworthy in 1999 severance is a major social problem that can separate communities, reduce neighbor connections, and cause communities to deteriorate. Communities may become suburban communities as a result of urbanization, with no sense of connectivity. In contrast to other regions of the world, such as East Asia or Europe, where cities are denser and development patterns are less stratified (i.e., mixed-use is more typical), this expansion is most widespread in North America. As a result, the automobile is a less dominating form of transportation there (Newman, P. Kenworthy, 1999).

Table 1. 1. Sustainability Factors Impact on Transportation

Environmental	Economic	Social
• Air Pollution • Climate Changes • Noise Pollution • Noise Pollution • Water Pollution • Degradation of area • Non-renewable resource depletion	• Accessibility Quality • Traffic Congestion • Infrastructure cost • Consumer costs • Mobility Barrier • Accident damages • Depletion of hydrocarbon fuels	• Equity/Fairness • Impacts on mobility Disadvantaged • Affordability • Human Health Impact • Community Cohesion • Community livability • Aesthetics

Source: (Litman, 2009)

1.1.2. Sustainable Public Transportation System

Public transportation is the key tool to bring sustainability to the transportation sector (Forkenbrock & Foster, 1990). As we know that transportation engineering is a wide field so to bring sustainability as a whole, we have to apply sustainability in its subfields like pavement and design engineering, parking system, and public transportation system with the help of Intelligent transportation systems (ITS). According to Schiller & Kenworthy in 2010, public transportation can play a significant role in lowering vehicle travel and dependency in cities because of its space efficiency and social benefits. They also claim that these benefits are spread over a variety of sustainability criteria.

These advantages may span all of the consequences listed in Table 1.1. including greater access (social), decreased emissions and land use, higher economic efficiency, and contributions to economic activity (economy). Four major points support public transportation as a key transportation intervention for promoting sustainability in cities (Valiantis, 2014).

I. Businesses and individuals change their locational preferences when there is good public transport
II. Instead of making separate car trips, people who use public transportation consolidate their travels into one.
III. Transit-using households should leave their cars.
IV. Walking or cycling are popular ways for public transportation to get to stations and stops. The benefits of public transit extend beyond immediate transportation services.

When there are all facilities of public transportation at a standard level, the mindset of people automatically changes and they prefer to use PT instead of their vehicles to avoid fuel consumption and traffic congestion.

1.1.3. Importance of Public Transportation

Public transportation is the backbone of countries for development and due to public transportation great revenue can be generated but it requires a huge investment for transportation sectors to follow the rules of sustainability. There are some reasons which make sustainable public transportation so important for any nation (Mr. Kamran Ahmed Assistant Professor SCEE, 2021).

Sustainable public transportation can carry a greater number of people in a few means of transport resulting in less traffic congestion (Friman et al., 2020). That will cause a great reduction in private car using which ultimately leads the transportation sector toward sustainability. Improving accessibility in public transportation makes it more significant because of easy access to all, for example, disabling special paths for entrance via a wheelchair, etc. It also causes social interaction within the community because all kinds of people traveling in the same transit cause equality and also leads to many possibilities for social circle (Adeel et al., 2016). A sustainable public vehicle like BRT is designed with new technology keeping sustainability rules of nature in mind hence it causes less air pollution and ultimately less vehicle movement will be observed when people prefer to use PT so these factors make our globe less harmful. Public transportation involves physical activities of people as they have to ride a cycle or go on their feet to a bus stand which leads towards an active life and sustainable Public transportation helps in the reduction of accidents hence creating a safer road environment for all kinds of the human being (Xia et al., 2015). Therefore, the sustainability factor is important for public transportation concerning environmental, social, and economic factors.

To get sustainability in transportation public transportation system should make so efficient so that it can perform better in mixed dense areas and urban cities (May & Crass, 2007). So, the development of effective public transportation is the only solution available to tackle the problem of traffic congestion in moderate and major cities. Compared to private cars, public vehicles have substantially bigger loading capabilities and can share space with other passengers. The average passenger area occupied by a public vehicle is substantially smaller than that of a private car.

1.2. Study Area

For sustainability in public transportation, Pakistan is selected as the study area and more specifically its capital is chosen for research work. People in Pakistan's major cities like Islamabad, Rawalpindi, Karachi, and Lahore squander almost three hours every day delayed in traffic on workdays. Even in middle-sized cities like Sialkot, Gujranwala, Multan, Muzaffarabad, Sargodha, and others, traffic congestion is a typical occurrence.

The issue of escalating traffic in major cities is one that the Islamic Republic of Pakistan, like the majority of other developing nations, must deal with. The demand for traffic in Pakistan's two largest cities, Islamabad, and Rawalpindi have increased dramatically in recent years. The main cause of this expansion is population explosions brought on by people leaving their home regions in search of higher living standards. In addition to population growth, factors that contribute to an increase in the number of automobiles on the road include rising car ownership due to more inexpensive auto finance and leasing options and a dearth of a reliable public transportation system. With a total size of 906.5 square kilometers, Islamabad is 25% urban. Islamabad has a 2 million population (Pakistan Bureau of Statistics, 2017) (2017 census) with a density of 2211 people per square kilometer. It is ranked as Pakistan's tenth-most populous city. Islamabad, the nation's capital, is situated immediately adjacent to Rawalpindi. The population density of Rawalpindi, which has a population of 2,09 million, is 8,100 people per square kilometer. Twin Cities refers to both cities. Figure 1.1. shows the geographic location of the twin cities on the Pakistan map. And Table 1.2. indicates the coordinates of Islamabad and Rawalpindi respectively.

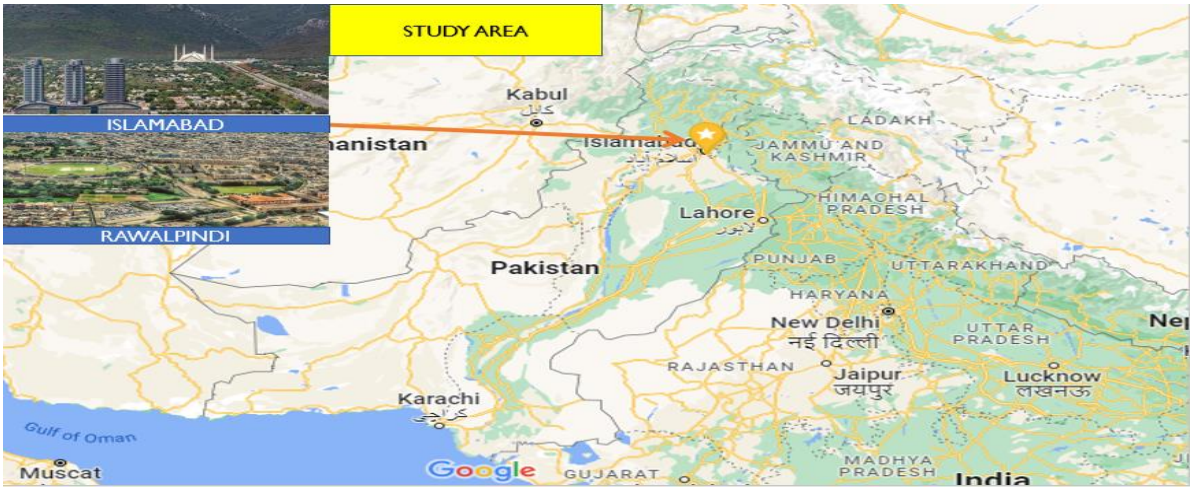


Figure 1. 1. Location of the area selected for the research work

Source: (Google maps)

Table 1. 2. Location of research Area

Location	**Coordinates**
Islamabad	33.7294º N, 73.0931º E
Rawalpindi	33.5984º N, 73.0441º E

1.2.1. Current Public Transport Modes of Transportation in Twin Cities

In Rawalpindi and Islamabad, respectively, the Regional Transport Authority (RTA) and Islamabad Transport Authority oversee public transportation. In twin cities, public transportation accounts for 42% of the market share, according to a (NESPAK, 2017) survey. Twin cities offer a variety of public transportation options. Figure 1.2 represents a visual representation of the various modes of public transportation available in Rawalpindi and Islamabad. Some of the modes mentioned, such as the green line bus service and orange line bus service, would likely be different types of city buses that serve the area. Taxi and motorway buses are the type of intercity bus service that provides transportation between the twin cities and other locations. These different modes of public transportation provide residents and visitors with different options for getting around the twin cities and reaching their destinations.

Figure 1. 2. Different Modes of Public transportation in twin cities

Source: (Noman et al., 2020**)**

1.3. Background

The country's most valued capital asset and only means of intercity public transportation in 1947 were the railways (Nabi, 2001). The majority of people traveling through Pakistan at the time were transported by Pakistan Railway (North Western Railway) (Khan, 1957). This fact was recognized in the First Five-Year Plan (1955–1960) (Khan, 1957), which stated:

The backbone of [West] Pakistan's transport system is a broad-gauge railway network. It is a system of main lines, one in each of five parallel river valleys, interlinked and

stretching from the coast to Afghanistan and India's frontiers (Govt. of Pakistan, National Planning Board 1957: 485 (Khan, 1957).

Up until 1947, there was hardly any motorized traffic in metropolitan areas (Railway, 1982). For instance, in the city of Lahore, a mixed land use pattern was present with residences, workplaces, bazaars (commercial centers), and community spaces all close by. As a result, walking and Tonga were the two most popular modes of transportation (horse-drawn carriage).

The early metropolitan areas, such as Lahore, had limited motorized traffic with a mixed land use pattern consisting of residential, commercial, and community spaces. Walking and Tonga (horse-drawn carriage) were the main modes of transportation. In 1939, the Motor Vehicle Act was revised and the Punjab Road Transport Board was established to provide efficient, affordable, and coordinated public transportation services (Khan, 1957). In 1957, the West Pakistan road transport board was established as per the recommendations of the first five-year plan. The KRTC department was set up in 1959 to manage the bus-based urban public transportation in Karachi. The Second five-year plan in 1965 marked a shift in transportation priorities as it allocated more financial resources to roads than railways. The Motor Vehicle Act of 1939 was revised in 1951, and Punjab's road transport board was constituted. The Punjab Road transport board's primary responsibility was to offer the province effective, sufficient, affordable, and coordinated public transportation services. The first five-year plan's recommendation led to the establishment of West Pakistan (M. Imran, 2009). According to the plan, the perception driving this action was:

Road transport is particularly suited to the conditions and requirements of Pakistan the motor vehicle is more adaptable than the railways to varying degrees of traffic intensity and permits a greater degree of speed and efficiency in haulage over short distances… there is a close relationship between the volume of transport and the level of economic activity because each depends upon the other. (Government of Pakistan in 1965)

The National Transport Research Center released a draught National Transport Policy in 1991 (M. Imran, 2009). According to the approach of NTRC, Buses should be taken into account for the public transportation system in major cities of Pakistan. This strategy might have been used since the World Bank was unable to provide the funding necessary to put in place a rail-based mass transit system. In 1991 Prime minister initiated the public transportation scheme in a better way by establishing the department of communication 1991 (M. Imran, 2009). For the welfare of public transportation, the communication department started to import taxis, buses, and mini-buses (M. Imran, 2009).

The first broad step for addressing environmental issues was to establish a National Conservation Strategy (NCS) (Govt. of Pakistan, Environment and Urban Affairs Division and International Union for Conservation of Nature 1992) (M. Imran, 2009). The NCS paid very little attention to the transportation industries. The plan took into account the wider

ecological effects of transportation and gave energy and air pollution issues special consideration.

The prime minister of Pakistan in 1996, began a mass transit project in twin cities as an important part of Prime Minister Benazir Bhutto's development program for large cities (M. Imran, 2009).

This project was about connecting railway stations to the feeder coasters (mini buses) in Islamabad with an urban rail link between Rawalpindi and Islamabad. This service's primary goals were to lessen traffic congestion during rush hours, clean up the air, and utilize already-existing train infrastructure (Govt. of Pakistan, NTRC 1996) (M. Imran, 2009).

The Federal Ministry of Industries and Production's Small and Medium Enterprise Development Authority (SMEDA) created the National Transport Strategy in 1999 (Govt. of Pakistan, SMEDA 1999).

In the later century government of Panjab launched a mega project of public transportation in twin cities for the welfare of the people but unfortunately due to corruption all mega projects are not well being constructed and suffered from a lack of funds.

1.4. Problem Statement

As a result of rapid urbanization is taking place, leading to overburdening of our metropolitan cities. Designing an effective public transportation system is a worldwide task, but developing countries must use the system sustainably to avoid future infrastructure construction or expansion challenges if specifically, Pakistan is taken into account air pollution and traffic problems are the severe issue of Pakistan specifically for twin cities which caused plenty of fatal injuries and accident on road every day. This research aims toward the evaluation of sustainability factors in public transportation in Islamabad and Rawalpindi based on survey-based data and available data. This research aims to evaluate the major factors which are affecting public transportation and violating the laws of sustainability in public transportation and ranking these factors according to their impact.

To contribute to the research on sustainability that has been done. This thesis will answer the following question.

Box 1. 1. Aim of the Research

- Find out the sustainability factors in public transportation
- Identify the cause-and-effect group of the sustainability factors.
- Rank the sustainability factors

1.5. Disposition

The master thesis is going to be as follows, after this general introduction to sustainable transportation, its importance, and sustainability in the public transportation sector covered by the background of the search-based country and problem statement. The next chapter will be the literature review in which a brief discussion about the working and sustainability importance in transportation and figuring out sustainability factors in the transportation system Moreover, the literature review chapter consists of the MCDM technique involved in this research. Then chapter 3 the methodology, which explains the method, data, and the process of the thesis. Chapter 4 and 5 is about the findings, analysis, and comments from methodology, and chapter 6 is based on the conclusion based on research. Chapter 7 covers references from different books, journals, and web pages that had been used during and lastly chapter 8 includes appendixes that have been used in this research.

2. LITERATURE REVIEW

2.1. Sustainable Transportation

The idea of sustainability is typically viewed as a means of generating welfare for the present generation without jeopardizing future generations' chances of achieving at least the same levels of welfare (Himanen et al., 2005).

There have been many definitions of sustainability and sustainable development developed during the past few decades. There is currently no definition of sustainability that is accepted worldwide (Perman et al., 2006). The many conceptualizations of sustainability, however, are complementary rather than competing with one another

Box 2.2. Six concepts of Sustainability

I. Sustainable condition is one in which consumption (or utility) doesn't decline with time.
II. A sustainable condition is all about managing the sources for the future.
III. A situation that is sustainable is one in which the stock of natural capital doesn't decline over time.
IV. Sustainability is all about the managing the resources at 100% of positive yield for future too.
V. sustainable state is one that satisfies the prerequisites for long-term ecological resilience.
VI. Sustainable development as institutional growth and consensus-building.

Source: (Himanen et al., 2005, p. 86.)

There is not currently a single, agreed-upon definition for sustainable transportation systems. According to (Richardson & Markandya, 1992), A sustainable transportation system is one that "Can be sustained into the indefinite future without causing great or irreparable harm to future generations of people throughout the world." This concept takes into account many things, including social and economic access, safety, traffic congestion, and automobile emissions. When it comes to sustainable development, both developed and developing countries face significant challenges in the choice and planning of their future transportation networks. Accessibility, mobility, human safety, environmental protection, economic growth, and social equality all need to be balanced (Jin et al., 2018). It can be said that public transportation that is environmentally, economically, and socially responsible fits

into all three categories of sustainability. Sustainable transportation is a holistic approach that aims to improve the overall quality of life and well-being of people by providing efficient and safe mobility, reducing environmental and social impacts, and promoting social and economic equity (J. Banister, D. Givoni, and E.Kahn-Nisser, 2018).

Even though there are no codes and regulations worldwide, the majority of definitions have similar underlying concepts. The objectives of sustainable mobility and the function of urban planning are more crucial to this argument than a definition. According to (Schiller & Kenworthy, 2010), Sustainable transportation aims to minimize the negative social and environmental impacts of current mobility patterns while simultaneously promoting better, healthier approaches to meeting the requirements of individuals and communities. Sustainable transportation is a multifaceted concept that encompasses economic, social, and environmental aspects of transportation and seeks to ensure that the mobility needs of people and goods are met in a manner that is economically viable, socially acceptable, and environmentally sound (S.K.Geurs and B.van Wee, 2004). Therefore, rather than boosting mobility to address the current inaccessibility, it is important to give closer and improved access to key daily objectives such as shopping, work, basic healthcare, and recreation. To eliminate longer commutes and the need for a car, cities must be designed as mixed-use areas with a variety of services offered on-site or nearby. It's also necessary to cut back on resource use, waste, and the frequent negative effects of transportation on public spaces. Sustainable transportation is a concept that aims to provide mobility while minimizing negative environmental and social impacts, promoting economic efficiency, and enhancing the quality of life (M.C.N.McNally, 2011)

Sustainable transportation is a multifaceted concept that encompasses economic, social, and environmental aspects of transportation and seeks to ensure that the mobility needs of people and goods are met in a manner that is economically viable, socially acceptable, and environmentally sound (S.K.Geurs and B.van Wee, 2004). Sustainable transport development is not solely dependent on technical procedures; it is also a social process that influences, among other things, the economy, politics, the public, and planning. By reducing reliance on the car as the primary form of private transportation, it strives to minimize the financial cost to both society and the individual. It is crucial to transition today's motorized transportation to sustainable mobility due to climate changes and population development in urban areas. Therefore, it is essential to reconsider land use and transportation planning. A successful conversion can only be ensured if all relevant disciplines collaborate. Strong sustainability concepts, in contrast, place a strong focus on the planet's overall and ecological systems' absolute carrying capacity (Neumayer, 2013).

Strong sustainability proponents contend that sustainability demands that the level of natural capital not decline, whereas weak sustainability proponents contend that the total of natural capital and human-made capital must not decline (Neumayer, 2013). Even if there are various definitions of sustainability, the goal of sustainable development is to consider people's well-being regardless of where and when they live. This method is used to assess how sustainable human behavior is across a range of economic sectors, including transportation.

The term "sustainable transport" is most frequently used to refer to discussions of transportation concerns in the context of sustainable development (Feitelson, 2002). The word "sustainable development" serves as the foundation for the idea of sustainable transportation. One way to look at sustainable transportation is to examine the sustainability of the transportation system as a whole, with a focus on its external effects on the environment, public health, safety and security, land usage, and congestion. Additionally, future transportation systems' potential effects on overall sustainable development might be taken into account when evaluating the sustainability of transportation. The Organization for Economics and Development (OECD) defines sustainable transportation as a system that provides "Access to people, places, goods, and services in an environmentally responsible, socially acceptable, and economically viable manner" as part of the worldwide definition of sustainable development. (The Vancouver Conference, 1996) (OECD, 2002). However, the fundamental trend in defining sustainable transportation is still to consider its environmental, social, and economic aspects.

The environmental aspect of a sustainable transportation system draws attention to the point that transportation activities consumption of non-renewable natural resources and by emitting toxic gases such as polluting gases (GHG). An environmentally sustainable transportation system aligns with the principles of sustainable development, as defined by the OECD in 2002, and economists such as Daly in 2003. This type of transportation system meets the needs for mobility and access while also ensuring that renewable resources are used within their regenerative capacity and non-renewable resources are used below the rates at which renewable alternatives are developed. In other words, an environmentally sustainable transportation system balances the need for transportation with the need to preserve the environment and natural resources for future generations (Daly, 2003).

The idea of economically sustainable transportation is reliant on full cost accounting and full cost-pricing systems that take into account economic factors originating from transportation activity impacting sustainable development (specifically, unsustainability, decrease in economic growth, and non-priced inter-sectorial linkages; public goods; uncompetitive markets; pathetic planning and high discount rates; risk and uncertainty, irreversibility, and policy failures) (Richardson & Markandya, 1992). According to several definitions of economically sustainable transport, transportation must be cost-effective and responsive to continuously changing demands in a way that the commercial and free market may operate without large detrimental externalities and distributional implications (May & Crass, 2007). A great quality of life often depends on having good physical access to jobs, housing, healthcare, education, and other amenities. On the one side, attaining economic advancement demands having good physical access to resources and markets.

2.2. Sustainable Public Transportation

According to Jeon in 2007, sustainable public transportation should enable the fulfillment of the fundamental access requirements of people and societies, both within and across generations, in a better and consistent way that is meaningful for human beings.

I. Keeping emissions and waste to levels that the world can absorb reduces the use of non-renewable fuel resources to the maximum extent possible (Jeon, 2007; Jeon et al., 2010).
II. Sustainably high yield, recycles and repurposes its parts, and reduces both the noise produced and the amount of land used (Jeon, 2007; Jeon et al., 2010).
III. Offers a range of public transportation options, is reasonably priced, and runs effectively. And encourages economic expansion (Jeon, 2007; Jeon et al., 2010).

There is a substantial body of theoretical and empirical research in the field of public transportation performance analysis that has examined transit performance from several angles, including effectiveness, efficiency, economic performance, and environmental impact. Different studies have been carried out to know sustainability in public transportation by assessing transportation more deeply and transportation has become a keen interest of researchers to bring modification and new technologies. According to (Vreeker & Nijkamp, 2005) complex, transportation planning issues call for the use of both theoretical analysis and real-world policy.

According to (Pope, Jenny; Annandale, Dr. David; Morrison-Saunders, 2000), To achieve sustainability, It is necessary to analyze the consequences of the current laws, regulations, plans, programs, initiatives, practices, and actions in transportation. According to (Pope, Jenny; Annandale, and Dr. David; Morrison-Saunders, 2000) more precise methodologies are needed if evaluation is to be utilized to improve sustainability because the majority of definitions and methods for measuring sustainability are broad and describe a variety of operations (Pope et al., 2004).

Indicators are used in planning and analyzing transportation networks to determine trends and simulate or analyses impacts (Litman, 2009).To enhance the foundation for making decisions, the Subcommittee further recommends that complete and balanced indicator sets should contain indicators from all main issue categories (Sohail et al., 2006).

According to (Litman & Burwell, 2006), traditional assessment methods used in transportation analysis often focus on traveling patterns and may not achieve sustainability in transportation which makes it more compulsory to develop methodology and indicators for analysis of sustainability. This point makes a clear direction for researchers to further research and investigate more methods for evaluating sustainability in transportation and more specifically in public transportation.

2.3. Triple Line Bottom

Planning, policy choices, and implementation of critical procedures for creating a sustainable outcome are guided by the Triple Bottom Line concept (Zako & Moore, 2014) (Hipogrosso & Nesmachnow, 2020). Agencies and businesses are looking at all of the bottom-line components when contemplating how to deliver transportation solutions and infrastructure more sustainably.

I. ECONOMY – Encourage a healthy economy while cost-effectively improving infrastructure. Costs associated with infrastructure must be manageable and acceptable to society. User costs, including private fees, must be successful and within the means of both individuals and households (Zako & Moore, 2014).
II. SOCIAL — Provide mobility options for everyone, especially those who are economically disadvantaged; address social needs by making transportation accessible, secure, and safe; and create the infrastructure that benefits local communities (Zako & Moore, 2014).
III. ENVIRONMENT — Develop environmentally friendly solutions that can improve the environment, lessen emissions of toxic pollutants and gases from the transportation system, and cut down on the number of raw materials needed to support transportation (Zako & Moore, 2014).

The figure2.1 (Purvis et al., 2019) shows the pillars of sustainability i.e., Economy, Social, and environment. The Economy pillar encompasses the financial and economic viability of the transportation system, including factors such as cost-effectiveness, job creation, and economic growth. A sustainable transportation system must be financially viable and provide economic benefits to the communities it serves. The Social pillar concerns the social equity and well-being of individuals and communities. This includes considerations such as accessibility, safety, and community engagement. A sustainable transportation system must be accessible to all members of the community and provide safe, reliable transportation options. The Environment pillar focuses on the impact of transportation on the natural environment, including considerations such as resource conservation, emissions, waste reduction, and the protection of ecosystems and biodiversity. A sustainable transportation system must minimize its negative impact on the environment and promote the use of environmentally friendly transportation options.

Overall, Figure 2.1 highlights the importance of considering all three pillars of sustainability in the design and implementation of transportation systems. By balancing economic, social, and environmental concerns, transportation systems can be designed to be truly sustainable and support the long-term well-being of communities and the natural environment.

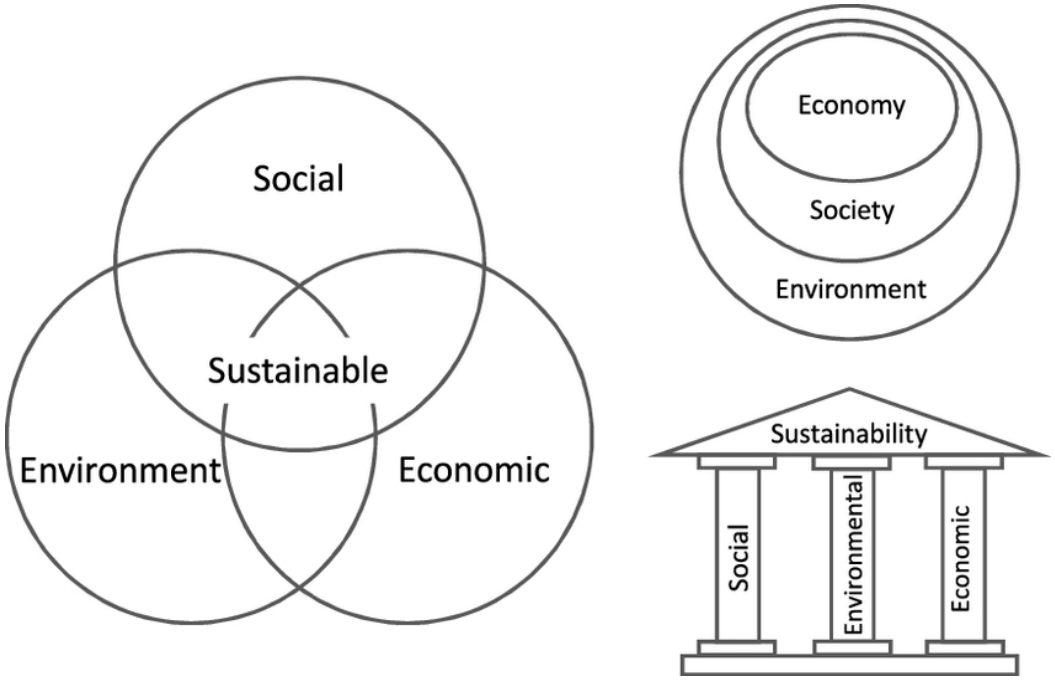


Figure 2. 1. Three Pillars of Sustainability

Source: (Zako & Moore, 2014)

The studies evaluation of sustainability factors are included by (Miller et al., 2016a) to create a set of transit concerns and sustainability goals concerning three pillars of sustainability

According to some research some important factors to take into account when figuring out how public transport can improve sustainability for the above-mentioned pillars are shown below. Table 2.1. shows factors and sustainability considerations carried out in different research.

Table 2. 1. Factors and Sustainability Consideration from the literature review study

Factors	Sustainability Consideration	Goals	*Linked to*
Environmental	Limited use of energy due to a decrease in passenger own vehicles	Minimum consumption of energy /km	(Dobranskyte-Niskota et al., 2007)(Miller et al., 2016a)(Haghshenas & Vaziri, 2012)(Litman, 2009)
	Less contribution towards climate changes	Minimum greenhouse gases effect/km	(Dobranskyte-Niskota et al., 2007),(Haghshenas & Vaziri, 2012),(Miller et al., 2016a),(Bongardt et al., 2011),(Jeon et al., 2010)
	Reduction of air pollution, water pollution, and land pollution	Reduce emissions or pollution per kilometer	(Dobranskyte-Niskota et al., 2007),(Haghshenas & Vaziri, 2012),(Miller et al., 2016a),(Bongardt et al., 2011),(Jeon et al., 2010)
	limiting ecological disruption	Reduce disturbance through system design and right-of-way	(Dobranskyte-Niskota et al., 2007),(Haghshenas & Vaziri, 2012),(Miller et al., 2016a),(Bongardt et al., 2011),(Jeon et al., 2010)(Litman, 2009)
Economics		Limited time travel	(Dobranskyte-Niskota et al., 2007),(Haghshenas & Vaziri, 2012),(Miller et al., 2016a),(Bongardt et al., 2011),(Jeon et al., 2010)(Litman, 2009)
		reduced direct financial costs	(Dobranskyte-Niskota et al., 2007)(Miller et al., 2016a),(Litman & Burwell, 2006)
		lower operating costs per traveler	(Dobranskyte-Niskota et al., 2007)(Miller et al., 2016a),(Haghshenas & Vaziri, 2012)

	Boost the system's economic performance	Minimum capital cost	(Dobranskyte-Niskota et al., 2007)(Miller et al., 2016a)(Haghshenas & Vaziri, 2012)
	Improve System independence	maximize recovery or lessen the need for a subsidy	(Dobranskyte-Niskota et al., 2007)(Miller et al., 2016a)
Social	Better affordability	Reduce the amount of money that users or households pay for transportation.	(Dobranskyte-Niskota et al., 2007),(Haghshenas & Vaziri, 2012)(Miller et al., 2016a)(Jeon et al., 2010)
	Ease of accessibility	increasing accessibility in all areas (user, system)	(Dobranskyte-Niskota et al., 2007),(Haghshenas & Vaziri, 2012)(Miller et al., 2016a)(Bongardt et al., 2011),(Jeon et al., 2010)(Litman, 2009)
	Minimum health Impact	Reduce exposure to illness/death from pollutants that influence human health.	(Dobranskyte-Niskota et al., 2007)(Miller et al., 2016a)(Bongardt et al., 2011),(Jeon et al., 2010)
	Limit traffic accidents	minimize system operation-related harm and fatalities	(Jeon et al., 2010)(Miller et al., 2016a)(Dobranskyte-Niskota et al., 2007),(Bongardt et al., 2011),(Litman, 2021)
System effectiveness	Enhance operations and capacity usage	maximize capacity and dependability use	(Dobranskyte-Niskota et al., 2007),(Litman, 2021)

2.2.1. Environmental Factors of Sustainability

Generally, transportation uses resources from the environment to facilitate movement ki (Yang et al., 2016). For example, food, energy, and fuel for cars and light rail vehicles all use resources to make mobility possible. However, using these resources has an impact on the ecosystem. Transportation frameworks are likewise viewed as a component of the climate, in that they make a new nature of climate for people (Low, 2013). Since transportation systems interact with, utilize resources from, and are connected to the environment, discussing how they affect the environment is essential for a discussion about

sustainable mobility. In addition to energy production and industrial processes, transportation is the primary cause of air pollution and makes a considerable contribution to pollution (Dobranskyte-Niskota et al., 2007). According to Rothengatter in 2003, environmental factors are different at local, regional, and global levels that's means the impact of environmental factors tends to affect sustainability at all levels.

Many of the effects being looked at will continue to evolve in non-industrialized nations, nations undergoing rapid modernization, like Japan, and nations that are in transition, like those in Eastern Europe (Rothengatter, 2003). According to (Rothengatter, 2003) predictions, the environmental effects of transportation will continue to expand as the volume of cars on the road, especially in urban areas. The impact per journey will also increase, according to the (Rothengatter, 2003) second point, when less ecologically friendly ways overtake less harmful modes like the train, coach, or other modes in market share.

The following are significant problems with transportation systems (Miller et al., 2016b)

I. Due to their reliance on non-renewable energy sources, current transportation systems are regarded to be energy-demanding and in violation of sustainability ideals (Miller et al., 2016a, 2016b).
II. The majority of current transportation networks are centered on private automobiles, which are not the most energy-efficient method (Miller et al., 2016a, 2016b).
III. Although there is uncertainty regarding technology shift, a change to denser urban forms, different modes of transportation (such as bicycle public transportation), and other technologies can cut energy use (Miller et al., 2016a, 2016b).

Transportation networks are significant sources of greenhouse gas emissions that contribute to climate change, such as CO^2 (Schipper & Fulton, 2003). (Bongardt et al., 2011)(Litman, 2009) commented that "Overall transportation is responsible for 13% of worldwide GHG emissions and 23% of energy-related CO^2 emissions." Emissions from transportation systems that affect air quality can have an impact on the environment. Due to the use of a variety of fuel types, emissions are frequently closely related to energy consumption (Banister, 2005). Due to their harmful effects on the surrounding environment, these emissions are regarded as local pollutants. Following is a summary of these contaminants from (Pope et al., 2004):

- Carbon Monoxide: Transport is the main source of CO (90% of it comes from cars), an extremely hazardous gas.
- Nitrogen oxides (NOx): cause serious lung diseases.
- Hydrocarbons (HCs) are recognized as carcinogens.
- Particulate matter (PM) exacerbates respiratory conditions, and PM 2.5 can be harmful.

2.2.2. Economic Factors of Sustainability

The economic aspect of sustainable transportation is built on an understanding of how transportation either accelerates or retards economic development (Litman, 2009). On the other side, unsustainable transportation can reduce the economic growth of any country.

Moving people and products is the responsibility of transportation; if a system is unable to achieve this, it will affect the community's economic sustainability (Garrison & Ward, 2000). Additionally, it is declared that transportation and economic growth are interconnected both in communities and nations. An efficient public transport system is a key factor in the improvement of economic growth (Vreeker & Nijkamp, 2005). Congestion can sometimes cause to damage the economies in a tremendous amount and decreases a region's overall economic viability as a result of the backlog of personnel and commodities (Moavenzadeh et al., 2002),(Moavenzadeh & Markow, 2007). Large automobile-oriented highways have isolated communities, which has led to several social problems. Additionally, freeway traffic pollution has led to local and worldwide environmental problems (Banister, 2005).

One need not search far to find a clear example of this issue in the developed world than the daily occurrence of clogged streets transporting commuters. The sustainable factors of the transportation system for cities and regions have suffered as a result of the expansion of many cities to accommodate heavy automobile use (Newman, P. Kenworthy, 1999). Mobility concerns and transportation-related challenges in emerging nations have an impact on residents' possibilities, economic processes, and quality of life (Robinson & Thagesen, 2004). Citizens' mobility and accessibility to fundamental public services and vital requirements are restricted by a lack of access to adequate transportation infrastructure and services (e.g., health, and education). Transportation networks that are not well planned and maintained also hinder economic development. Strong transportation infrastructure has been claimed to be a core part of a town's growth, considering economic factors and possibilities available for residents (Robinson & Thagesen, 2004).

At the beginning of the twenty-first century, over fifty percent of humanity resided in urban areas. In the 21st century, predicted that the bulk of people would live in urban cities rather than rural ones (Robinson & Thagesen, 2004). The majority of this transition will take place in emerging nations since the developed world already experienced a change from rural to urban living during the 20th century. The need for well-being is growing as urban populations continue to rise throughout the twenty-first century. Cities must avoid violating the laws of sustainability in transportation development if they are to find planned and engineered transportation alternatives. There are numerous sustainability difficulties with transportation networks in many industrialized countries' cities, including social, economic, and environmental ones (Banister, 2005). These difficulties are an important reminder that to reduce the detrimental effects of transportation, the consideration of sustainability factors in transportation systems needs to be better acknowledged. In industrialized countries, there is a rising tendency toward the creation of new systems focused on sustainability and the upgrading of existing systems to be more sustainable. A considerable interest in more

environmentally friendly travel is indicated, for instance, by the innovative technologies of ITS to control demand and increased investments in bigger and more effective public transportation networks.

2.2.3. Social Factors of Sustainability

Compared to other types of impacts, social effects are more difficult to measure, and assessment methods are less accurate for social factors of sustainability in transportation (Sinha & Labi, 2007). Over the last few years, much improvement has been done in recognizing and exploring social impacts. The social effects of transportation are examined in this section.

One way that transportation networks contribute to the general welfare of the population is by connecting people to other people and places (Cidell, 2012). However, auto-dependent and unsustainable transportation systems usually fail to develop fair and affordable transportation. The failure of the American transportation system happens when personal automobile access is restricted, causing accessibility to break down (auto dependency) (Cidell, 2012). Additionally, those who are physically, socially, or economically challenged need accessible transportation options. On the other hand, unsustainable transportation refers to transportation systems or modes that have negative impacts on the environment, society, and economy. These systems are often characterized by their lack of accessibility and inclusivity, which can lead to social isolation and exclusion of certain individuals or communities. This can restrict access to mobility, activities, and opportunities, making it difficult for these individuals to fully participate in society. In short, transportation systems that do not provide universal access to mobility and that might isolate and exclude residents from activities are considered to be unsustainable (Schiller & Kenworthy, 2010).

Transportation can harm people's health because of pollution and traffic. Noise and pollution can reduce the standard of health effects from the environment or immediate effects from pollutants like particulate matter (Moavenzadeh & Markow, 2007). The WHO establishes air quality levels to lessen the burden of sickness and mortality brought on by toxic gases.

Previous studies on sustainable transportation have identified several factors that contribute to the sustainability of public transportation systems. However, these studies have not yet ranked these factors or evaluated their relationship to one another. To fully understand the sustainability of public transportation systems, it is important to conduct a holistic ranking of these factors. This can be achieved through the use of multi-criteria decision-making techniques.

To rank these factors and assess the sustainability of public transportation systems, this study will utilize a multi-criteria decision-making approach. This approach allows for the evaluation of various factors that contribute to the sustainability of transportation systems, such as environmental impact, economic viability, and social responsibility.

Previous studies have also used this approach to evaluate the sustainability of transportation systems. For example, some studies have used multi-criteria decision-making techniques to assess the environmental impact of different transportation modes, such as buses and trains. Other studies have used this approach to evaluate the economic and social benefits of public transportation.

Overall, this study aims to build upon previous research by utilizing a multi-criteria decision-making technique to holistically rank the factors that contribute to the sustainability of public transportation systems and understand their relationship to one another.

2.4. Methodology literature

Awasthi et al., (2011) presented a multicriteria decision-making approach for selecting sustainability transportation systems under uncertain conditions. They first assessed the sustainability criteria for transportation and then evaluated these criteria using expert judgment and at the end based on score criteria under the TOPSIS technique they determined the best alternative. Shabani et al., (2022) provided a framework based on the best-worst (BWM) and fuzzy technique to assess customer satisfaction in Public transport in Tehran during the pandemic. Yang et al., (2016) considered MCDM to evaluate the sustainability of initiatives involving transportation infrastructure considering the pillars of sustainability and modeled zero-one-goal programming (ZOGP) for transportation projects in Taiwan for evaluation of sustainability. Solangi et al., (2021) evaluated the renewable energy barriers in Pakistan by using the Fuzzy TOPSIS method and they concluded that government policies play an important role to overcome the barriers. Chandra & Kumar 2020, developed a methodology for measuring crowd-based social interaction for assessing sustainable mobility systems, including public transportation, cycling, and walking. Nawaz & Ali, (2020) evaluated the link between social, behavioral, and active transport in Pakistan by using Decision-Making Trial and Evaluation Laboratory (DEMATEL). The Decision-making trial and evaluation laboratory (DEMATEL) was first introduced by the Geneva Research Centre of the Battelle Memorial Institute to illustrate the structure of complex causal interactions using matrices or digraphs (Gabus & Fontela, 1972). The DEMATEL can be used for studying and resolving complex and interconnected situations since it can confirm the interdependence of elements and help create a map to reflect relative relationships among different factors (Si et al., 2018). The DEMATEL is considered an efficient technique for locating complicated system cause-and-effect chain components (Si et al., 2018). The DEMATEL approach had been utilized by many researchers (Fu et al., 2011) (Bai & Sarkis, 2013) (Sricharan & Kumar, 2018). The DEMATEL approach evaluates the cause-and-effect group of various parameters and helps to rank those factors (Kijewska et al., 2018). By grouping, the factors into subcategories DEMATEL can show the relationship between different factors (Falatoonitoosi et al., 2014). The DEMATEL technique has been used in different fields like supply chain management (Bulgak & Pawar, 2006), Quality control sorting (Ciptomulyono et al., 2022), Analysis of sustainable barriers in transportation (Rajak et al., 2021) (Mombeni et al., 2022) in industrial management (Sadeghi-Niaraki, 2020), and the entrepreneurship evaluation (Jamali et al., 2018).

3. METHODOLOGY

The main factors which will be used in the methodology are three pillars of sustainability (Clune & Zehnder, 2018) (Purvis et al., 2019). Based on internet research, and Literature studies some important factors of sustainability are evaluated concerning transportation. Figure 3.1 is a representation of various factors of sustainability related to transportation, which has been identified through literature studies. The factors are categorized into three main categories: environmental, social, and economic. Environmental factors include air pollution, water pollution, and noise pollution, which are considered significant concerns in sustainable transportation. Economic factors, on the other hand, include traffic congestion, accessibility, accident damage, infrastructure, and consumer cost, which are crucial elements that need to be considered in a sustainable transportation system. Finally, social factors include affordability, equity, the impact of transportation on human health, community cohesion and livability, and aesthetic parameters of transportation. These factors play a crucial role in ensuring that transportation is not only environmentally and economically sustainable but also socially sustainable, taking into account the well-being of the people who use it.

Therefore, Figure 3.1 highlights the importance of considering all these factors in a comprehensive and integrated approach to sustainable transportation.

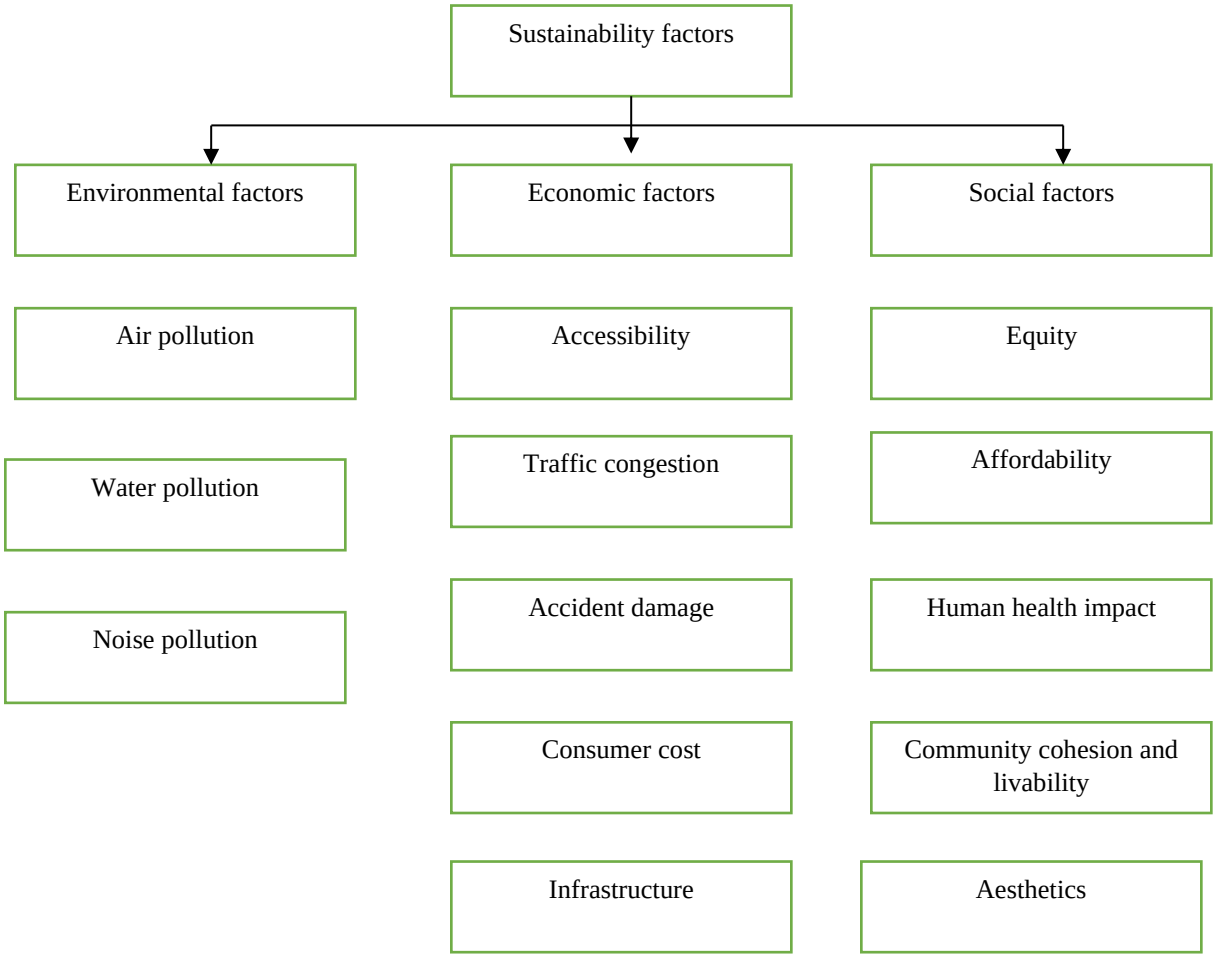


Figure 3. 1. Factor of sustainability for Public Transportation in Pakistan

To assess the sustainability of the transportation system, various environmental, economic, and social parameters have been identified and methods for collecting data have been established. These parameters include water pollution, noise pollution, air pollution, accessibility, traffic congestion, consumer cost, infrastructure cost, and accident damages.

In terms of water pollution, data is obtained on the presence of toxic materials in the water supply, using existing data sources. To measure noise pollution, the rate of change in noise levels over recent years is recorded based on available information. Air pollution data is gathered through experimental methods.

To understand the level of accessibility, data is collected through questionnaires administered to the public. Traffic congestion is measured through a combination of physical surveys and questionnaires. Data on consumer cost and infrastructure cost is sourced from the transportation departments. Accident damages are obtained from the official website of the transportation department. Table 3.1 outlines the various environmental, economic, and

social parameters of sustainability related to transportation, as well as the methods for collecting data for each relevant factor.

For water pollution, data is collected on the number of toxic materials in water based on available data. For noise pollution, data is collected on the rate of change in noise pollution in recent years based on available data. Air pollution data is collected through experimental methods.

Accessibility data is collected through questionnaire surveys, while traffic congestion data is collected through a combination of physical surveys and questionnaire surveys. Consumer cost and infrastructure cost data are obtained from the relevant transportation departments. Accident damages data is extracted from the official website of the transportation department.

Data on equity, affordability and the impact of transportation on human health is collected through questionnaire surveys. Data on community cohesion and livability, as well as aesthetic parameters of transportation, is collected through a combination of physical surveys and questionnaire surveys.

Therefore, Table 3.1 provides a comprehensive overview of the various factors of sustainability related to transportation and the methods for collecting data for each factor, highlighting the importance of a systematic and data-driven approach to sustainable transportation.

Table 3. 1. Data collection methodology for various parameters of Sustainability

	Factors	**Data collection method**
Environmental	Water pollution	Number of toxic materials in water based on available data
	Noise pollution	Rate of change of noise pollution in the recent year based on available data
	Air pollution	Experimental method for collection of data
Economic	Accessibility	Questionnaire survey-based data collection
	Traffic congestion	Physical survey and questionnaire survey-based data collection
	Consumer cost	Data provided by the relevant department of transportation
	Infrastructure cost	Data provided by the relevant department of transportation
Social	Accident damages	Data is extracted from the official website of the transportation department
	Equity	Questionnaire survey-based data collection
	Affordability	Based on physical and questionnaire survey
	Human health impact	Questionnaire survey-based data collection
	Community cohesion & livability	Questionnaire survey-based data collection
	Aesthetics	Physical survey and questionnaire survey-based data collection

3.1. Research Approach

The term "research approach" refers to the systematic plan and strategy adopted by a researcher to gather, analyze, and interpret data for a study. This approach encompasses the methods and techniques used for data collection, as well as the methods for data analysis and interpretation of findings (Creswell, 2014). In a mixed research design approach, multiple

methodologies and methods are utilized to gain a comprehensive understanding of the research topic. This approach allows for the triangulation of data and can increase the robustness of the findings. The mixed research design approach is particularly useful when the research question is complex, and different perspectives are needed to fully understand the topic.

3.1.1. Study Design

A choice survey was developed and given to students at various universities as well as to citizens of Islamabad and Rawalpindi to fulfill the study's research goals. A method for determining the economic and social prospects of alternative transportation solutions is the choice survey style. Five experts were figured out from the responses based on their designation and an online interview is conducted.

3.1.2. Research Task

Four major tasks were identified to achieve the goals of this study. Figure 3.2. shows the task carried out in this research.

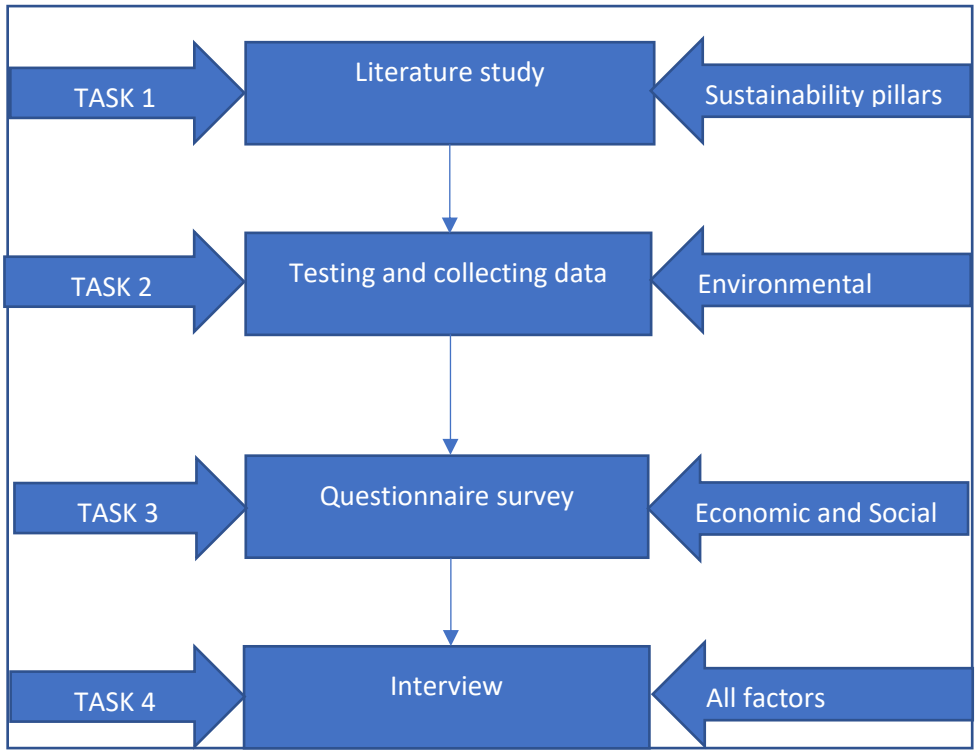


Figure 3. 2. Steps carried out in research approach

Task 1 Literature Study

This task required an extensive evaluation of previous research to identify some key environmental and economic sustainability indicators for the transportation system.

Task 2 Testing

This task includes the data finding by testing method and evaluation based on the result of the obtained data. This task implements those parameters which could not be found in past studies. The comparison-based analysis is used to find the relative data.

Task 3 Survey and Findings

Some parameters of sustainability under economic and social factors are identified and evaluated based on a questionnaire survey based on the Likert scale (Joshi et al., 2015), and binary scale (Dolnicar et al., 2011), and then data obtained from the survey is analyzed in SPSS under Cronbach's alpha reliability coefficient method.

Task 4 Interview

Five respondents are selected based on their designation and a short interview is conducted which is based on the impact of sustainable factors in transportation on each other.

3.1.3. Statical Analysis of Data

For statical analysis of survey data, SPSS software has been used. It is used to evaluate statistical data. A variety of data types can be examined using SPSS. Common sources include things like survey results, client databases from companies, Google Analytics, research findings, and server log files. For analysis and customization, SPSS supports a wide range of different types of data as well as almost all structured data formats.

Lee Cronbach created the alpha statistic, which is a number between 0 and 1, to quantify the internal consistency of a test or scale (Tavakol & Dennick, 2011). Cronbach's alpha is a different value that lies from 0 to 1 and evaluates the reliability of the system. In other words, Cronbach's alpha is an approach to measure the strength in terms of reliability (Tavakol & Dennick, 2011).

$$\boldsymbol{\alpha} = \frac{\boldsymbol{k} \times \bar{\boldsymbol{c}}}{\bar{\boldsymbol{v}} + (\boldsymbol{k} - \boldsymbol{1})\bar{\boldsymbol{c}}} \tag{3.1}$$

Basic Principles for Results

After conducting a reliability analysis, the results were compared with the standard Cronbach's Alpha as presented in Table 3.2. This table displays Cronbach's Alpha value and the relative consistency of the data.

Cronbach's Alpha value is a widely used measure of internal consistency or reliability in psychometric research (Tavakol & Dennick, 2011). It measures the correlation between items within a test or questionnaire and ranges from 0 to 1, with higher values indicating greater reliability. In Table 3.2, Cronbach's Alpha value is presented for the data analyzed in the study.

The relative consistency, on the other hand, indicates how well the items in the questionnaire are related to each other. In table 3.2, the relative consistency is presented alongside Cronbach's Alpha value to provide a clearer understanding of the reliability of the data.

It is important to note that a high Cronbach's Alpha value and relative consistency indicate that the data collected is reliable and consistent, providing a strong foundation for further analysis and conclusions. The results presented in Table 3.2 provide valuable insights into the reliability of the data used in the study and contribute to the overall validity of the research findings.

Table 3. 2. Cronbach’s Alpha Standards

Cronbach’s Alpha	Consistency
$\alpha \geq 0.9$	Excellent
$0.9 \geq \alpha \geq 0.8$	Good
$0.8 \geq \alpha \geq 0.7$	Acceptable
$0.7 \geq \alpha \geq 0.6$	Questionable
$0.6 \geq \alpha \geq 0.5$	Poor
$0.5 > \alpha$	Unacceptable

Source: (Tavakol & Dennick, 2011)

3.1.4. Steps Involved in the DEMATEL Approach for Identifying Key Factors for Sustainability in Public Transportation

DEMATEL is regarded as an efficient technique for identifying the correlation in a complex system (Kijewska et al., 2018). It focuses on assessing the interdependencies between elements and identifying the crucial ones using a visual structural model. DEMATEL provides a gateway for decision-makers to implement new techniques for improvement in any system (Si et al., 2018). It is particularly useful in situations where the problem is complex and there are multiple interacting factors involved. The steps carried out in DEMATEL are as follows:

1. Identify the decision-making problem: The first step in using DEMATEL is to clearly define the problem that needs to be solved. In this research, the main aim is to identify the key factors for sustainability in public transportation (Falatoonitoosi et al., 2014)

2. Identify the relevant factors: The next step is to identify the factors that are relevant to the decision-making problem. These include technical, economic, social, and environmental factors which have a strong influence on the sustainability of transportation (Falatoonitoosi et al., 2014).

3. Collect data on the factors: Once the relevant factors have been identified, data needs to be collected on these factors to evaluate their importance (Bai & Sarkis, 2013; Falatoonitoosi et al., 2014; Rajak et al., 2021).

4. Analyze the data: The collected data should then be analyzed to identify the causal relationships between the factors. This is typically done using a technique called pairwise comparison, which involves comparing each pair of factors to determine their relative importance.

5. Identify the most important factors: Once the causal relationships between the factors have been identified, the most important factors can be identified. These are the factors that have the greatest impact on the decision-making problem and are

Figure 3.3 represents a visual representation of the basic steps involved in the DEMATEL approach as applied in various studies related to identifying key factors for sustainability in public transportation. The figure shows the sequential steps involved in using the DEMATEL method, starting from defining the decision-making problem, identifying the relevant factors, collecting data, analyzing the data, and finally identifying the most important factors.

Each step is depicted as a separate box, with arrows connecting each step to indicate the progression from one step to the next. The figure provides a clear overview of the DEMATEL method and how it can be used to identify the key factors that have a significant impact on sustainability in public transportation.

It is important to note that figure 3.3 is a representation of the steps involved in the DEMATEL approach as carried out in previous studies and may vary slightly depending on the specific application and research design. Overall, Figure 3.3 serves as a helpful guide for those looking to use the DEMATEL method in their research on sustainability in public transportation.

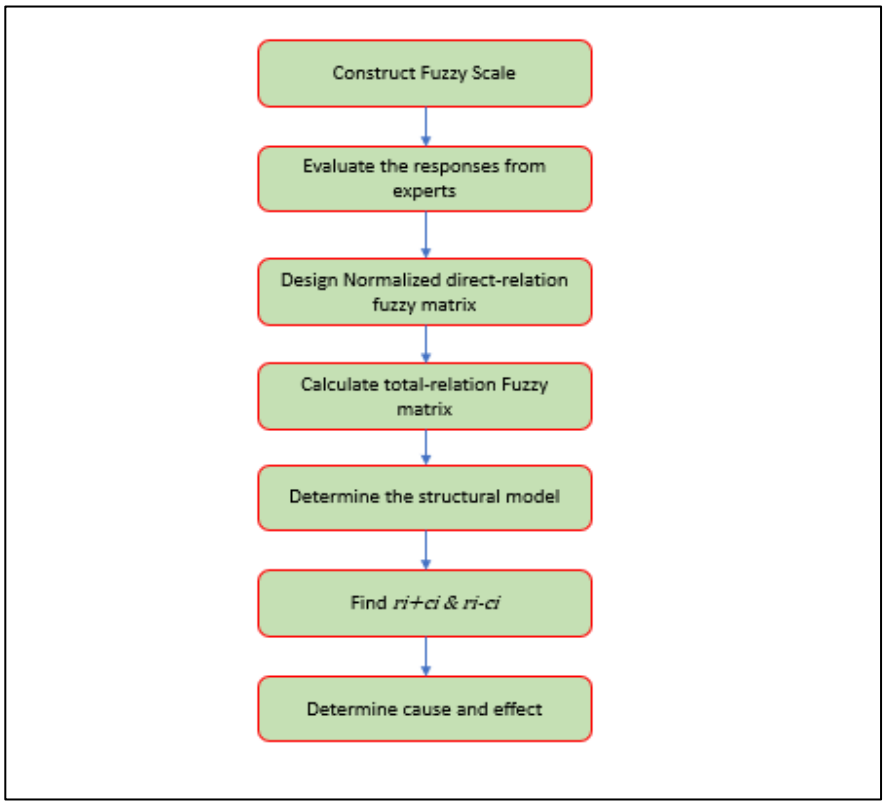


Figure 3. 3. The DEMATEL approach steps involved in this study

Source: (Si et al., 2018)

3.2. Environmental Factors of Sustainability

During the latter half of the 20th century, there was a remarkable increase in the distance traveled globally (Mattioli, 2016). The phenomenal growth in distance traveled worldwide during the latter half of the 20th century has raised environmental and social concerns, with implications for justice. Due to a heavy reliance on oil, the transportation sector plays a significant role in contributing to the problem of climate change (Mattioli, 2016). The first important pillar of sustainability is environmental aspects. Environmental sustainability in transportation is measured by the impacts of the system on the natural environment and its efficiency and effectiveness in reducing negative environmental impacts such as air and water pollution, greenhouse gas emissions, and noise pollution (Mihyeon

Jeon & Amekudzi, 2005). It is assessed based on air pollution, noise pollution, and water pollution due to transportation in twin cities. The subject of sustainable transportation typically centers on the negative effects of transportation on the environment (Buehler, 2010). The primary cause of transportation's failure to be environmentally sustainable is dependence on hydro fuels (Banister & Pucher, 2003). On the one hand, transportation uses an unsustainable amount of oil, a finite resource whose output appears to be permanently declining (Tyagi & Sreenath, 2022). On the other side, using fossil fuels to power the transportation sector results in a variety of air emissions that have an impact on resources, ecosystems, and human health. A significant portion of all emissions is caused by transportation. Some of the components of transportation emissions are as follows (Rao, 2010)

- Carbon dioxide (CO^2)
- Particulate matter (PM)
- Nitrogen oxides (NOx)
- Sulfur dioxide (SO^2)
- Carbon monoxide (CO)
- Iron (Fe)
- Benzene and volatile components.

Transportation activities have a negative impact on the environment due to several reasons. Firstly, vehicle traffic and aircraft movements lead to an increase in noise pollution which can have adverse effects on human health and the environment (Profillidis et al., 2014). Secondly, the production and maintenance of fuels and vehicles also contribute to water pollution through emissions from upstream and downstream activities (Nixon & Saphores, 2007). Lastly, the emission of greenhouse gases and other toxic substances from transportation activities results in air pollution, which can cause harm to the environment, ecosystems, and human health (Pietrzak & Pietrzak, 2021). These negative effects highlight the need for the transportation sector to focus on sustainability and find ways to reduce its impact on the environment.

3.2.1. Impact of Transportation on Air Pollution

The transport industry is a major contributor to air pollution worldwide, with the road transport sector being the primary source of urban pollution (Pietrzak, 2021). The increasing number of automobiles on the road, particularly in emerging nations with a high proportion of older technology vehicles, is a significant contributor to pollution levels (Colvile et al., 2001). Vehicle emissions are the primary source of toxic gases in cities like Islamabad and Rawalpindi and are responsible for the majority of ambient pollution levels throughout the year. Additionally, older vehicles such as buses, trucks, and cars that use lower-quality fuel and outdated technology emit significantly more pollution than newer, cleaner vehicles. Urbanization and certain practices such as open-air burning of waste and biomass also contribute to pollution in cities like Islamabad (Raza et al., 2022).

3.2.2. Materials and Methods for Air Pollution

Monitoring and Sampling

At specific locations in the twin cities, the concentration of major air pollutants (pm2.5) was measured through sampling carried out by a mobile application (AQI) which is highly capable of measuring air pollutants at any location at any time.

PM2.5 are very tinny microscopic particles with a size of less than 2.5mm and are also known as fine particles (Muthukumar et al., 2022). Particulate matter (PM) is a mixture of several compounds rather than a homogeneous contaminant. It consists of a complex mixture of solids and aerosols, including dry solid particles, liquid-coated solid cores, and minute liquid droplets. Particles can contain inorganic ions, metallic compounds, elemental carbon, organic compounds, and chemicals from the earth's crust. They can vary greatly in size, shape, and chemical makeup (Muthukumar et al., 2022).

Table 3.3 presents the collection of data on the air quality index (AQI) at four selected locations. The table lists the four locations, along with their corresponding coordinates. The coordinates provide a precise location for each of the sites, allowing for accurate measurements to be taken.

The data collection took place over seven days with the assistance of former colleagues. The locations were selected based on their suitability for AQI testing and their representation of different areas within the region of interest.

Table 3.3 serves as an important record of the AQI data collected at each of the four locations, providing a comprehensive overview of the air quality conditions in these areas. The data in the table will be used to carry out further analysis and draw conclusions about air quality and its impact on the environment and human health.

Table 3. 3. Selected locations for air quality test

SITE	Location	Coordinates
A	Austria Embassy (ISLAMABAD)	33.715090°N ,73.032190°E
B	NUST (ISLAMABAD)	33.6425° N, 72.9930° E
C	Bahria Town (RAWALPINDI)	33.4786° N, 73.0789° E
D	Faizabad (RAWALPINDI)	33.6600° N, 73.0833° E

3.2.3. Impact of Transportation on Water Pollution

Water pollution is a significant concern to transportation systems (Colvile et al., 2001). Runoff from roads and highways, which contain pollutants such as fuel residues, plastic particles, and engine oil, can affect water sources, storage reservoirs, and infrastructure (Nixon & Saphores, 2007). This can lead to contamination of water, making it harmful to drink or use for other purposes. Additionally, transportation can have both direct and indirect impacts on watersheds, through erosion, sedimentation, and contaminated discharge caused by highway construction, operation, and maintenance (Profillidis et al., 2014).

Transportation also contributes to water pollution through the transportation of wastewater and toxic materials. Places such as petrol pumps, repair shops, service stations, and freight terminals all release harmful materials into the water through discharge, leakage, and cleaning (Colvile et al., 2001). Furthermore, air pollution also contributes to water contamination, as precipitation washes away pollutants and debris from roads, leading to higher levels of pollutants in urban areas with higher traffic volume than in rural areas (Adeel et al., 2016).

3.2.4. Methodology for the Analysis of Water Pollution

Our today activities may appear after so long. This implies that current practices could have an impact on water quality for a very long time. May be someone thinks that materials do not contaminate the water but it is wrong it will happen in the future. And that is what sustainability asked us to think about for the future.

Numerous factors are used in water quality tests, including alkalinity, Bicarbonate, Calcium (mg/l), Lead (ppb), Hardness (mg/l), Odor (sensitivity test), pH, Turbidity, Trace and Ultra Trace Elements, etc. (M. S. Imran et al., 2016). The result for these tests have been collected from Pakistan Council of Research in Water Resources (PCRWR).

For data analysis of water, pollution Data is collected from PCRWR. Data is derived from the general publication of water quality reports by PCRWR for different years.

PCRWR has data for the following years only.

- 2005-6 (PCRWR, 2006)
- 2015-16 (M. S. Imran et al., 2016)
- 2020-21 (Rasheed et al., 2021)

Laboratory Testing by PCRWR

APHA standard methodologies, the samples of water were examined for aesthetic, physio-chemical, and bacterial characteristics by PCRWR.

3.2.5. Impact of Transportation on Noise Pollution

The day the wheel was created, the noise was born. In actuality, both technology and noise were born with the invention of the wheel. Noise is any unwarranted disturbance that occurs between 20 Hz to 20000 Hz, the range of frequencies that are normally audible to humans (concha-Barrientos et al., 2004).

Noise pollution is a growing problem that negatively impacts people's quality of life globally. It has risen to alarming levels due to factors such as technological advancement, industrial development, urbanization, and transportation systems (Awasthi et al., 2011). To address the negative health impacts caused by transportation and other sources, the level of noise pollution must be studied and regulated. Different nations have implemented various measures to combat noise pollution, such as regulating vehicular noise, inspecting vehicles, limiting truck operations during certain hours, and imposing fines for noise violations. Noise pollution has risen significantly due to urbanization, making it difficult to distinguish between sound and noise, as any sound that is deemed chaotic or out of tune is considered noise. Noise pollution can be categorized into two broad categories: environmental noise, primarily from vehicles, trains, and airplanes, and occupational noise, primarily from industrial machinery, construction equipment, and workplace noise (Kalim et al., 2014).

3.2.6. Methodology for the Analysis of Noise Pollution

It can be observed that noise pollution is an alarming challenge in Pakistan, especially in Rawalpindi due to heavy traffic.

Unfortunately, due to a lack of technology, instruments, and awareness not more than one research (Kalim et al., 2014) had been done on the noise pollution of twin cities. For recent data, I have conducted meetings with the government institute of environmental protection but they didn’t have any meaningful data regarding noise pollution. Therefore, experimental data from one research (Kalim et al., 2014) has been used for the analysis of noise pollution in the transportation sector. That research was conducted for overall sources of noise pollution and I have used only transportation-related sources for analysis.

Using a sound level meter, noise emission is measured. The decibel is a measurement of sound intensity. The hearing is represented by decibel zero. While sounds at the top of the range, around 150 decibels, can harm eardrums, they are so quiet that they are nearly difficult to hear at the lower end of the scale, 0-10 decibels.

3.3. Economic factors of sustainability

Economics is considered the second pillar of sustainability in transportation. A city's economy can grow because of sustainable mobility, but it can also make it more difficult to supply important social services if it is not well designed.

The following factors are considered in this research as economic factors for discussing social sustainability.

- Accessibility Quality
- Traffic Congestion
- Infrastructure cost
- Consumer costs
- Accident damages

3.3.1. Accessibility

Accessibility, which is defined as people's ability to access desired services and activities, is the primary goal of most transportation-related activities (May & Crass, 2007). Except for the minor amount of travel without a specific destination in mind, accessibility is the ultimate objective of the majority of transportation-related activities and should be the main emphasis of transportation planning (Cidell, 2012).

- Numerous elements influence this accessibility as a social aspect of sustainability.
- Mobility. Physical mobility and, consequently, the quality of travel modes (accessibility, speed, frequency, comfort, etc.).
- The closeness of the distances between destinations and the land use characteristics of the development are some of the factors that influence the development of these areas.
- The connectivity of the transport system is also a factor that influences the development of these areas. The quality of the connections between the different modes of transportation, such as public and private transit, is additionally a factor that influences the development of these areas.
- Convenience is the simplicity of booking a trip, paying for it, and transporting luggage.
- Acceptability in society. Sometimes a person's ability to employ a mode depends on their social standing.

Planning decisions may be influenced by the evaluation of transportation. For instance, if the quality of a transportation system is measured by factors related to an on-road situation such as traffic speeds, and congestion delays, improving roadways is the only way to avoid it. If mobility (the movement of people and commodities) is the basis for transportation evaluation, then enhancements to ridesharing and PT services can also be considered.

Accessibility of Public transportation in Islamabad and Rawalpindi

The major objective of systems acquire is to offer commuters a quality, efficient, sustainable, safe, and dependable transportation system. In twin cities, government-owned public transportation was once available, but it is now nearly nonexistent due to a lack of interest and incorrect information, policies, and incapacity to oversee and run the infrastructure for public transportation. Privately operated public transportation stepped up

to fill the void, and numerous private operators began running public transportation on various routes in twin cities. Private operators use Suzuki, minibusses, and vans, none of which are dependable, comfortable, or on a set schedule. Figure 3.4 presents a visual representation of some of the public transportation used in Islamabad and Rawalpindi. This figure provides a clear and concise overview of the different types of public transportation available in these cities and helps to highlight the variety and diversity of the transportation options available. Figure 3.4 serves as a useful reference for decision-makers and planners who are responsible for improving transportation in these cities. It also provides a visual representation of the transportation options available to residents, allowing them to make informed choices about how they travel. Overall, the information presented in Figure 3.4 is an important step in understanding the public transportation landscape in Islamabad and Rawalpindi and will inform future efforts to improve transportation in these cities.

Figure 3. 4. Different modes of public transport in twin cities

Source: (Adeel et al., 2016**)**

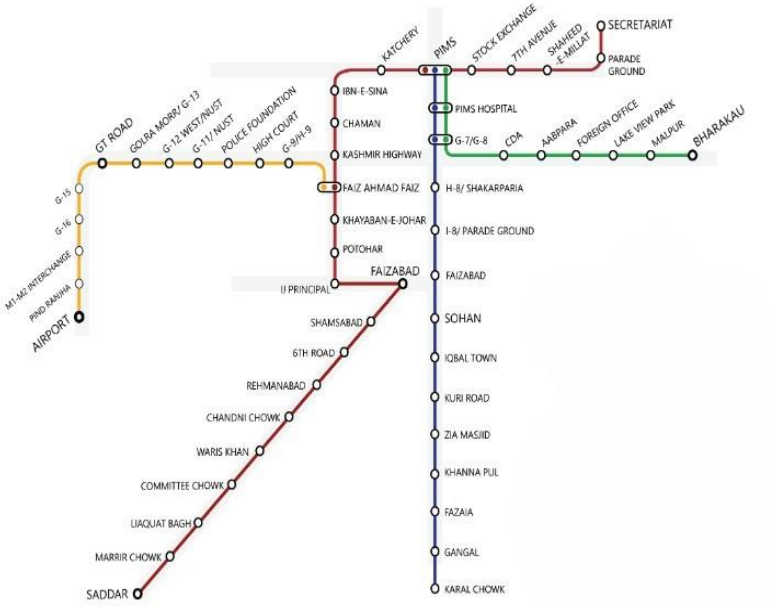
Despite having contracts with the government, these private operators lack a check and balance system that would guarantee the correct operation and safety of the vehicles.

The vans, minibusses, and Suzuki that are now being driven by private owners in Islamabad and Rawalpindi are depicted in figure 3.4. Punjab Metrobus Authority runs a BRT system called the Islamabad-Rawalpindi Metro bus. The BRT consists of a single corridor that connects the Twin Cities and offers access to the main regions for commerce, housing, industry, and educational institutions. 24 stations are now open throughout the 22.4 kilometers long track (Mr. Kamran Ahmed Assistant Professor SCEE, 2021).

Modern command and control center in charge of overseeing operations. Figure 3.5 provides a visual representation of the various features of the Islamabad Rawalpindi BRT (Bus Rapid Transit) system. BRT systems are a form of public transportation that aims to provide faster, more efficient, and more reliable service compared to traditional bus systems. Figure 3.5 provides a comprehensive overview of the features of the Islamabad Rawalpindi BRT system and is an important tool for understanding and improving public transportation in these cities.

Bus Terminal

Corridor



Route of BRT in Islamabad and Rawalpindi

Figure 3. 5. Features of BRT in twin cities

Source: (Mr. Kamran Ahmed Assistant Professor SCEE, 2021)

3.3.2. Methodology for Evaluating Accessibility

A sample poll was done in twin cities to evaluate accessibility and the passenger's perception regarding the current public transportation system. The survey was based on private public transportation services and as well as for BRT.

3.3.3. Traffic Congestion

Traffic congestion has become a widespread issue, impacting both developed and developing nations (Raza et al., 2022). The situation is characterized by prolonged delays in transportation, increased risk of accidents, and environmental degradation (Profillidis et al., 2014). The effects of traffic congestion are far-reaching and can negatively impact economic

efficiency, with delayed shipments and decreased productivity (Oguchi et al., 2017). Additionally, traffic congestion has a significant social impact, causing increased stress levels, wasted time, and reduced quality of life (Garrison & Ward, 2000). The problem is particularly prevalent in developing countries, where a combination of factors has contributed to its rapid growth. For example, rising middle-class incomes, increased access to credit, declining vehicle prices, and the availability of used vehicles have all contributed to a dramatic increase in the number of motor vehicles on the roads (Oviedo & Guzman, 2020). The consequences of traffic congestion are a cause for concern and highlight the need for effective and sustainable solutions. This has resulted in unacceptable travel times, particularly during peak hours, and increased driver frustration leading to aggressive behavior (Robinson & Thagesen, 2004). According to a study by the World Bank, urban traffic congestion costs developing countries an estimated 1-2% of their GDP (World Bank, 2018) and it's a major issue that needs to be addressed.

Traffic Congestion in Islamabad and Rawalpindi

The rise of motorization, driven by the increased mobility of people, goods, and services, has had a profound impact on human growth and economic development (Gouldson & Murphy, 1996). The growth of the transportation sector has made it easier for people to move around, allowing for greater access to job opportunities, goods and services, and social activities (Awasthi et al., 2011). This growth has, however, also led to many negative consequences. Traffic congestion, delays, accidents, and environmental issues are among the most significant problems that have arisen from the increased use of motor vehicles (Oguchi et al., 2017). These challenges have not only diminished economic efficiency and productivity but also had detrimental social consequences, making it important for countries to develop strategies to mitigate these negative impacts (Awasthi et al., 2011).

This has mainly been seen in terms of the decline in efficient traffic flow, an increase in the number of pollutants released into the atmosphere by automobile exhaust, traffic congestion, uncontrolled urban expansion, and land use, dependence on oil, and other associated issues in twin cities (Mr. Kamran Ahmed Assistant Professor SCEE, 2021). Figure 3.6 provides a visual representation of the traffic congestion situation in Islamabad and Rawalpindi. The snap highlights the magnitude of the problem and how it affects the daily life of the citizens. The images depict vehicles stuck in long lines, which indicates that the current public transportation system is not adequate to meet the demand. The figure helps to show the need for improved public transportation systems to alleviate the traffic problems in these cities.

Figure 3. 6. Traffic Congestion of Islamabad and Rawalpindi

Source: Samaa web desk

3.3.4. Methodology for Evaluating Traffic Congestion

The survey was conducted to evaluate traffic congestion. Questions were asked electronically and physically from students and residents of twin cities concerning both private and public transport.

3.3.5. Infrastructure Cost

The development of transportation infrastructure, including roads, ports, and airports, is essential for a country's economic growth and sustainable development (Profillidis et al., 2014). These facilities play a crucial role in enabling the flow of goods and people, thus fueling human progress and economic prosperity (Hail & McQuaid, 2021). Unfortunately, in many developing countries, the lack of proper transportation infrastructure and inadequate public transportation systems has led to a rise in personal car usage (Adeel et al., 2016). This has resulted in increased traffic congestion, air pollution, and other environmental concerns, which can negatively impact the quality of life for the citizens and hinder sustainable development (Garrison & Ward, 2000). Hence, proper and well-planned transportation infrastructure is crucial in addressing these challenges and promoting a sustainable and thriving future. To address these issues, many cities in the developing world have implemented mass transit systems, and more are considering them.

Infrastructure Cost of Public Transport in Twin Cities

Investing in public transportation infrastructure has a multitude of positive impacts on a city and its inhabitants (Forkenbrock & Foster, 1990). A well-functioning public transportation system can alleviate urban traffic congestion, increase daily commuter mobility, reduce air pollution, lower carbon emissions, boost economic growth, and drive economic activity (Friman et al., 2020). Recognizing the importance of a strong public transportation network, the governments of Islamabad and Rawalpindi have allocated resources to enhance their cities' public transit systems (Mr. Kamran Ahmed Assistant Professor SCEE, 2021). These improvements include the implementation of the Islamabad BRT, the introduction of electric buses on various routes in both cities, and the establishment of feeder routes for the existing Islamabad Rawalpindi BRT system.

To estimate the direct investment in public transportation the government of Panjab Sector Development program (PSDP) data is examined for recent years. Keep in mind that city-wise infrastructure cost for the transportation sector is not available the overall data of the transportation sector for Panjab province is used for calculation.

Major Infrastructure Cost of Twin Cities

First phase: Red Line (Metro Bus)

The BRT construction started on February 28th, 2014, and it was finished in June 2015, with 60 buses originally operating on the route. The project, which cost about Rs. 44.31 billion (US$190 million) and was funded by both the federal government and the Punjab provincial government, was overseen by the Rawalpindi Development Authority (Line, 2022).

2nd Phase: Blue, Green, and Orange Lines

The 16-billion-rupee orange line track, which runs for 25.6 kilometers from Peshawar Morr (turn) to New Islamabad International Airport, began construction in 2017 and was initially expected to be finished in 2018. On April 18, 2022, it was inaugurated after a five-year delay (Line, 2022).

3.3.6. Accident Damages

The first consideration in planning efforts for vehicle transportation is road traffic safety. The economic component of measuring traffic safety on the roads is crucial, and analyzing the damage caused by traffic accidents is important (Santos et al., 2010).

Accidental harm directly affects society by causing many people to die or become permanently disabled and by causing financial difficulties.

Accident Damages in Twin Cities

Although preventable, road traffic accidents are a serious global public health concern that, if not promptly and effectively addressed, might rapidly deteriorate 90% of all accident-related deaths globally occur in low- and middle-income countries (Valiantis, 2014). The main contributing factors for accidents are thought to be the rapidly growing number of vehicles, the application of traffic laws, changes in lifestyle, risk-taking, and abnormal behaviors of drivers. Inadequate planning and ignorance of traffic regulations are significant contributors to road accidents in the twin cities of Islamabad and Rawalpindi. The absence of proper regulation and control over factors such as the age of drivers and the validity of driving licenses results in a high frequency of road accidents. To address this issue and promote road safety, authorities need to enforce traffic laws and regulations effectively, as well as educate drivers about the importance of responsible and safe driving practices. Inadequate planning and ignorance of traffic regulations are significant contributors to road accidents in the twin cities of Islamabad and Rawalpindi (Sohail et al., 2006). The absence of proper regulation and control over factors such as the age of drivers and the validity of driving licenses results in a high frequency of road accidents (Mr. Kamran Ahmed Assistant Professor SCEE, 2021). To address this issue and promote road safety, it is important for authorities to enforce traffic laws and regulations effectively, as well as to educate drivers about the importance of responsible and safe driving practices (Mr. Kamran Ahmed Assistant Professor SCEE, 2021).

3.3.7. Consumer Cost

A sustainable economy tends to favor fairness, including to those who live in distant places and times, efficient use of natural resources, and sensitivity to environmental and social constraints Consumer cost plays a crucial role in transportation decision-making (Santos et al., 2010). It can be used to characterize problems, weigh costs and benefits, and find strategies that advance sustainability objectives. Consumer costs in transportation are the expenses that the companies that provide transportation services bear at their own expense. Public transportation systems, in both developed and developing countries, have been enhanced to make them more user-friendly and attractive to daily commuters (Evangelinos & Tscharaktschiew, 2021). These systems incur a range of operational costs, including maintenance, wages for drivers and employees, fuel expenses, and other fixed expenditures (Raza et al., 2022). To offset these costs, the primary sources of income for these systems are passenger fares and advertising, which can be found in bus terminals and other high-traffic areas (Mr. Kamran Ahmed Assistant Professor SCEE, 2021).

3.4. Social factors of sustainability

Social sustainability means the fulfillment of social demands through equitable public engagement in the development of transportation policies and a just distribution of transportation services (Adeel et al., 2016). Social is considered to be the important third pillar of sustainability. The social component of sustainability is taking on greater significance in both transportation and urban development (Garrison & Ward, 2000). Equity,

variety, quality of life, and social cohesion for various social groups are key components of social sustainability (Profillidis et al., 2014). Transport in general will not be sustainable if the social component is ignored (Santos et al., 2010).

The Significance of Transportation in Social Development

There are three key causes of transportation's social un-sustainability, particularly in low-income nations like Pakistan (Mr. Kamran Ahmed Assistant Professor SCEE, 2021).

- Reduced availability of transportation services
- Excess of private cars
- Increased social exclusion

The following factors are considered as social factors of sustainability in public transportation in this research.

- Equity/Fairness
- Human Health Impact due to transportation
- Community Cohesion and Community Livability
- Aesthetics

3.4.1. Equity/Fairness

The distribution of advantages and costs, and whether that is regarded as fair and reasonable, are referred to as social equity (also known as fairness and justice)(Haider & Badami, 2004). Equity can be analyzed in one line you get your desire product with money or you get available with that money (Oviedo & Guzman, 2020).

Equity in Twin Cities

The aging population in Islamabad and Rawalpindi is rapidly increasing, leading to potential transportation challenges as older individuals may face difficulties accessing or utilizing public transportation (Adeel et al., 2016).In the context of public transportation in Islamabad and Rawalpindi, equity and fairness pertain to ensuring that all individuals, regardless of their income, social status, or other factors, have access to reliable, affordable, and safe public transportation services (Adeel et al., 2016). To maintain the quality of life for all citizens, it is essential to provide efficient and accessible public transportation services for seniors and the general public alike.

3.4.2. Methodology for Evaluating Equity

A simple survey is conducted in twin cities to evaluate social equity parameters in public transportation.

3.4.3. Affordability

The term "affordability" describes a person's capacity to pay for essential products and services (Gómez-Lobo, 2011). It can be characterized as the state in which household earnings can cover the costs of Basic Needs, or simply as the fact that those with lower incomes do not have to worry as much about paying for necessities. Since affordability refers to a household's capacity for saving money, it is particularly visible in the spending habits of lower-income households and in how they react to monetary shocks like decreased income or increased cost burdens (Gómez-Lobo, 2011). For instance, public transportation tends to be more affordable because it gives lower-income commuters a backup plan when their vehicles aren't available. When creating a transportation system strategy and long-term planning, the affordability of the public transportation system is a key factor (Gómez-Lobo, 2011).

3.4.4. Human Health Impact due to Transportation

Transportation has a variety of health effects. Access to education, work, healthcare, food, and other amenities is made possible by transportation, yet automotive transportation systems are a significant contributor to key global health concerns like climate change, air pollution, obesity, and road accidents. Transport also contributes to a variety of disorders linked to physical inactivity, including type 2 diabetes, cardiovascular disease, dementia, bowel and breast malignancies, noise pollution, stress, and environmental degradation (Randal et al., 2022).

Methodology for Evaluating the Impact of Transportation on Health

A physical survey and electronic questionnaire survey are conducted in twin cities for a better understanding of the impact of the transportation industry on human health. It is practically observed how people are violating laws and promoting such hazardous factors for themselves.

3.4.5. Community Cohesion and Livability

Community cohesion and livability are crucial factors in the social development of transportation systems. Community cohesion refers to the level and nature of interactions among residents in a community (Lucy, 2006). This can have both short-term and long-term benefits, such as increased safety, reduced crime and poverty, and increased property values. The public realm, consisting of areas where people frequently interact such as sidewalks and roadways, can also play a role in community cohesion. Using public transportation or walking can promote more positive interactions among residents than driving does. Community livability, on the other hand, refers to the extent to which a community improves the overall quality of life for its residents. Public transportation plays a vital role in this, connecting different communities to essential services such as schools, hospitals, parks, and other facilities. This improves access to these services and increases the overall livability of a community (Litman, 2021).

3.4.6. Methodology for Community Cohesion and Livability

A simple life satisfaction scale survey is conducted in twin cities for evaluating the moral value of community cohesion and livability.

3.4.7. Aesthetics

Aesthetic factors play a crucial role in the overall enjoyment, comfort, and appeal of public transportation (Profillidis et al., 2014). As society's desire for mobility continues to grow, the demand for modern and visually pleasing transportation infrastructure increases. The functionality and usability of public transportation are closely tied to aesthetic factors such as the appearance of stations and vehicles, the cleanliness and condition of the rides, and the overall visual appeal of the system. The emphasis on aesthetic factors is not only to enhance the user experience but also to increase productivity and improve the overall service quality of the transportation system (Evangelinos & Tscharaktschiew, 2021).

3.4.8. Methodology for Evaluating Aesthetics Parameters in Twin Cities

The social aesthetic of public transportation refers to the overall attitudes and perceptions people hold toward its use (Profillidis et al., 2014). This encompasses factors such as comfort, convenience, accessibility, safety, and quality of service, as well as the societal norms and values associated with taking public transportation versus driving a private vehicle (Javid et al., 2016). The social aesthetic is a critical factor that influences individuals' decisions to use public transportation, and can significantly impact the success and sustainability of these systems (Evangelinos & Tscharaktschiew, 2021). To improve the social aesthetic, it is necessary to prioritize initiatives such as providing high-quality services, promoting public transportation as a sustainable option, and upgrading the infrastructure (Evangelinos & Tscharaktschiew, 2021). To measure the impact of these efforts, a questionnaire survey can be conducted to evaluate the aesthetic aspects of the public transportation system.

4. ANALYSIS

In this chapter on analysis, the method of the Decision-Making Trial and Evaluation Laboratory (DEMATEL) to identify the causal relationships between the factors that affect the transportation system. This technique can be used to identify the interdependencies between the factors and how they influence one another. For example, traffic congestion may have a direct influence on accessibility and consumer cost but it may also have an indirect influence on other factors such as community cohesion & livability and human health impact.

After identifying these causal relationships through DEMATEL, sensitivity analysis is performed to determine the rank of factors under different criteria. Sensitivity analysis identifies which factors have the greatest impact on the system and which ones are most sensitive to changes. The combination of these methods can be used to identify the most critical factors and the potential impact of changes in these factors on the overall system.

4.1. DEMATEL Analysis

The following steps are involved in the DEMATEL approach (Kijewska et al., 2018).

Step 1-Determine the Experts

From questionnaire survey responses five experts are determined based on their designation and their knowledge related to public transportation.

Step 2-Determine Factor and Design Fuzzy Scale

In this step, all factors of sustainability are kept in mind and their preferences in the questionnaire and as well as their effect and linguistic variable scale are designed. Table 4.1. lists the number of factors considered in the DEMATEL approach. These factors are relevant to the decision-making problem being addressed, in this case, the sustainability of public transportation. The table shows the number of factors considered and provides a summary of the data used in the analysis. This information is important for understanding the scope and limitations of the research and for interpreting the results of the DEMATEL analysis. The table provides a clear and concise representation of the factors considered in the study, making it easy for readers to quickly understand the main aspects of the research. Table 4.2. shows the linguistic scale which has been used for evaluating responses ranging from 0 to 3. Table 4.2 displays the linguistic scale used for evaluating the responses in the study on sustainability in public transportation. This table shows the different levels of response options used to rate the factors that were considered in the DEMATEL approach. The linguistic scale provides a standardized method for expressing the opinions and perceptions of the respondents in a numerical format, making it easier to analyze the data and draw conclusions.

Table 4. 1. Factors Considered in the DEMATEL Approach for Sustainability in Public Transportation

A1	Traffic congestion	Based on the routine of traveling and average time delay for the desired destination and frequency of traffic congestion faced in a monotonous routine.
A2	Accessibility	Based on the number of departures, waiting for time and access to the closest point of the transit
A3	Infrastructure	Based on the feasibility of existing infrastructure for transportation.
A4	Consumer cost	Based on the expenses to revenue ratio of public transportation
A5	Accident	Based on Accident damages including fatal and non-fatal.
A6	Equity	Based on seat availability, the driver's attitude
A7	Affordability	Based on average household income.
A8	Human health Impact	Based on diseases and other human health impacts due to transportation
A9	Community Cohesion and livability	Based on meaningful interaction, discrimination cost criteria for less fortune, Independency, Cultural diversity
A10	Aesthetic	Based on comfort level and leisure of journey in public transport.
A11	Water pollution	Based on the general scale of water pollution
A12	Noise pollution	Based on traffic congestion situation.
A13	Air pollution	Based on toxic gas emissions from automobiles

Table 4. 2. Variable scales

0	No Influence
1	Low Influence
2	Medium Influence
3	High Influence

Source: (Rajak et al., 2021)

Step 3 Average Response Matrix

Based on all responses from the respondent. The average response matrix is evaluated.

Step 4 Design Normalized Direct Relation Matrix

The total of all the matrix's rows and columns is computed to normalize. The value k can be used to denote the biggest sum of the row and column sums. Each direct-relation matrix element must be divided by k to normalize.

$$k = \max\left\{max \sum_{j=1}^{n} x_{ij}\,, \sum_{i=1}^{n} x_{ij}\right\} \tag{4.1}$$

$$D = \frac{1}{k} * X \tag{4.2}$$

$Where,$

$$k = 28.4$$

Matrix 4.1 is a representation of the results from a DEMATEL (Decision Making Trial and Evaluation Laboratory) analysis. This analysis is used to identify the relationships between different factors that affect a specific system, in this case, public transportation in the twin cities of Islamabad and Rawalpindi.

Matrix 4. 1. Normalized Matrix for DEMATEL approach

D=Normalized Matrix	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13
A1	0	0.098591549	0.07	0.07	0.106	0.028	0.035	0.085	0.014	0.099	0.106	0.099	0.056
A2	0.099	0	0.07	0.07	0.007	0.056	0.063	0.063	0.035	0.035	0.035	0.042	0.007
A3	0.106	0.070422535	0	0.085	0.07	0.063	0.063	0.042	0.092	0.085	0.07	0.049	0.014
A4	0.035	0.091549296	0.092	0	0.028	0.085	0.07	0.007	0.092	0.063	0	0	0
A5	0.106	0.091549296	0.099	0.049	0	0.035	0.035	0.092	0.042	0.092	0.056	0.056	0.035
A6	0.035	0.098591549	0.07	0.099	0.014	0	0.085	0.099	0.07	0.035	0.042	0.007	0.007
A7	0.099	0.098591549	0.063	0.078	0.035	0.099	0	0.035	0.07	0.063	0.028	0.035	0.035
A8	0.078	0.035211268	0.035	0.014	0.099	0.021	0.042	0	0.042	0.007	0.07	0.035	0.042
A9	0.049	0.084507042	0.063	0.063	0.042	0.092	0.07	0.035	0	0.042	0.042	0.042	0.014
A10	0.099	0.098591549	0.099	0.092	0.035	0.07	0.063	0.049	0.099	0	0.035	0.049	0.042
A11	0.092	0.042253521	0.042	0.007	0.063	0.014	0.014	0.106	0.042	0.106	0	0.014	0.021
A12	0.106	0.049295775	0.014	0.042	0.021	0.007	0.007	0.106	0.078	0.07	0.014	0	0.007
A13	0.099	0.063380282	0.049	0.007	0.042	0.007	0.035	0.099	0.042	0.078	0.014	0.014	0

Step 5 Calculate total-relation Fuzzy matrix

The fuzzy total-relation matrix can be computed as follows after the normalized matrix has been calculated:

$$T = D(I - D)^{-1} \quad (4.3)$$

Where,

$$I = Identity\ Matrix$$

Step 6 Calculation of Threshold Value

After the total relation Matrix threshold value is calculated to draw a network relationship. Calculating the average values of the matrix T is sufficient to determine the threshold value for relations. All values in matrix T that are less than the threshold value are set to ignore after the threshold intensity has been established, meaning that the causal relationship previously described is not taken into account.

$$Threshold\ value\ T = 0.1588$$

Step 7 Find $\tilde{r}_i + \tilde{c}_i$ & $\tilde{r}_i - \tilde{c}_i$

The formula for calculating the sum of rows ($\tilde{r}_i$) and columns ($\tilde{c}_i$) (Rajak et al., 2021) is as follows:

$$\tilde{r}_i = \sum_{j=1}^{n} T_{ij} \quad (4.4)$$

$$\tilde{c}_i = \sum_{i=1}^{n} T_{ij} \quad (4.5)$$

The values of $\tilde{r}_i + \tilde{c}_i$ & $\tilde{r}_i - \tilde{c}_i$ can then be derived by $\tilde{r}_i$ and $\tilde{c}_i$, where $\tilde{r}_i + \tilde{c}_i$ denotes how significant a factor is to the system as a whole and $\tilde{r}_i - \tilde{c}_i$ denotes the net effects or cause that factor has on the system.

Table 4.3. contained the value of $\tilde{r}_i + \tilde{c}_i$ & $\tilde{r}_i - \tilde{c}_i$ for all factors which have been used in the DEMATEL approach.

Table 4. 3. Cause and effect group

Parameters	$\tilde{r}_i$	$\tilde{c}_i$	$\tilde{r}_i + \tilde{c}_i$	$\tilde{r}_i - \tilde{c}_i$	**Comments**
Traffic congestion	2.61182	2.9686	5.58042	-0.3567	Effect
Accessibility	1.82894	2.8121	4.64104	-0.9831	Effect
Infrastructure	2.50871	2.3876	4.89631	0.12111	Cause
Consumer cost	1.80632	2.165	3.97132	-0.3586	Effect
Accident	2.44126	1.8047	4.24596	0.63656	Cause
Equity	2.00749	1.8538	3.86129	0.15369	Cause
Affordability	2.28820	1.8588	4.14700	0.42940	Cause
Human health Impact	1.64082	2.3932	4.03402	-0.7523	Effect
Community Cohesion and livability	1.98042	2.1687	4.14912	-0.1882	Effect
Aesthetic	2.54731	2.3175	4.86481	0.22981	Cause
Water pollution	1.79962	1.7028	3.50242	0.09682	Cause
Noise Pollution	1.624452	1.4801	3.10455	0.14435	Cause
Air pollution	1.74797	0.9204	2.66837	0.82757	Cause

4.2. Sensitivity Analysis

Sensitivity analysis is the common approach to identifying the rank and behavior of different parameters in the system(Foumani & Jenab, 2012).In other words, sensitivity analysis helps to predict the factors which have a high influence based on different weightage criteria. Equal weightage criteria are considered for all the respondents(Rajesh & Ravi, 2015). Five different scenarios have been created to identify the higher parameter among all sustainability factors. Based on sensitivity analysis, total relationship matrices of factors of sustainable transportation were obtained for each scenario. Cause and effect values are identified and all factors are ranked accordingly. Table 4.4. is designed for sensitivity analysis for all respondents based on equal weightage criteria.

Table 4. 4. Weightage criteria for sensitivity analysis

	Respondent 1	**respondent 2**	**Respondent 3**	**Respondent 4**	**Respondent 5**
Scenario 1	0.3	0.2	0.2	0.2	0.1
Scenario 2	0.2	0.3	0.2	0.1	0.2
Scenario 3	0.2	0.1	0.3	0.2	0.2
Scenario 4	0.2	0.2	0.1	0.3	0.2
Scenario 5	0.1	0.2	0.2	0.2	0.3

5. FINDINGS

In this chapter, the results of different factors that affect the transportation system are presented. The results are presented in a logical order, starting with the factors for which data has been collected from websites, literature reviews, and other sources.

Next, the results of the questionnaire survey that was conducted to gather data on factors such as traffic congestion and accessibility. These results are interpreted on a reliability scale.

Finally, the results of the DEMATEL and sensitivity analysis are interpreted. The results of the DEMATEL analysis elaborate on the causal relationships between the factors and how they influence one another. The results of the sensitivity analysis will show how changes in one factor will affect the overall system.

5.1. Air pollution due to Transportation

Data and Analysis

The collection of AQI for different locations on the same days is presented in table 5.1. Then the concentration of PM2.5 is calculated with the help of the AQI calculator. The analysis is done on the bases of the standard of AQI (Appendix C) Value feedback is provided accordingly to the standard of AQI.

Table 5. 1. AQI values and categories for a different location in twin cities

SITE	Week	AQI	Concentration of PM2.5 ug/m^3	AQI category	Feedback	Health effect statements	Cautionary Statements
A	Day 1	156	65.1	Unhealthy	The categories most in danger are the elderly, children, and those with heart or respiratory conditions.	Enhanced respiratory effects in the general population, aggravation of heart or lung illness, and early mortality in people with cardiopulmonary disease and the elderly.	The elderly, children, and those who have respiratory or cardiovascular problems should avoid extended exertion; everyone else should limit it.
	Day 2	181	113.6	Unhealthy			
	Day 3	155	63.2	Unhealthy			
	Day 4	117	41.9	Unhealthy for Sensitive Groups	The categories most in danger are the elderly, children, and those with heart or respiratory conditions.	Increased likelihood of respiratory symptoms in sensitive people, deterioration of heart or lung conditions, and early mortality in elderly people and those with cardiopulmonary conditions.	Children, the elderly, and those who have heart or respiratory conditions should avoid prolonged exertion.
	Day 5	83	27.3	Moderate	People with respiratory or heart disease, the elderly and children are the groups most at risk.	Unusually sensitive people may think about reducing sustained or vigorous exercise.	Unusually sensitive people may think about minimizing lengthy or strenuous activity.
	Day 6	75	23.5	Moderate			
	Day 7	74	23	Moderate			
B	Day 1	120	43.2	Unhealthy for sensitive people	People with respiratory or heart disease, the elderly and children are the groups most at risk.	Increased likelihood of respiratory symptoms in sensitive people, deterioration of heart or lung conditions, and early mortality in old people and those with cardiopulmonary conditions.	Children, the elderly, and those who have heart or respiratory conditions should avoid extended effort.

	Day 2	165	82.6	Unhealthy	The categories most in danger are the elderly, children, and those with heart or respiratory conditions.	enhanced respiratory effects in the general population, aggravation of heart or lung illness, and early mortality in people with cardiopulmonary disease and the elderly.	The elderly, children, and those who have respiratory or cardiovascular problems should avoid extended exertion; everyone else should limit it.
	Day 3	105	37.1	Unhealthy for Sensitive Groups	with respiratory or heart disease, the elderly and children are the groups most at risk.	likelihood of respiratory symptoms in sensitive people, deterioration of heart or lung conditions, and early mortality in old people and those with cardiopulmonary conditions.	elderly, and those who have heart or respiratory conditions should avoid extended effort.
	Day 4	140	51.3	Unhealthy for Sensitive Groups			
	Day 5	99	34.9	Moderate	People with respiratory or heart disease, the elderly and children are the groups most at risk.	Unusually sensitive people should consider reducing prolonged or heavy exertion.	People with unusually high sensitivity may think about cutting back on extended or strenuous activity.
	Day 6	73	22.5	Moderate			
	Day 7	71	21.6	Moderate			
C	Day 1	83	27.3	Moderate	People with respiratory or heart disease, the elderly and children are the groups most at risk.	Unusually sensitive people should consider reducing prolonged or heavy exertion.	People with unusually high sensitivity may think about cutting back on extended or strenuous activity.
	Day 2	155	63.2	Unhealthy	People with respiratory or heart disease, the elderly and children are the groups most at risk.	increased respiratory effects in the general population, aggravation of heart or lung disease, and early mortality in people with cardiopulmonary disease and the elderly.	The elderly, children, and those who have respiratory or cardiovascular problems should avoid extended exertion; everyone else should limit it.

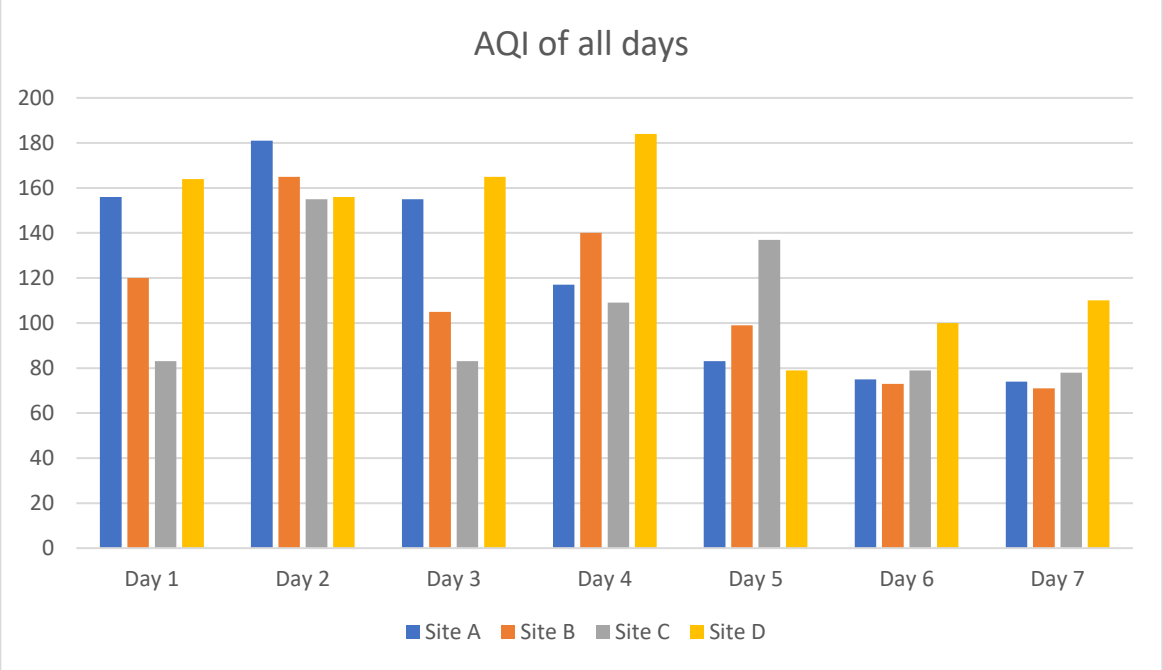
	Day 3	83	27.3	Moderate	People with respiratory or heart disease, the elderly and children are the groups most at risk.	Unusually sensitive people should consider reducing prolonged or heavy exertion.	People with unusually high sensitivity may think about cutting back on extended or strenuous activity.
	Day 4	109	38.7	Unhealthy for Sensitive Groups	The categories most in danger are the elderly, children, and those with heart or respiratory conditions.	Increased likelihood of respiratory symptoms in sensitive people, deterioration of heart or lung conditions, and early mortality in elderly people and those with cardiopulmonary conditions.	Avoid prolonged exertion if you have a respiratory or heart condition, are elderly, or are a child.
	Day 5	137	50.1	Unhealthy for Sensitive Groups			
	Day 6	79	25.4	Moderate	The groups most at risk are the elderly, children, and those with heart or respiratory conditions.	Unusually sensitive people should think about reducing extended or strenuous activity.	Unusually sensitive people should consider reducing prolonged or heavy exertion.
	Day 7	78	24.9	Moderate			
D	Day 1	164	80.6	Unhealthy	The categories most in danger are the elderly, children, and those with heart or respiratory conditions.	Increased aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; increased respiratory effects in the general population.	The elderly, children and those who have respiratory or cardiovascular disease should avoid prolonged exertion; everyone else should limit it.
	Day 2	156	65.1	Unhealthy			
	Day 3	165	82.6	Unhealthy			
	Day 4	184	119.4	Unhealthy			
	Day 5	79	25.4	Moderate	The groups most at risk are the elderly, children, and those with heart or respiratory conditions.	Unusually sensitive people should think about reducing extended or strenuous activity.	Unusually sensitive people should consider reducing prolonged or heavy exertion.
	Day 6	100	35.4	Moderate			

	Day 7	110	39.1	Unhealthy for Sensitive Groups	The categories most in danger are the elderly, children, and those with heart or respiratory conditions.	Increased likelihood of respiratory symptoms in sensitive people, deterioration of heart or lung conditions, and early mortality in elderly people and those with cardiopulmonary conditions.	Avoid prolonged exertion if you have a respiratory or heart condition, are elderly, or are a child.

The comparative result of the Air Quality Index (AQI) for seven days in different locations is presented in Graph 5.1. The AQI was determined based on the PM 2.5 concentration calculated using an AQI calculator and was collected on the same days for each location. The standard for AQI used in the analysis is outlined in Appendix C. The graph reveals that the highest values of AQI were consistently recorded in the Rawalpindi site located in Faizabad. The high AQI in this area is likely due to the heavy traffic volume and the presence of Faizabad as one of the busiest roadways in the twin cities, serving as a gateway to Rawalpindi and Islamabad from numerous cities and rural areas. The large amount of traffic, particularly from diesel-powered vehicles, releases significant amounts of pollutants into the atmosphere, leading to high levels of PM 2.5. The graph offers a visual representation of the AQI data, allowing for a clear comparison of air quality in different locations. The high AQI readings in Faizabad, as shown in the graph, indicate that air pollution is a major concern in the area and may have harmful effects on the health of the local population.

Overall, Graph 5.1 provides valuable information for addressing the issue of air pollution in Rawalpindi and Islamabad, enabling stakeholders to make informed decisions about managing the problem and reducing its impact on the community.

Graph 5. 1. Comparison of AQI of all days in twin cities



5.2. Water Pollution due to Transportation

Contingent upon PCWR Groundwater is primarily used to supplement Islamabad's water sources, and there are more than 290 tube wells in the city. The city's water quality was observed at 24 fixed points. Tables 5.2, 5.3, and 5.4 contain the results of water quality testing carried out by NDWQS (National Drinking Water Quality Surveillance) in respective years at 24 fixed points in Islamabad. The tables show the results of testing for Iron (Fe), Total Coliforms, and E. Coli. Each table provides the following information:

- The total number of samples analyzed
- The number of contaminated samples
- The percentage of contaminated samples

The data in the tables provide a summary of the water quality at various points in Islamabad, including the level of Iron (Fe) and bacteria (Total Coliforms and E. Coli) in the water. The data may be used to monitor the water quality and identify potential issues with the water supply in Islamabad.

Table 5. 2. The level of major parameters exceeding the NDWQS in twin cities (2020-21)

Sr#1	Water Quality Parameters	Unit	The total number of samples Analyzed	Number of Contaminated samples	% Of contaminated samples
1	Iron (Fe)	mg/l	24	4	17
2	Total coliforms	CFU/100 ml	24	6	25
3	E.Coli	CFU/100 ml	24	3	13

Source: (Rasheed et al., 2021)

Table 5. 3. The level of major parameters exceeding the NDWQS in twin cities (2015-16)

Sr#1	Water Quality Parameters	Unit	The total number of samples Analyzed	Number of Contaminated samples	% Of contaminated samples
1	Fe	mg/l	25	3	12
2	Total coliforms	CFU/100 ml	25	17	68
3	E.Coli	CFU/100 ml	25	3	12

Source: (M. S. Imran et al., 2016)

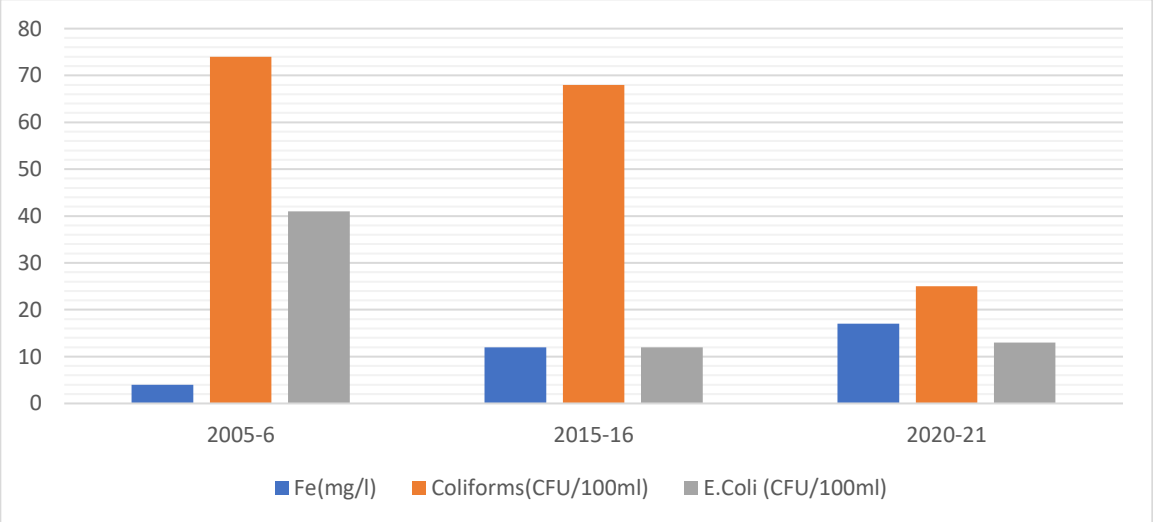
Table 5. 4. The level of major parameters exceeding the NDWQS in twin cities (2005-6)

Sr#1	Water Quality Parameters	Unit	The total number of samples Analyzed	Number of Contaminated samples	Percentage Of contaminated samples
1	Fe	mg/l	27	1	4
2	Total coliforms	CFU/100 ml	27	20	74
3	E.Coli	CFU/100 ml	27	11	41

Source: (PCRWR, 2006)

A comparison of water quality data concerning Iron (Fe), Total Coliforms, and E. Coli. of different years is presented in Graph 5.2. The data is displayed in a visually appealing format, making it easier to understand the trends and patterns in the water quality over time. The graph showcases the changes in the levels of Iron (Fe), Total Coliforms, and E. Coli. through the years, providing a clear understanding of the overall trend in water quality in Islamabad. Overall, the graph provides valuable information about the water quality in Islamabad, allowing stakeholders to make informed decisions about the water supply and take steps to address any issues that may arise.

Graph 5. 2. Comparison of Water Quality Parameters



The quality of water has improved in recent years. The main pollutants found in the water are organic compounds, which can come from a variety of sources. These sources include waste management practices, gasoline and oil spills, and emissions from vehicles. Organic compounds are particularly dangerous for groundwater quality as they are difficult to vaporize, resistant to chemical and biological degradation, and relatively soluble.

Furthermore, many of these organic compounds have been linked to cancer, making their presence in groundwater a significant public health concern. To address this issue, it is important to consider the proper disposal of materials that can contaminate water resources such as vehicle fuels, engine oil, brake oil, hydraulic oil, grease, and other parts. This includes ensuring that there is no runoff or any other water resources nearby during the disposal process. In addition, it is important to be mindful of the potential impact of these materials on the environment when disposing of them.

5.3. Noise Pollution due to Transportation

The data was collected from roads, hospitals, residential areas, and other points, with a focus on transportation data. Table 5.5 contains data on noise levels collected from different locations in Rawalpindi and Islamabad during the day time. The table presents the minimum, maximum, and mean values of the most alarming locations. The data in Table 5.5 provides a comprehensive picture of the noise levels in the study area, specifically on the roads. This information is valuable for understanding the sources of noise pollution and its impact on the local community. The minimum, maximum, and mean values allow for a comparison of the noise levels at different locations and provide a clearer understanding of the extent of the noise problem. APPENDIX D provides the typical noise level standards according to the EPA and Victoria, as presented in the research of Jariwala et al. (2017). This information provides a benchmark against which the data in Table 5.5 can be compared, allowing for an assessment of the severity of the noise pollution in the study area. Overall, Table 5.5 and APPENDIX D provides valuable information for addressing the issue of noise pollution in Rawalpindi and Islamabad, enabling stakeholders to make informed decisions about managing the problem and reducing its impact on the community.

Table 5. 5. Measurement of Db at different spots of roadways in twin cities

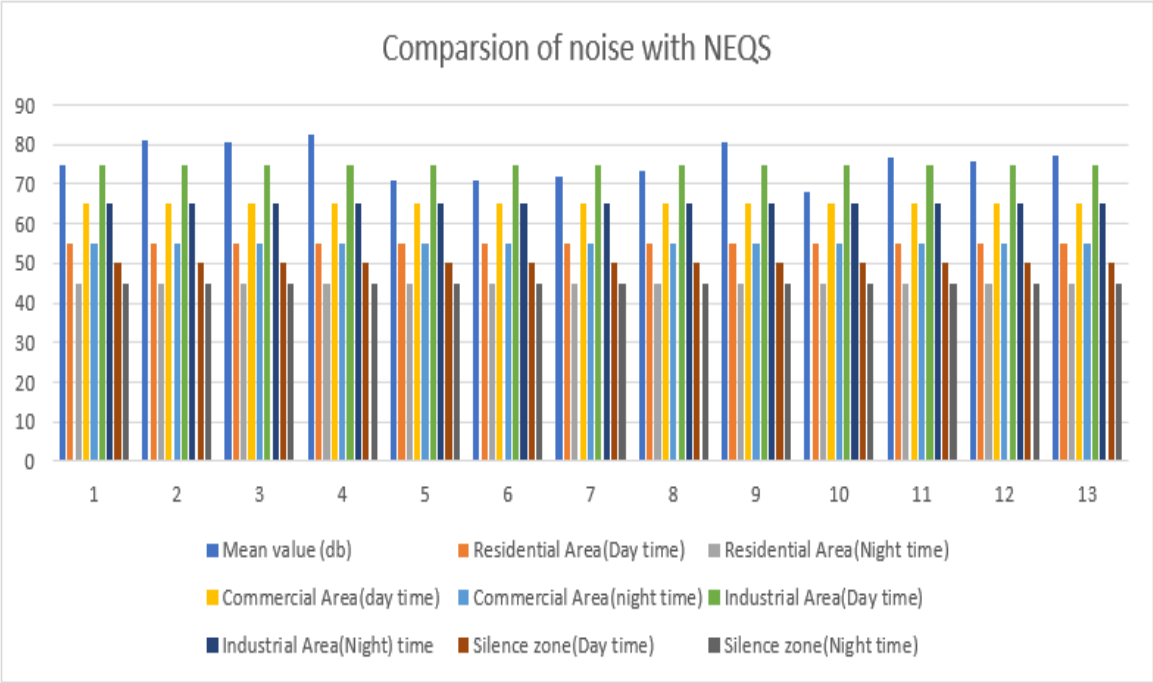
Roads and Choaks	Maximum value(dB)	Minimum value(dB)	Mean value (dB)
IJP Peshawar road	88.2	68.2	75.0
IJP Toll plaza	94.2	70.0	81.1
IJP carriage factory	89.7	70.2	80.6
IJP Pir wadhai more	101.0	71.2	82.4
Faizabad	82.6	66.2	71.1
6^{th} road	86.9	65.1	70.8
sadiqabad	80.1	65.7	72.1
Chandni Chowk flyover	101.9	61.9	73.5
Service road	92.5	76.1	80.4
Committee Chowk	72.2	61.9	68.3
Islamabad international Airport	102.5	59.2	76.6
Railway station	77.7	72.3	75.96
Peer badai Bus stop	85.3	68.1	77.01

Source: (Kalim et al., 2014)

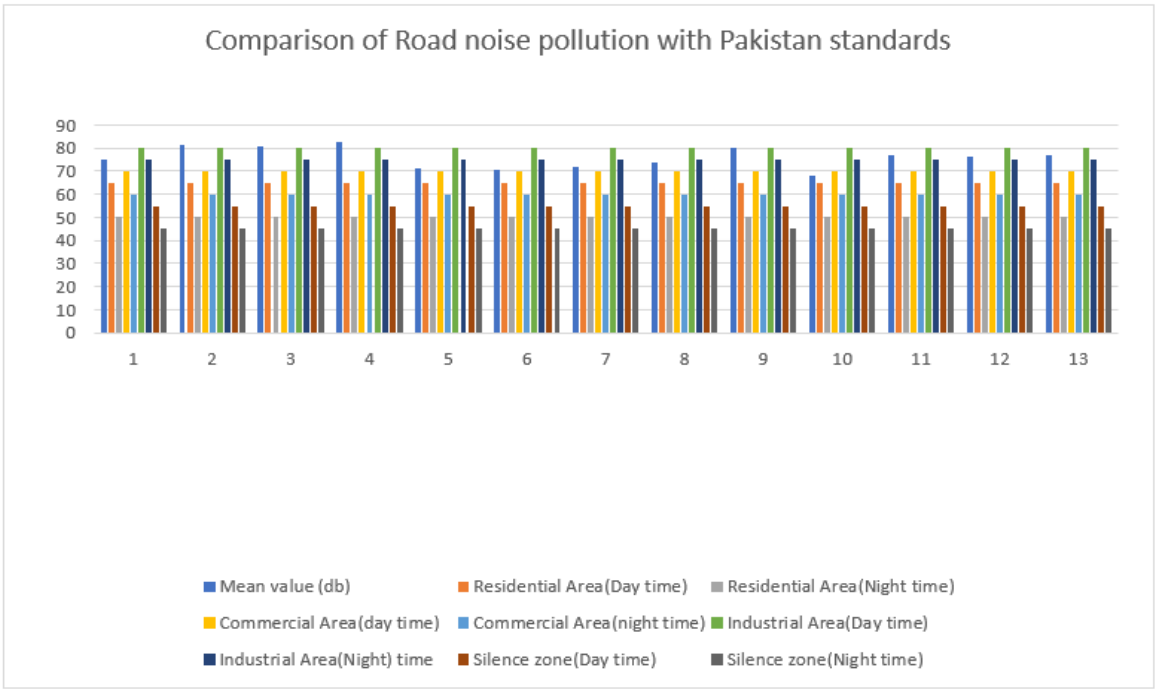
The comparison of noise levels on roads due to traffic with the National Environmental Quality Standards (NEQS) and the Punjab government standards is presented in Graphs 5.3 and 5.4, respectively. The data clearly shows that the noise levels on roads are consistently exceeding both the NEQS and the Punjab government standards. This raises significant concerns for the transportation industry in Pakistan and its potential impact on human health and the environment, particularly in the absence of a comparison between the transportation and industrial sectors. The primary source of noise pollution on roads and in residential areas is motor vehicle traffic, which includes the use of pressure horns, audio systems, and poorly tuned engines. Communities located near roads and bus

stops are particularly vulnerable to traffic noise, which can have a profound impact on their health and well-being. The problem is exacerbated by unplanned urbanization, which has led to the loss of green spaces and an increase in noise pollution. These results emphasize the critical need for addressing the issue of noise pollution in Rawalpindi and Islamabad. Effective measures, such as stricter regulations on vehicle emissions, the promotion of quiet vehicles, and the preservation of green spaces, could help to mitigate the negative impact of noise pollution on local communities. Overall, Graphs 5.3 and 5.4 provide valuable insights into the problem of noise pollution in the twin cities and the need for effective solutions to address this issue.

Graph 5. 3. Comparison of Road Traffic Noise Level with NEQS standards



Graph 5. 4. Comparison of Road Traffic Noise Level with Panjab Government Standards



5.4. Infrastructure Cost

To calculate the direct investment in public transportation in the Panjab province, the government data from the Panjab Sector Development Program (PSDP) is analyzed in recent years. However, specific city-wise infrastructure cost information for the transportation sector is not available. Therefore, the overall data for the transportation sector in Panjab province is utilized for the calculation. Table 5.6 shows the investment in the transportation sector in Panjab province over the recent years from 2013 to 2022. The table provides information on the total amount of funding allocated to the transportation sector by the government through the Panjab Sector Development Program (PSDP). The data in the table is an estimate of the direct investment in public transportation in the province and helps to understand the trend in the funding for transportation infrastructure. This information can be used to evaluate the government's commitment to the development of public transportation in Panjab and determine the need for additional investment in the sector.

Table 5. 6. Investment in Transportation Sector in Panjab Province (2013-2022)

Investment in the transportation sector (Rs Million)	**Investment in the transportation sector ($ Millions)**	**Era**
109.265	0.48	2013-14
191.130	0.85	2014-15
364.747	1.63	2015-16
21660.398	96.8	2017-18
13977.204	62.48	2018-19
248.308	1.11	2019-20
254.753	1.13	2020-21
451.32	2.01	2021-22

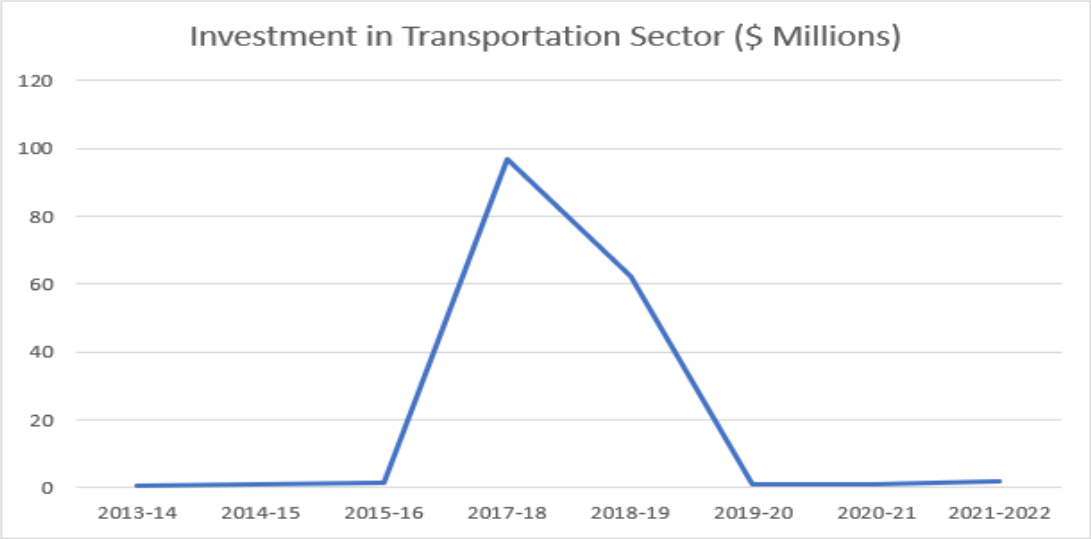
Source: Federal Budget from Finance Division of Government of Pakistan

Investment in the transportation sector in Panjab province over the years is depicted in Graph 5.5. The graph presents an inconsistent pattern of investment, indicating fluctuations in funding for transportation infrastructure.

A closer examination of the graph reveals that investment from 2015 to 2019 was relatively higher compared to other years. This increase in investment can be attributed to the launch of the highly-ambitious metro bus project in April 2014 and the initiation of its construction work in March 2015. This significant investment in the transportation sector during this period highlights the government's strong commitment to developing public transportation infrastructure in the province.

Overall, graph 5.5. provides insights into the trend in investment in the transportation sector in Panjab and highlights the need for a structured approach to investment in this important sector.

Graph 5. 5. Investment Trend in Transportation Sector in Panjab Province



Source: Federal Budget from Finance Division of Government of Pakistan

5.5. Accidents Damage

The data for accidental damage in the twin cities of Rawalpindi and Islamabad were collected from the National Transport Research Center (NTRC). Table 5.7 presents the accident data for different years as obtained from the NTRC. The table provides a comprehensive overview of the frequency and severity of accidents in the twin cities and serves as a useful resource for understanding the state of road safety in the region. Table 5.7 presents the data on the number of accidents, the total number of vehicles involved, and the number of fatal and non-fatal injuries in Rawalpindi and Islamabad for different years from 2012 to 2018. The data was obtained from the National Transport Research Center (NTRC) and provides valuable insights into the state of road safety in the region.

Table 5.7. shows the trend in the number of accidents, vehicles involved, and injuries over time and highlights the need for effective measures to improve road safety and reduce the number of accidents. The information can be used to identify areas where improvement is needed and to evaluate the effectiveness of existing road safety measures.

Overall, Table 5.7 provides a comprehensive overview of the road safety situation in the twin cities and serves as a valuable resource for decision-makers and stakeholders who are working to improve road safety in the region.

Table 5. 7. Accidental Damage Data in Rawalpindi and Islamabad (2012-2018)

Year	Total Number of Accidents	Accident Fatal	Accident Non-Fatal	Persons Killed	Persons Injured	Total Number of Vehicles Involved
2012-13	201	107	94	109	180	212
2013-14	256	120	136	132	206	256
2014-15	216	107	109	118	182	217
2015-16	244	120	124	140	209	244
2017-18	204	104	100	137	172	210

Source: (NTRC department)

The data in the table shows the trend of road accidents in Rawalpindi and Islamabad from 2012 to 2018. The information is presented in terms of the total number of accidents, accident fatalities, non-fatal accidents, the number of people killed, injured, and the total number of vehicles involved. From the data, it can be seen that the number of road accidents has not seen a significant decrease over the years. This is a matter of concern as road accidents result in significant costs in terms of human lives and economic resources.

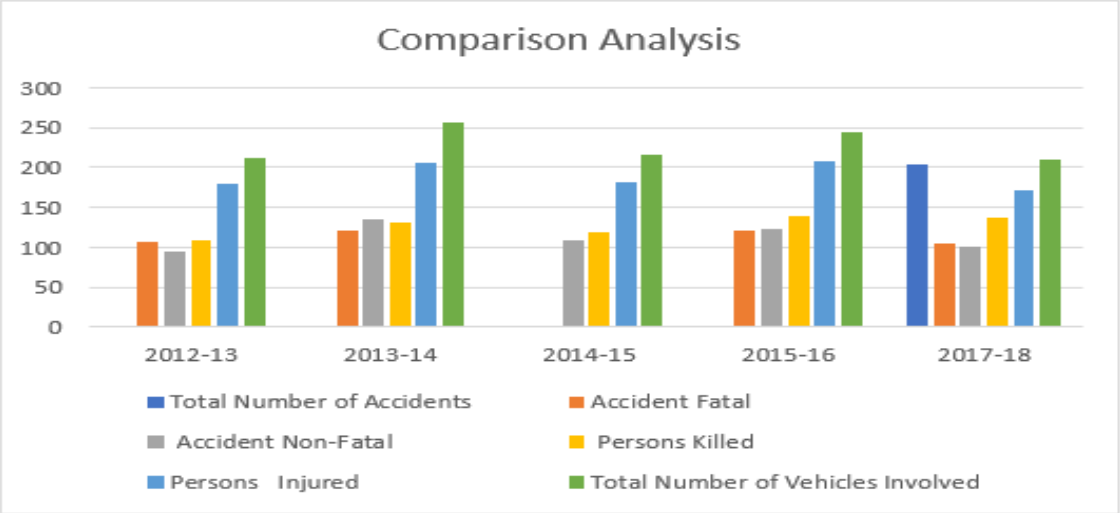
The year-wise trend in the number of road accidents in Rawalpindi and Islamabad is illustrated in Graph 5.6. This visual representation provides a clear picture of the state of road safety in the region and highlights the urgent need for measures to reduce the number of accidents. The data shown in the graph can be used to identify areas that require improvement and evaluate the impact of current road safety measures. It is a valuable resource for decision-makers and stakeholders who aim to enhance road safety in Rawalpindi and Islamabad.

The reasons for this lack of improvement can be attributed to several factors, including strong violations of traffic rules, weak enforcement of traffic regulations by

government bodies, a lack of road safety awareness, poor road design, and the widespread use of vehicles without airbags. The situation is particularly dire in Rawalpindi, where these problems are prevalent.

Overall, graph 5.6 highlights the importance of addressing the issue of road safety in the twin cities and the need for effective measures to reduce the number of accidents and improve road safety.

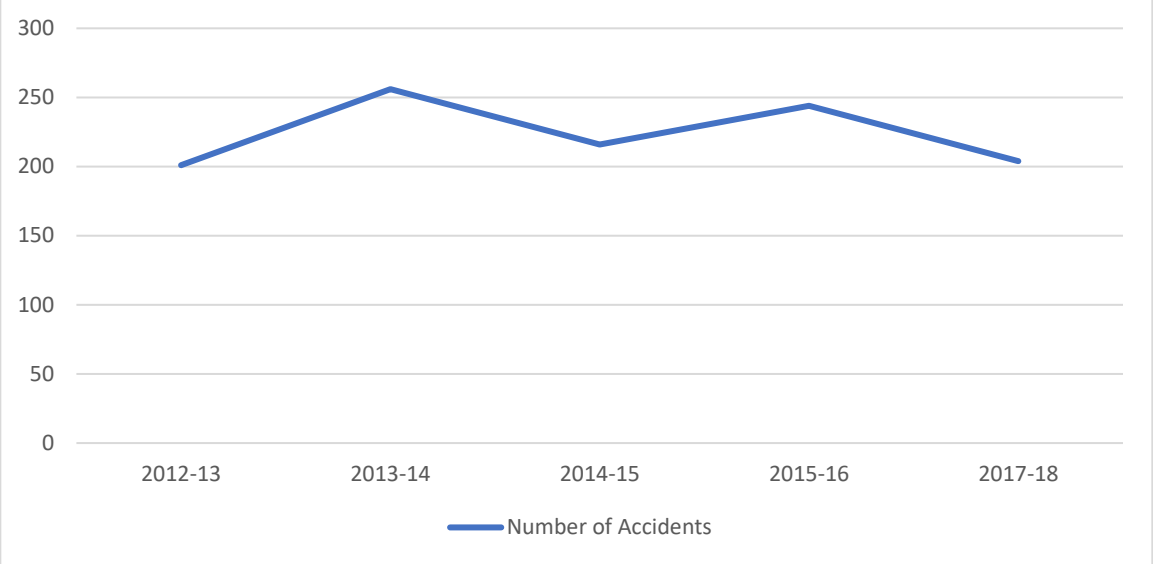
Graph 5. 6. Year-Wise Road Accident Data in Rawalpindi and Islamabad



Source: National Transport Research Center (NTRC) Pakistan

The trend line of road accidents in Rawalpindi and Islamabad depicted in Graph 5.7 highlights the fluctuations in the number of accidents over a given period. The graph presents an overview of the situation of road safety in the twin cities and provides valuable insights into the trend of road accidents. The fluctuations in the number of accidents can be easily identified from the graph, which helps in determining the success or failure of current road safety measures. This information can also be useful in pinpointing problem areas and in taking informed decisions for enhancing road safety in the future. Overall, Graph 5.7 provides a comprehensive view of the situation of road safety in Rawalpindi and Islamabad and can serve as a crucial resource in developing effective strategies to improve road safety.

Graph 5. 7. Trend Line of Road Accidents in Rawalpindi and Islamabad



Source: National Transport Research Center (NTRC) Pakistan

5.6. Consumer Cost

Consumer Cost of Public Transport in Twin cities.

The meeting was conducted with the Capital development authority (CDA). Table 5.8 presents the fare revenue and expenses data obtained from the Capital Development Authority (CDA) for the Bus Rapid Transit (BRT) system in Islamabad and Rawalpindi. This data provides valuable insights into the financial performance of the BRT system in the twin cities, including revenue generated from fares and the costs associated with operating and maintaining the system. The information presented in Table 5.8 can be used to make informed decisions about the future development and management of the BRT system in Islamabad and Rawalpindi.

Table 5. 8. Fare Revenue and Expenses for Bus Rapid Transit in Twin Cities

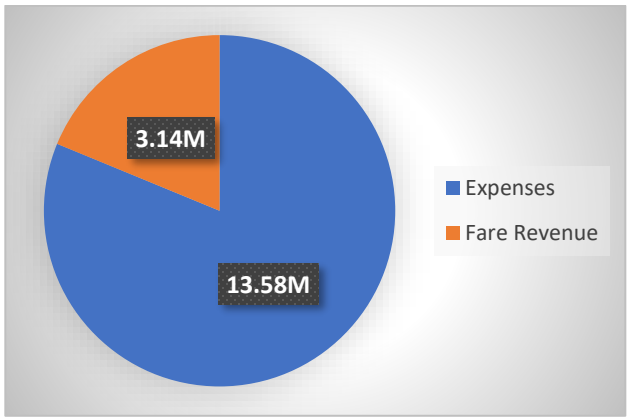
Public Transport	Fare Revenue	Expenses	Ratio
Metro (Islamabad-Rawalpindi)	3.14M	13.58M	4.32

Source: Capital Development Authority (CDA) Pakistan

Table 5.8 showcases the fare revenue and expenses for the Bus Rapid Transit (BRT) system in Islamabad & Rawalpindi, as obtained from the Capital Development Authority (CDA). The analysis of the data shows that the fare-to-expense ratio for BRT is 4.32, which is higher compared to other revenue-generating departments.

Graph 5.8 visually represents the fare to the expense ratio of the BRT system. It provides a clear picture of the relationship between fare revenue and expenses, allowing for a better understanding of the financial performance of the BRT. The graph highlights the high fare-to-expense ratio, providing valuable insights into the financial viability of the BRT system and its potential to generate revenue. The graph and table together provide a comprehensive understanding of the financial aspect of the BRT system and can be used to inform future decision-making related to the BRT and public transportation in the twin cities.

Graph 5. 8. Fare to Expense Ratio of BRT in Islamabad and Rawalpindi



Source: Capital Development Authority (CDA) Pakistan

5.7. Affordability

To evaluate the affordability of public transportation in Pakistan, the data from the Pakistan Economic Survey (2021-22) is analyzed based on the average household income. The survey indicates that the average mean household income is $150 (33,000 Rs/-). The data is used to analyze the daily use of transportation about the average household income. This information is crucial to determine the affordability of public transportation for the general population. Table 5.9 shows the average household income and total monthly public transportation expenses for residents of Islamabad and Rawalpindi, Pakistan. The table presented the average household income and cost of using public transportation (either the BRT system or other modes of transportation) in the two cities. The table is used to determine the affordability of public transportation based on the average household income. By considering 60 tickets per month, the table calculates the total monthly public transportation expense for a resident.

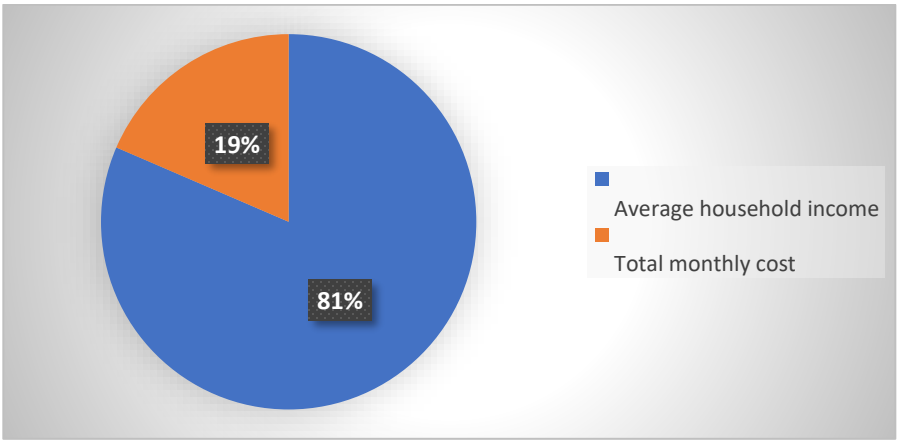
Table 5. 9. Average Household Income and Monthly Public Transportation Expense in Islamabad and Rawalpindi

Services	Single Ticket Price	Monthly cost price (60 tickets) in Rupees
BRT	45	2700
Other Public Transport	80	4800
Total monthly cost		7500
Average household income		33,000
Travel cost to Income Ratio		4.4
Percentage of transportation expense from average household income		22.72%

Source: Pakistan Economic Survey (2021-22)

Graph 5.9 shows the ratio of the average household income to the total monthly cost of public transportation expenses in Islamabad and Rawalpindi. According to general practices, a household should not spend more than 20% of its total income on transportation expenses. However, the data in Graph 5.9 indicates that the percentage of transportation expenses from the average household income is relatively high in the twin cities.

Graph 5. 9. Ratio of Average Household Income to Monthly Public Transportation Expense in Islamabad and Rawalpindi



Source: Pakistan Economic Survey (2021-22)

5.8. Results of Questionnaire Survey for other parameters

The information in APPENDIX A of the thesis presents a questionnaire survey conducted to assess the impact of public transportation on various factors in a community. The survey seeks to evaluate the accessibility, traffic congestion, equity, human health impact, community cohesion and livability, and aesthetic aspects of public transportation in Islamabad and Rawalpindi. The survey results are analyzed using the Cronbach Alpha reliability coefficient, which is a statistical measure of the internal consistency or reliability of a questionnaire.

The Cronbach Alpha reliability coefficient is used to determine the reliability of the survey results by evaluating the consistency of the system.

The use of the Cronbach Alpha reliability coefficient helps to ensure the validity and reliability of the results from the questionnaire survey, which can be used to inform decisions and improve the public transportation system in a community. The results of the survey can provide valuable insights into the impact of public transportation on various aspects of community life, including accessibility, traffic congestion, equity, human health, community cohesion and livability, and aesthetics. Table 5.10 presents the results of the reliability analysis of the questionnaire survey conducted to assess the impact of public transportation on various factors in Islamabad and Rawalpindi. The reliability values in the table show the internal consistency or reliability of each of the parameters evaluated in the survey. Table 5.10 provides crucial information about the reliability of the results from the questionnaire survey, which is essential for ensuring the validity and reliability of the results and for making informed decisions about the public transportation system in the area.

Table 5.10. Reliability coefficient of various factors

Factors	**Cronbach Alpha reliability coefficient**	**Consistency**
Accessibility	0.815	Good
Traffic Congestion	0.395	Unacceptable
Equity	0.638	Questionable
Human Health Impact	0.574	Poor
Community Cohesion and livability	0.671	Acceptable
Aesthetics	0.768	Acceptable

The reliability coefficients presented in the table reflect the internal consistency or reliability of the answers provided by the participants in the questionnaire survey. The reliability coefficient ranges from 0 to 1, with a value of 1 indicating complete consistency and a value of 0 indicating no consistency.

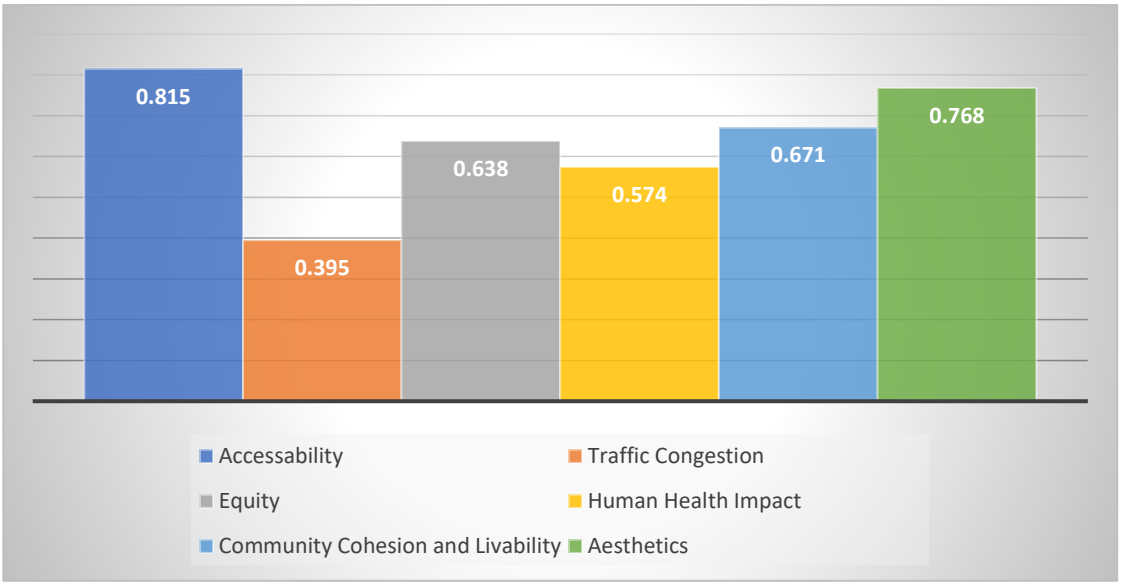
From the analysis of the reliability coefficients, it can be seen that the traffic congestion parameter has a low-reliability coefficient of 0.395. This indicates that the answers provided by the participants regarding traffic congestion are not consistent, which could be due to varying experiences and opinions. The low-reliability coefficient for traffic congestion suggests that the transportation system in the twin cities of Pakistan is heavily impacted by traffic congestion, leading to an unsustainable transportation system.

On the other hand, the accessibility parameter has a relatively high-reliability coefficient of 0.815, indicating that the answers provided by the participants regarding accessibility are consistent and reliable. The high-reliability coefficient for accessibility suggests that the public transportation system in the twin cities of Pakistan is considered accessible in terms of schedule and frequency of departures. This is considered a positive aspect of the transportation system.

Graph 5.10 provides a visual representation of the reliability coefficients for the different parameters evaluated in the questionnaire survey. The graph highlights the relative importance of each parameter and provides a quick overview of the reliability of the results from the questionnaire survey.

Overall, the analysis of the reliability coefficients and the graph suggests that while the public transportation system in the twin cities of Pakistan has some positive aspects, traffic congestion remains a significant issue that needs to be addressed to improve the sustainability of the transportation system. The low-reliability coefficient for traffic congestion highlights the need for action to improve the traffic flow and reduce congestion in the transportation system.

Graph 5. 10. Reliability Coefficient of Public Transportation Factors in Islamabad and Rawalpindi



5.9. Results from DEMATEL Analysis

By considering the threshold value, the relationship between different factors has been evaluated and the results are represented in Figure 5.1 and Matrix 5.1. These results provide valuable insights into the impact of different factors on the public transportation system and can inform decision-making to improve the sustainability of the transportation system in the twin cities of Pakistan.

The threshold value in the DEMATEL approach is used to determine the significance of the relationship between different factors. It sets a minimum level of relationship strength below which the relationship between factors is considered to be negligible. The threshold value helps to filter out insignificant relationships and focus on the most important relationships between factors.

The threshold value is used to evaluate the relationship between different factors in the public transportation system. The results of the DEMATEL analysis and provide valuable insights into the impact of different factors on the sustainability of the public transportation system in the twin cities of Pakistan.

Matrix 5.1 is a total relationship matrix that displays the relationship between different factors in the DEMATEL analysis. The matrix shows the relationship strength between each factor, with elements in bold text indicating a strong relationship. Elements with a value less than the threshold value are considered to have a minimum effect on each

other and are ignored in the analysis. These results can be used to inform decision-making and improve the sustainability of the public transportation system in the twin cities of Pakistan.

In the DEMATEL analysis, the relationship between various factors affecting the sustainability of the transportation system in the twin cities of Pakistan has been evaluated and represented in a total relation matrix. The matrix, known as Matrix 5.1, showcases the strength of relationships between each factor, where a bold text is used to highlight the strong relationship between two factors, while elements with a value lower than the specified threshold value are considered to have a minimal impact on each other and are disregarded.

Matrix 5. 1. Total Relation Matrix

	Total Relation Matrix T=D(I-D) ^-1												
	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11**	**A12**	**A13**
A1	**0.2**	**0.3**	**0.2**	**0.2**	**0.2**	0.2	0.2	**0.2**	**0.2**	**0.3**	**0.2**	**0.2**	0.1
A2	**0.2**	0.1	**0.2**	**0.2**	0.1	0.1	0.2	**0.2**	0.1	0.1	0.1	0.1	0.1
A3	**0.3**	**0.3**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**	0.1	0.1
A4	**0.2**	**0.2**	**0.2**	0.1	0.1	**0.2**	**0.2**	0.1	**0.2**	**0.2**	0.1	0.1	0.0
A5	**0.3**	**0.3**	**0.2**	**0.2**	0.1	0.2	0.2	**0.2**	**0.2**	**0.2**	**0.2**	0.2	0.1
A6	**0.2**	**0.2**	**0.2**	**0.2**	0.1	0.1	**0.2**	**0.2**	**0.2**	0.2	0.1	0.1	0.1
A7	**0.3**	**0.3**	**0.2**	**0.2**	0.1	**0.2**	0.1	**0.2**	**0.2**	**0.2**	0.1	0.1	0.1
A8	**0.2**	0.2	0.1	0.1	**0.2**	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
A9	**0.2**	**0.2**	**0.2**	**0.2**	0.1	**0.2**	**0.2**	0.2	0.1	**0.2**	0.1	0.1	0.1
A10	**0.3**	**0.3**	**0.3**	**0.2**	0.2	**0.2**	**0.2**	**0.2**	**0.2**	0.2	0.2	0.2	0.1
A11	**0.2**	**0.2**	0.2	0.1	0.2	0.1	0.1	**0.2**	0.1	**0.2**	0.1	0.1	0.1
A12	**0.2**	**0.2**	0.1	0.1	0.1	0.1	0.1	**0.2**	**0.2**	**0.2**	0.1	0.1	0.1
A13	**0.2**	**0.2**	0.2	0.1	0.1	0.1	0.1	**0.2**	0.1	**0.2**	0.1	0.1	0.1

Based on the DEMATEL threshold value, it can be observed that traffic congestion has a strong causal relationship with several factors affecting the transportation system, including accessibility, infrastructure, consumer cost, accident damage, community cohesion & livability, aesthetic, noise pollution, and air pollution. These factors are closely interrelated and have a significant impact on the overall transportation system. Accessibility, which is critical to the usability of the transportation system, is strongly influenced by the infrastructure of public transportation, the consumer cost of transit, and aesthetic parameters such as the comfort level of the journey. Infrastructure, considered to be an important factor of economic sustainability, has a strong relationship with accessibility, consumer cost, accident damage, equity, affordability, and environmental pollution. Additionally, infrastructure can impact community cohesion & livability and can also reduce the human health impact of transportation. Consumer cost, which is a crucial factor in determining the

affordability of the transportation system, is mainly influenced by accessibility, traffic congestion, and the affordability of public transportation. Road accidents have a direct relationship with traffic congestion, and traffic congestion can be decreased by the high accessibility of public transportation and good infrastructure. Accidents also have a relationship with the community cohesion parameter and the impact of transportation on human health. Equity, which is an important aspect of sustainability, can be affected by traffic congestion, accessibility, and consumer cost of transit services. It also has a strong bond with the affordability and community cohesion & livability parameters of sustainability. Accessibility and consumer cost have a direct relationship with the affordability of public transportation. Human health is affected by traffic congestion and accidents, which can cause air pollution and noise pollution. Community cohesion & livability can be influenced by infrastructure, traffic congestion, accessibility, consumer cost, affordability, and equity. The aesthetic parameter, which is an important aspect of social sustainability, has a direct relationship with traffic congestion, accidents, infrastructure, and human health.

The DEMATEL analysis is a useful tool for understanding the inter-relationships between different factors that impact environmental sustainability in the transportation system of twin cities of Pakistan. Figure 5.1 presents a visual representation of these inter-relationships and provides valuable insights into the complex relationships between different factors. The diagram in Figure 5.1 is a network of interconnected factors, where each factor is represented as a node, and the lines connecting the nodes represent the relationship strength between different factors. The figure 5.1 allows decision-makers to quickly understand the impact of different factors on the transportation system and to identify areas where improvements can be made to enhance sustainability.

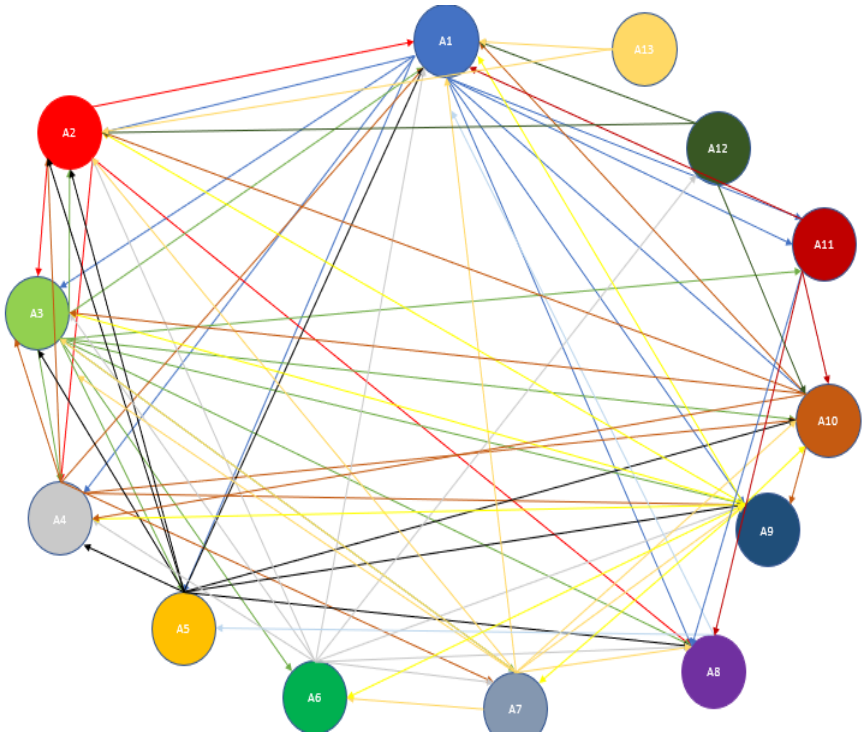


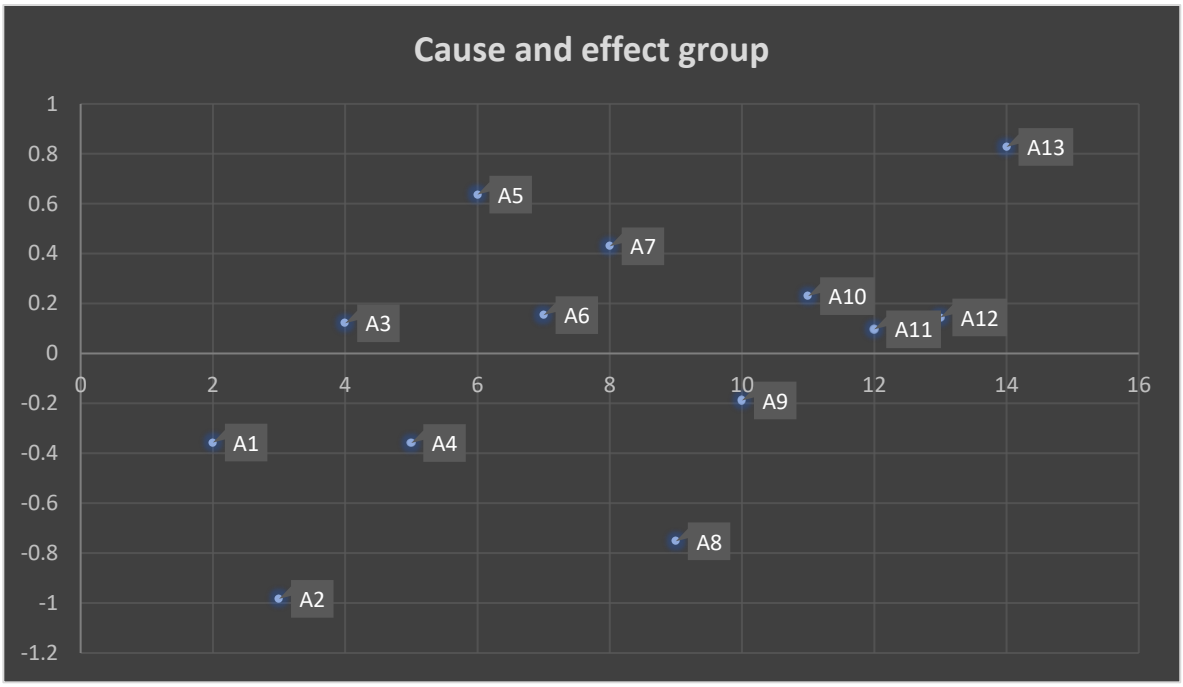
Figure 5. 1. Relationship of sustainability factors

The DEMATEL approach is a method used to identify and prioritize the most important sustainability factors in public transportation by analyzing the root causes of unsustainability. The results of this analysis are presented in a graph known as Graph 5.11. which indicates the cause & effect group of the factors. This graph is divided into two groups of sustainability factors, one above the x-axis and the other below it.

The factors above the x-axis, also known as the influential or causal group, are the sustainability factors that have the greatest influence on public transportation sustainability. These factors are considered to be the root causes of unsustainability and are the most important parameters to consider when addressing sustainability in transportation. For example, air pollution is the most important parameter to consider when dealing with sustainability in transportation, as it has the highest value for $\tilde{\boldsymbol{r}}_{\boldsymbol{i}} - \tilde{\boldsymbol{c}}_{\boldsymbol{i}}$ among all sustainability factors in the cause group.

On the other hand, the factors below the x-axis, also known as the effect or influenced group, are the sustainability factors that are affected by the factors in the influential group. These factors are considered to be the effects of the root causes of unsustainability and are important to consider when addressing sustainability in transportation. For example, traffic congestion is identified as a critical factor that can rapidly have an impact on sustainability, it is observed that traffic congestion has the highest value of $\tilde{\boldsymbol{r}}_{\boldsymbol{i}} + \tilde{\boldsymbol{c}}_{\boldsymbol{i}}$ and $\tilde{\boldsymbol{r}}_{\boldsymbol{i}}$ among the effect group.

Graph 5. 11. Cause and effect group of sustainability factors



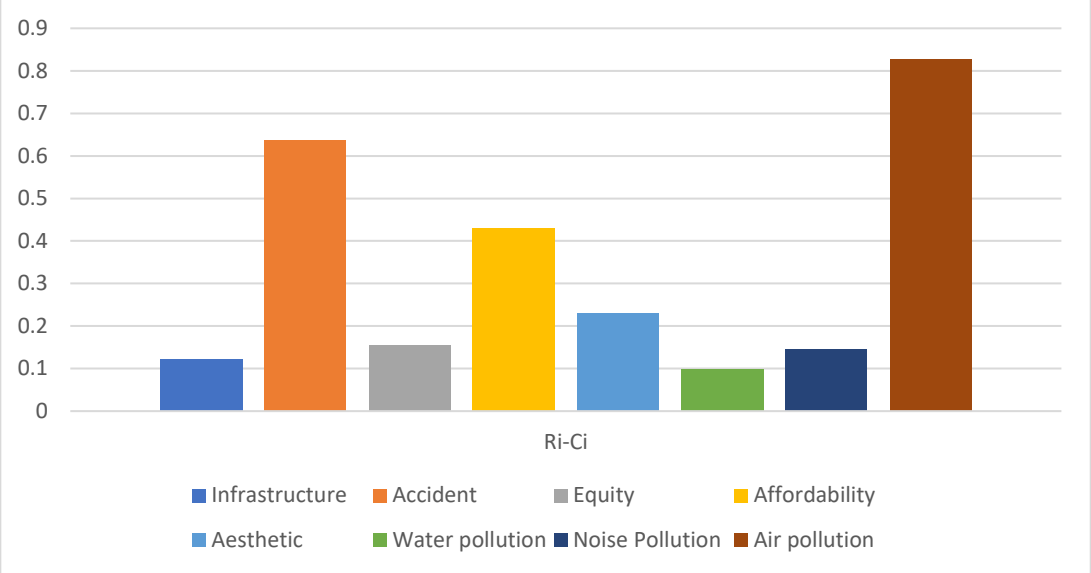
The DEMATEL approach is a method used to identify and prioritize the most important sustainability factors in public transportation. By analyzing the root causes of unsustainability, it is possible to pinpoint the key factors that have the greatest impact on the overall sustainability of the transportation system.

The results of this analysis indicate that air pollution is the most important parameter to consider when dealing with sustainability in transportation. This is because automobiles emission has a significant influence on the environment and ultimately have the highest impact on sustainability. The second highest value was observed for road accidents, which means that accidents on the roadway have a high impact on economic sustainability.

Other important parameters include the infrastructure of transportation, fairness, affordability, aesthetics of public transportation, noise pollution, and water pollution. These are all root-causing factors that should be considered when dealing with the sustainability of public transportation.

Graph 5.12. indicates that air pollution is the main causal factor in environmental sustainability and accident damage is the main alarm cause in economic factors of sustainability whereas affordability is the prime cause parameter in social sustainability of public transportation.

Graph 5. 12. Comparison of cause factors in sustainability



Traffic congestion is also identified as a critical factor that can rapidly have an impact on sustainability. It is observed that traffic congestion has the highest value of $\tilde{r}_i + \tilde{c}_i$ and $\tilde{r}_i$ among the effect group which means it is the central factor among the sustainability factors. This is because traffic congestion can affect the accessibility of public transportation, the operating cost of public transportation, and human health through pollution.

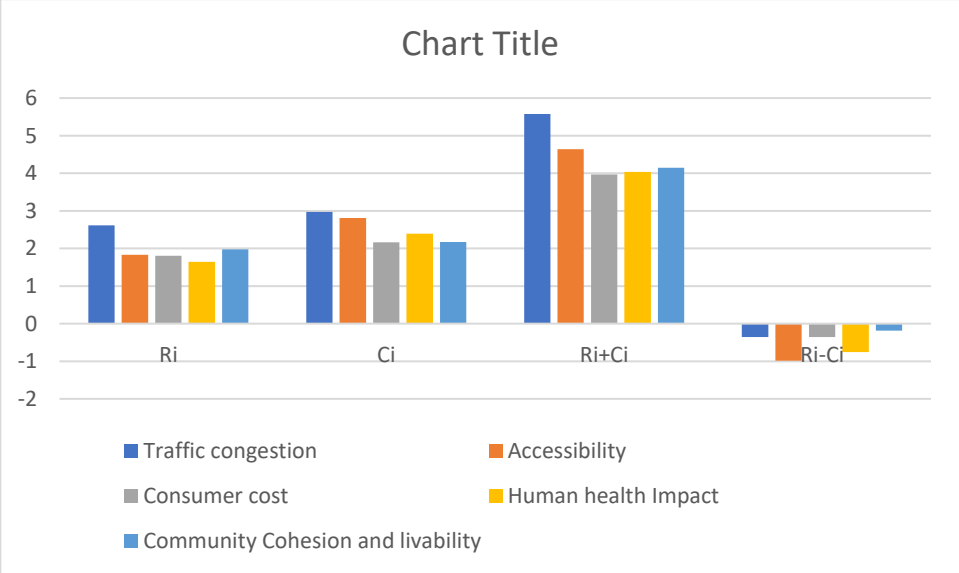
Graph 5.13 presents the results of a DEMATEL analysis, which is a method used to evaluate the causal relationships between different factors. Table 4.3 displays the values of Ri, Ci, Ri+Ci, and Ri-Ci for the effect and cause group of factors, which includes traffic congestion, accessibility, consumer Cost, human health impact, and community cohesion and livability as causal group of sustainability factors.

$\tilde{r}_i$ and $\tilde{c}_i$ are measures of the direct and indirect influence of each factor on the other factors, respectively. $\tilde{r}_i + \tilde{c}_i$ represents the overall impact of a factor on the system, and $\tilde{r}_i - \tilde{c}_i$ represents the net effect of a factor on the system.

Graph 5.13 presents these results visually, making it easier to understand the relationships between the factors. The graph shows that traffic congestion has the highest value of $\tilde{r}_i + \tilde{c}_i$ and is ranked first in the causal group of sustainability. This indicates that traffic congestion has the strongest overall impact on the system and is considered the most important factor to consider when addressing sustainability issues in the twin cities.

In summary, the DEMATEL approach has identified air pollution, road accidents, traffic congestion, and other factors as the most important parameters to consider when dealing with sustainability in public transportation. It is important to address these factors to ensure the long-term sustainability of the transportation system.

Graph 5. 13 Comparison of effect group of sustainability



5.10. Results of Sensitivity Analysis

The sensitivity analysis is a method used to evaluate the robustness of the results obtained from the DEMATEL approach. It is used to assess the impact of changing input data on the final results of the analysis. In this case, the sensitivity analysis was performed for five different scenarios in the transportation system of twin cities.

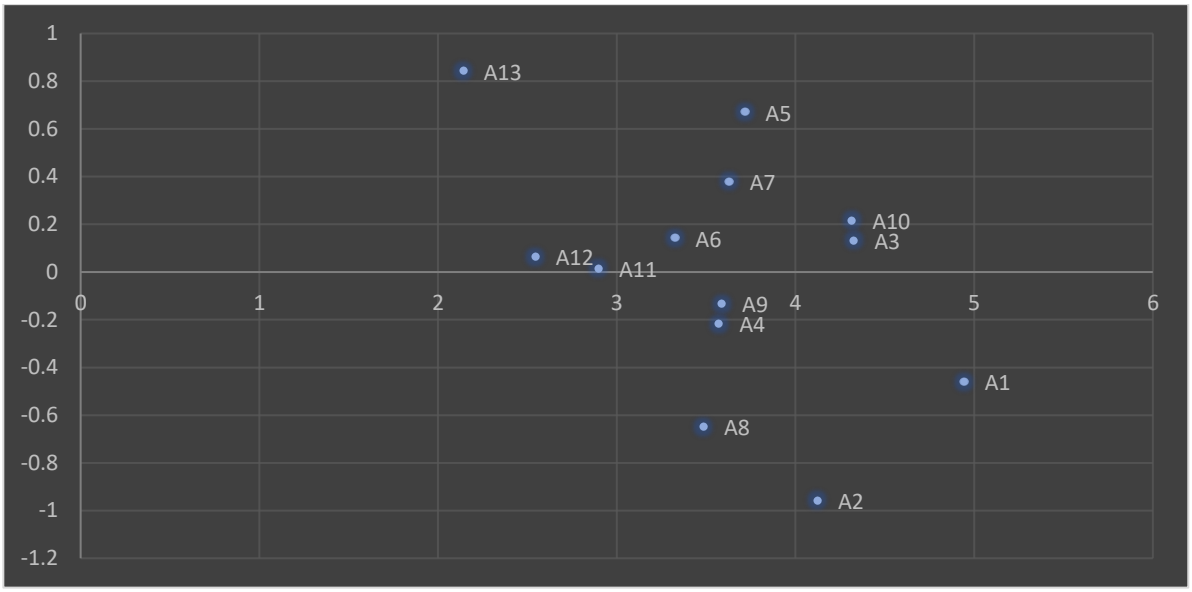
The results of the sensitivity analysis indicate that the cause-and-effect groups are similar for all five scenarios, as well as the same cause/effect rankings for sustainability-related parameters in public transportation, with some differences in order. This means that the key sustainability factors identified in the DEMATEL analysis are robust and consistent across different scenarios.

The key finding of the sensitivity analysis is that air pollution is the most important parameter of environmental sustainability concerning the transportation system of twin cities. Table 5.11. indicates the ranking of all factors of sustainability under different scenarios.

Graph 5.14, graph 5.15, graph 5.16, graph 5.17, and graph 5.18 are cause-and-effect groups of five different scenarios under the sensitivity analysis and indicate the same image

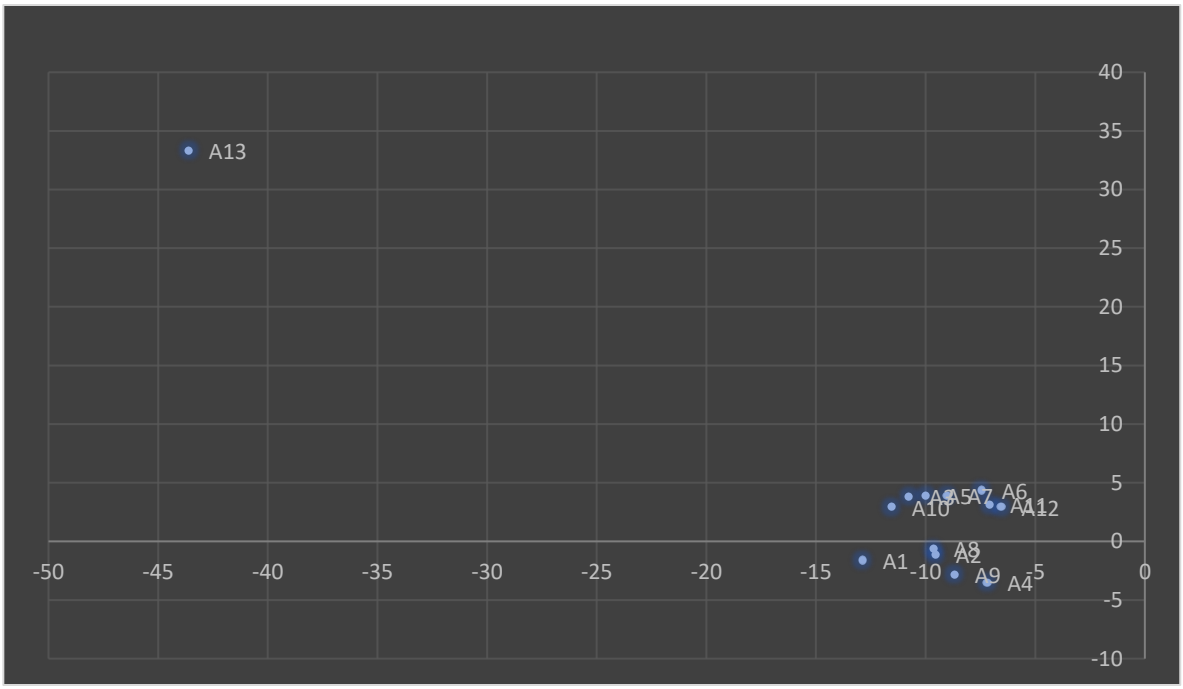
of the cause-and-effect group as graph 5.1 of the DEMATEL analysis. All the factors above the x-axis are ranked as cause groups and vice versa. This suggests that the key sustainability factors identified in the DEMATEL analysis are robust and consistent across different scenarios.

Graph 5. 14. Cause-and-effect group of scenarios 1

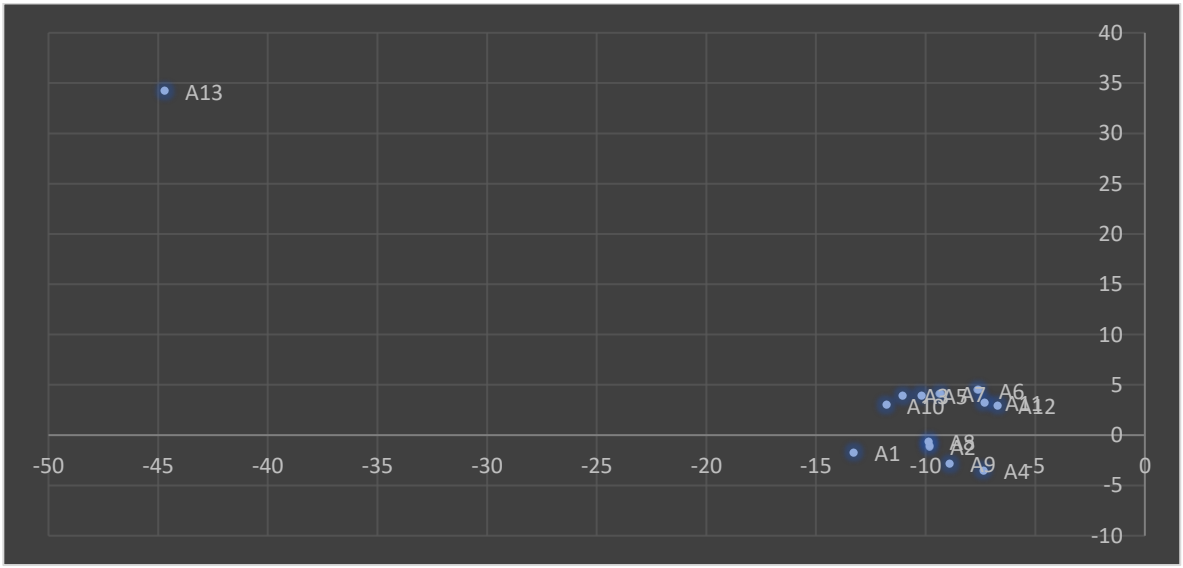


Graph 5. 15. Cause-and-effect group of scenarios 2

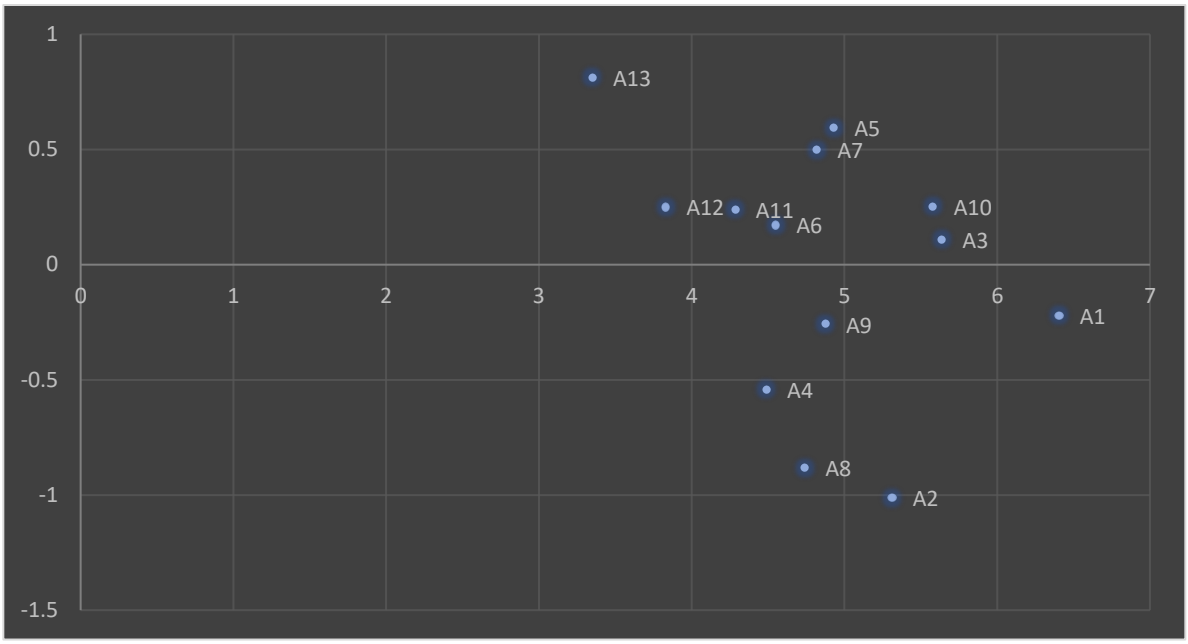
Graph 5. 16. Cause and effect group of scenarios 3



Graph 5. 17. Cause and effect group of scenarios 4



Graph 5. 18. Cause and effect group of scenarios 5



In summary, the sensitivity analysis confirms that air pollution is the most important parameter of environmental sustainability concerning the transportation system of twin cities. The results of the sensitivity analysis are consistent with the results of the DEMATEL analysis and suggest that the key sustainability factors identified in the DEMATEL analysis are robust and consistent across different scenarios. The key to reducing air pollution in the transportation sector is the promotion of public transportation.

The results of a sensitivity analysis, which was performed using the DEMATEL approach on 5 different scenarios, are presented in Table 5.11. The purpose of this analysis was to determine the most significant factors that impact environmental sustainability in the transportation system of the twin cities. The results provide valuable insights into the relative importance of various factors and can be used to inform decisions and policies aimed at improving the sustainability of the transportation system in the region.

The results show that air pollution is the most critical factor among all the sustainability factors considered, ranking first in all five scenarios. Meanwhile, traffic congestion is also an important factor with a high ranking due to its significant impact on sustainability.

The remaining factors, in order of importance, are Accidents, Affordability, Aesthetic, Equity, Infrastructure, Noise pollution, Water pollution, Community Cohesion & Livability, Consumer Cost, Human Health Impact, and Accessibility.

These results suggest that reducing air pollution and traffic congestion should be the top priority for improving the sustainability of the transportation system in twin cities.

Table 5. 11. Ranking of sustainability factors under different scenarios

Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
Factors	**R**	**Factors**	**R**	**Factors**	**R**	**Factors**	**R**	**Factors**	**R**
Air pollution	1	Air pollution	1	Air pollution	1	Air pollution	1	Air pollution	1
Accident	2	Accident	2	Equity	2	Equity	2	Accident	2
Affordability	3	Affordability	3	Affordability	3	Affordability	3	Affordability	3
Aesthetic	4	Aesthetic	4	Accident	4	Accident	4	Aesthetic	4
Equity	5	Water pollution	5	Infrastructure	5	Infrastructure	5	Noise pollution	5
Infrastructure	6	Noise pollution	6	Water pollution	6	Water pollution	6	Water pollution	6
Noise pollution	7	Equity	7	Noise pollution	7	Aesthetic	7	Equity	7
Water pollution	8	Infrastructure	8	Aesthetic	8	Noise pollution	8	Infrastructure	8
Community Cohesion & livability	9	Community Cohesion & livability	9	Human health Impact	9	Human health Impact	9	Traffic congestion	9
Traffic congestion	11	Consumer cost	10	Accessibility	10	Accessibility	10	Community Cohesion & livability	10
Consumer cost	10	Traffic congestion	11	Traffic congestion	11	Traffic congestion	11	Consumer cost	11
Human health Impact	12	Human health Impact	12	Community Cohesion & livability	12	Community Cohesion & livability	12	Human health Impact	12
Accessibility	13	Accessibility	13	Consumer cost	13	Consumer cost	13	Accessibility	13

6. CONCLUSION

In conclusion, the DEMATEL approach and sensitivity analysis have been used to identify and prioritize the most important sustainability factors in public transportation in the twin cities. The results of the analysis indicate that air pollution is the most important parameter of environmental sustainability concerning the transportation system of twin cities. The sensitivity analysis confirms that the key sustainability factors identified in the DEMATEL analysis are robust and consistent across different scenarios.

The DEMATEL approach has divided sustainability factors into two groups: the influential or causal group, which includes factors that have the greatest influence on public transportation sustainability, and the effect or influenced group, which includes factors that are affected by the factors in the influential group. By understanding the relationship between these two groups of factors, it is possible to identify and prioritize the most important sustainability factors in public transportation.

The second highest value is observed for road accidents which means accidents on the roadway have a high impact on economic sustainability. Other parameters like Infrastructure of transportation, fairness, Affordability, Aesthetics of Public transportation, Noise pollution, and Water pollution are also root-causing factors that should be considered while dealing with the sustainability of public transportation.

In summary, this research has demonstrated the importance of identifying and prioritizing key sustainability factors in public transportation. The DEMATEL approach and sensitivity analysis have been used to identify and prioritize the most important sustainability factors in public transportation in twin cities. The results of this analysis indicate that air pollution is the most important parameter of environmental sustainability concerning the transportation system of twin cities and that the promotion of public transportation is key to reducing air pollution in the transportation sector. The results are robust and consistent across different scenarios, making them useful for decision-making and planning in the transportation sector.

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APPENDIX

APPENDIX A: Questionnaire for Survey

What is your gender?

Give a short Introduction about your designation.

Accessibility

1. Waiting time is reasonable for public transport in twin cities.
2. Public transport mostly operates on a schedule.
3. The number of departures is reasonable.
4. The ticketing price is reasonable.
5. Do you normally get a seat on the bus?
6. Is transfer easy from one transit to another?
7. Do you have access to the closest point of the bus terminal?
8. Do you get any information about any critical situation?
9. Do you get any information on the bus stop?
10. Traveling by public transport is comfortable?
11. Modern trains and buses are available.
12. Public transport provides value for your money.

Traffic Congestion

13. Do you feel unsafe on any part of the journey?
14. how long it takes to get to work or any desired destination due to traffic congestion?
15. How long does it take to travel to work in rare cases of traffic?
16. Traffic congestion significantly affects productivity.
17. How frequently do you experience traffic congestion?
18. Would you say that in comparison to five years ago, traffic congestion has improved or remained the same?
19. Do you anticipate that traffic congestion will worsen, improve, or remain roughly the same over the next five years?
20. Is using a cell phone while driving in Pakistan a common activity?

Equity

21. There is a good number of seat availability in public transport.
22. Public Transport has stability in traveling.
23. Wait time for service is reasonable.
24. Satisfaction level for driver's attitude.
25. Entering and exiting is easy.
26. Internal temperature is reliable.
27. Stops are too far from the destination.

28. Travel reliability and time (Public transport has tardy services and takes too much time).
29. Satisfaction level of condition of buses and bus stops.
30. People with disabilities prefer to get a seat.
31. Do you feel secure in transit?
32. Is there any gender discrimination by the driver?

Human Health Impact

33. Air pollution and noise pollution due to transportation have a great impact on human health.
34. The transportation system of twin cities is sustainable.
35. Toxic emission of gases has a prominent effect on health.
36. Old engine buses are still using inside the city which cause serious health issues.
37. Metro bus services and green bus services are hygienic which makes travel comfortable and healthy.
38. The town planning of Rawalpindi is one of the important reasons for health problems due to congested roads.
39. Public transportation operators comply with government-issued standard operating procedures.
40. In Rawalpindi and Islamabad transportation is the main cause of haze.
41. Can you notice haze when occur?

Community Cohesion and livability

42. Do you believe people from different backgrounds gets on well together in their local area?
43. There are meaningful interactions with people from different backgrounds in the public transport of twin cities.
44. Accessibility and cost of transportation are less for less fortunate individuals (such as those without cars and those with low incomes) in comparison to more fortunate individuals in twin cities.
45. Children and older people can travel independently on public transport.
46. Perception of the impact of increased cultural diversity. But there is no such kind of diversity in Pakistan.
47. Perception of the impact of increased connection with neighbors, when you will use the same bus and same stop.
48. There is religious, caste, and ethnic discrimination in Pakistan.
49. In a livable community, people can safely go for a walk or ride a bike or can travel on public transport.

APPENDIX B: Input of five respondents for DEMATEL Analysis

Respondent 1

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13
A1	0	3	2	1	3	0	0	1	0	3	3	3	1
A2	3	0	2	3	0	0	2	1	0	1	1	1	0
A3	3	2	0	2	2	0	2	1	3	3	2	2	0
A4	2	3	3	0	1	2	2	0	2	2	0	0	0
A5	3	3	3	0	0	1	1	3	1	3	1	1	1
A6	1	3	1	2	0	0	2	3	2	1	1	0	0
A7	3	3	2	2	1	3	0	1	1	1	0	0	0
A8	3	1	1	0	3	2	1	0	1	0	2	1	1
A9	3	2	1	1	1	3	2	1	0	1	1	1	0
A10	3	3	3	3	1	2	2	1	3	0	1	1	0
A11	3	1	1	0	0	0	0	3	1	3	0	0	0
A12	3	1	0	1	0	0	0	3	2	2	0	0	0
A13	3	2	1	0	1	0	1	3	1	3	0	0	0

Respondent 2

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13
A1	0	3	2	2	3	1	1	3	0	3	3	3	1
A2	3	0	2	2	0	2	2	2	1	1	1	1	0
A3	3	2	0	3	2	3	2	1	3	2	2	2	0
A4	1	3	3	0	1	3	2	0	3	2	0	0	0
A5	3	3	3	2	0	1	1	3	1	3	2	2	1
A6	1	3	2	3	0	0	3	3	2	1	1	0	0
A7	3	3	2	3	1	3	0	1	3	2	1	1	1
A8	2	1	1	0	3	0	1	0	1	0	2	1	1
A9	1	3	2	2	1	3	2	1	0	1	1	1	0
A10	3	3	3	3	1	2	2	1	3	0	1	1	1
A11	3	1	1	0	2	0	0	3	1	3	0	0	0
A12	3	1	0	1	0	0	0	3	2	2	0	0	0
A13	3	2	1	0	1	0	1	3	1	2	0	0	0

Respondent 3

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13
A1	0	2	2	2	3	1	1	3	0	3	3	3	2
A2	3	0	2	2	0	2	2	2	1	1	1	1	0
A3	3	2	0	3	2	3	2	1	3	2	2	1	0
A4	1	3	3	0	1	3	2	0	3	2	0	0	0
A5	3	3	3	2	0	1	1	3	1	3	2	2	1
A6	1	3	2	3	0	0	3	3	2	1	1	0	0
A7	3	3	2	2	1	3	0	1	2	2	1	1	1
A8	2	1	1	0	3	0	1	0	1	0	2	1	1
A9	1	3	2	2	1	3	2	1	0	1	1	1	0
A10	3	3	3	3	1	2	2	1	3	0	1	1	1
A11	2	1	1	0	2	0	0	3	1	3	0	0	0
A12	3	1	0	1	0	0	0	3	2	2	0	0	0
A13	3	2	1	0	1	0	1	3	1	2	0	0	0

Respondent 4													
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13
A1	0	3	2	3	3	0	1	3	1	2	3	3	2
A2	3	0	2	2	0	2	2	2	1	1	1	1	0
A3	3	2	0	3	2	2	2	1	3	2	2	1	0
A4	1	3	3	0	1	2	2	0	3	2	0	0	0
A5	3	3	3	2	0	1	1	2	1	3	2	2	1
A6	1	3	2	3	0	0	3	3	2	1	1	0	0
A7	3	3	2	2	1	3	0	1	2	2	1	1	1
A8	2	1	1	0	3	0	1	0	1	0	2	1	1
A9	1	3	2	2	1	3	2	1	0	1	1	1	0
A10	3	3	3	3	1	2	2	1	3	0	1	1	1
A11	2	1	1	0	2	0	0	3	1	3	0	0	0
A12	3	1	0	1	0	0	0	3	2	2	0	0	0
A13	3	2	1	0	1	0	1	3	1	2	0	0	0

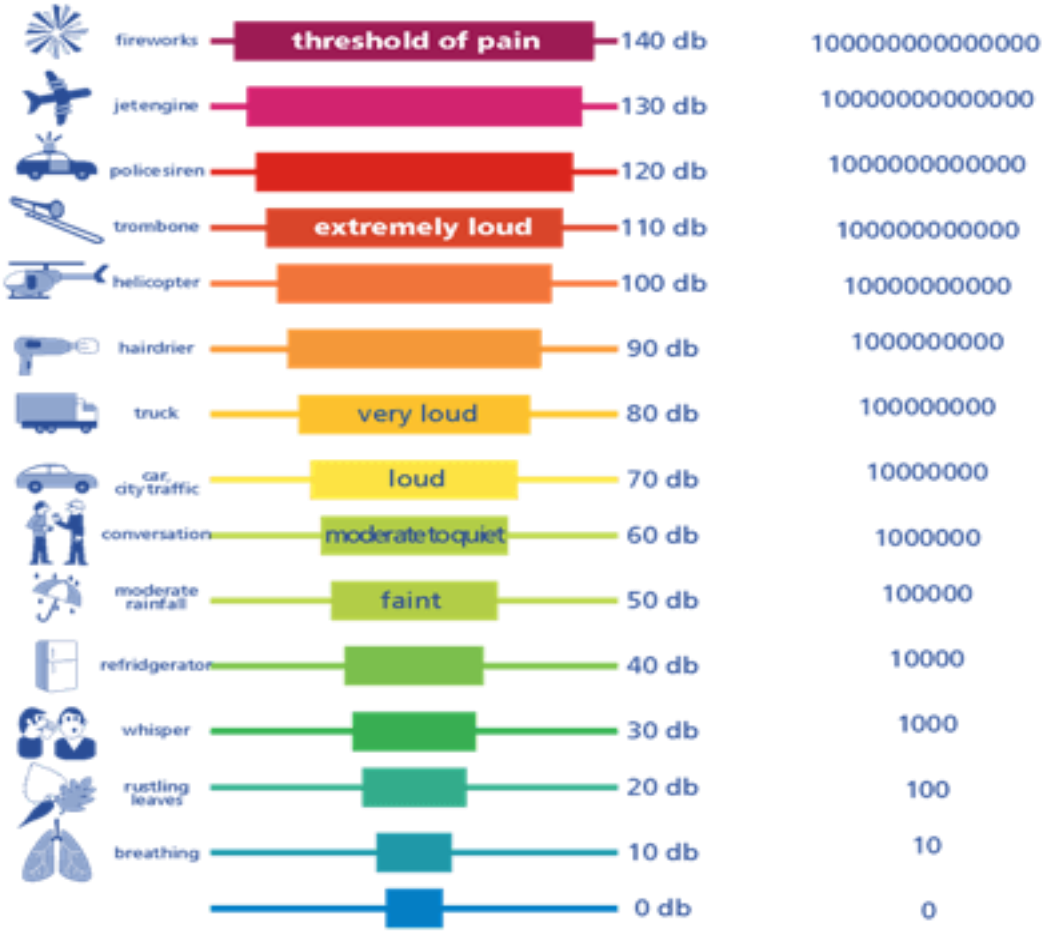
Respondent 5													
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13
A1	0	3	2	2	3	2	2	2	1	3	3	2	2
A2	2	0	2	1	1	2	1	2	2	1	1	2	1
A3	3	2	0	1	2	1	1	2	1	3	2	1	2
A4	0	1	1	0	0	2	2	1	2	1	0	0	0
A5	3	1	2	1	0	1	1	2	2	1	1	1	1
A6	1	2	3	3	2	0	1	2	2	1	2	1	1
A7	2	2	1	2	1	2	0	1	2	2	1	2	2
A8	2	1	1	2	2	1	2	0	2	1	2	1	2
A9	1	1	2	2	2	1	2	1	0	2	2	2	2
A10	2	2	2	1	1	2	1	3	2	0	1	3	3
A11	3	2	2	1	3	2	2	3	2	3	0	2	3
A12	3	3	2	2	3	1	1	3	3	2	2	0	1
A13	2	1	3	1	2	1	1	2	2	2	2	2	0

APPENDIX C: Standards for AQI parameters

Daily AQI color	Level of Concern	Value of Index	Description of air quality
Green	Good	0-50	Air pollution presents minimal to no risk, and the quality of the air is adequate.
Yellow	Moderate	51-100	The air is in good condition. But for some people, especially those who have very high sensitivity to air pollution, there might be a risk.
Orange	Unhealthy for sensitive group	101-150	Sensitive group members may experience negative health effects. It is less likely that the general public will be impacted.
Red	Unhealthy	151-200	Health consequences may be felt by some members of the general public; more severe health effects may be felt by members of sensitive groups.
Purple	Very unhealthy	201-300	Health warning: Everyone now faces a higher risk of negative health repercussions.
Maroon	Hazardous	301 to higher	Everyone is more likely to be impacted by emergency conditions, according to the health warning.

Source: AQI Application

APPENDIX D: Standards of noise pollution for different objects



Source:(Jariwala et al., 2017)

APPENDIX E: Panjab environment quality standards for noise level

No.	Category of area	Limits in dB	
		Day time	Night time
1	Residential Area	65	50
2	Commercial Area	70	60
3	Industrial Area	80	75
4	Silence zone	55	45

Source: (Kalim et al., 2014)

APPENDIX F: National environment quality standards (NEQS) for noise level

No.	Category of area	Limits in dB	
		Day time	**Night time**
1	Residential Area	55	45
2	Commercial Area	65	55
3	Industrial Area	75	65
4	Silence zone	50	45

Source: (Kalim et al., 2014)

APPENDIX G: List of respondents selected for the interview

Respondent 1	Age:50 Gender: Male Designation: Divisional Officer PWD
Respondent 2	Age: 32 Gender: Male Designation: Executive Engineer PWD
Respondent 3	Age: 34 Gender: Male Designation: Assistant Professor Department of transportation engineering
Respondent 4	Age:44 Gender: Male Designation: Professor Department of transportation engineering, NUST
Respondent 5	Age: 32 Gender: Male Designation: Assistant Professor Department of transportation engineering

APPENDIX H: Average response Matrix

X=Average Response Matrix

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13
A1	0	3	3	1	3	1	3	2	1	3	3	3	3
A2	3	0	2	3	3	3	3	1	2	3	1	1	2
A3	2	2	0	3	3	2	2	1	2	3	1	0	1
A4	2	2	2	0	1	3	2	0	2	3	0	1	0
A5	3	0	2	1	0	0	1	3	1	1	2	1	1
A6	1	2	2	2	1	0	3	1	3	2	0	0	0
A7	1	2	2	2	1	2	0	1	2	2	0	0	1
A8	2	2	1	0	3	3	1	0	1	1	3	3	3
A9	0	1	3	3	1	2	2	1	0	3	1	2	1
A10	2.8	1	2.4	1.8	2.6	1	1.8	0.2	1.2	0	3	2	2.2
A11	3	1	2	0	1.6	1.2	0.8	2	1.2	1	0	0.4	0.4
A12	2.8	1.2	1.4	0	1.6	0.2	1	1	1.2	1.4	0.4	0	0.4
A13	1.6	0.2	0.4	0	1	0.2	1	1.2	0.4	1.2	0.6	0.2	0

APPENDIX I: Results of sensitivity analysis under five different scenarios

Factors	Case 5			Case 4			Case 3			Case 2			Case 1		
	R	Ri-Ci	Ri+Ci	R	Ri-Ci	Ri+Ci	R	Ri-Ci	Ri+Ci	R	Ri-Ci	Ri+Ci	R	Ri-Ci	Ri+Ci
A1	9.00	-0.22	6.41	11.00	-1.73	-13.25	11.00	-1.63	-12.88	11.00	-0.39	5.49	11.00	-0.46	4.95
A2	13.00	-1.01	5.31	10.00	-1.13	-9.80	10.00	-1.15	-9.54	13.00	-0.96	4.53	13.00	-0.96	4.13
A3	8.00	0.11	5.64	5.00	3.91	-11.02	5.00	3.81	-10.75	8.00	0.13	4.79	6.00	0.13	4.33
A4	11.00	-0.54	4.49	13.00	-3.54	-7.35	13.00	-3.54	-7.19	10.00	-0.37	3.82	10.00	-0.22	3.57
A5	2.00	0.59	4.93	4.00	3.94	-10.17	4.00	3.88	-9.98	2.00	0.55	4.14	2.00	0.67	3.72
A6	7.00	0.17	4.55	2.00	4.46	-7.59	2.00	4.34	-7.44	7.00	0.16	3.77	5.00	0.14	3.33
A7	3.00	0.50	4.82	3.00	4.08	-9.33	3.00	3.88	-9.01	3.00	0.43	4.04	3.00	0.38	3.63
A8	12.00	-0.88	4.74	9.00	-0.64	-9.84	9.00	-0.64	-9.63	12.00	-0.69	4.00	12.00	-0.65	3.49
A9	10.00	-0.26	4.88	12.00	-2.88	-8.90	12.00	-2.85	-8.67	9.00	-0.18	4.08	9.00	-0.14	3.59
A10	4.00	0.25	5.58	7.00	2.97	-11.79	8.00	2.89	-11.55	4.00	0.19	4.78	4.00	0.22	4.32
A11	6.00	0.24	4.29	6.00	3.22	-7.30	6.00	3.09	-7.07	5.00	0.17	3.54	8.00	0.01	2.90
A12	5.00	0.25	3.83	8.00	2.95	-6.70	7.00	2.91	-6.54	6.00	0.16	3.17	7.00	0.06	2.55
A13	1.00	0.81	3.35	1.00	34.18	-44.68	1.00	33.32	-43.60	1.00	0.82	2.69	1.00	0.84	2.14