CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Sustainable Urban Expansion of Faisalabad and Rawalpindi Using Analytical Hierarchy Process and Geographic Information System

by

Shahzaib

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This humble effort is dedicated to

My Mother, Brother, and My Best Friend

For their belief in me and their continuous support

My Supervisor

For his guidance and support

CERTIFICATE OF APPROVAL

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(Shahzaib)

Abstract

As urbanization continues to reshape the global landscape, cities are facing the complex challenge of accommodating rapidly growing infrastructure while ensuring sustainability and resilience. This study investigates the dynamics of urban development by focusing on two metropolitan districts of Pakistan, Faisalabad and Rawalpindi. The main aim is to map suitable areas for their future expansion while ensuring sustainability and preserving the environment. The objective of this research is to recognize the challenges such as haphazard growth, and unplanned urbanization, and address them with logical and economical solutions. The urban transformation is rapid and Faisalabad and Rawalpindi are leading the way in this transformation. Six criteria are selected for mapping sustainable urban growth: population proximity, road network proximity, land value, proximity to built-up areas, proximity to water bodies, and Hazard proximity.

The scientific tools employed for mapping the suitable areas for expansion are the Analytical Hierarchy Process (AHP) and the Geographic Information Systems (GIS). AHP is used to logically assign priority weights showing the relative importance of each selected criterion while GIS serves as the mapping tool for visualizing spatial datasets considered in the study. The findings reveal that among the selected six criteria, the Road Network proximity carries the highest weight of 40.3% since it is what initiates urbanization, whereas Land use has the lowest weight of 2.7% due to flexibility in its nature as it can be altered easily. The overlay tool of GIS integrates the priority weights with the datasets of the criteria which generated the suitability maps of both districts. These suitability maps underscore the importance of preserving green spaces and conserving the distinct character of Faisalabad and Rawalpindi. The results propose that 28% area of Faisalabad district and 23% area of Rawalpindi district within existing boundaries can be used for future sustainable urbanization. The results are validated through google maps due to economical constraints.

It is observed that the highly suitable areas are predominantly clustered within existing urban cores and along well-connected transportation networks, serving as nuclei of potential urban growth. These suitability maps recommend that this study could serve as a strategic blueprint for urbanization, guiding sustainable development initiatives toward sustainability. The study holds the potential to guide policymakers, planners, and stakeholders in fostering sustainable urban growth deciding what type of construction and utilities are best, ensuring livable, inclusive, and environmentally responsible cities for current and future generations.

Key Words: Multi-Criteria Decision Models, Analytical Hierarchy Process (AHP), Geographical Information System (GIS), Sustainable Urbanization, Suitability maps.

Contents

List of Figures

List of Tables

Abbreviations

AHP	Analytic Hierarchy Process
C.I	Consistency Index
C.R	Consistency Ratio
GIS	Geographic Information System
LULC	Land Use and Land Cover
MCDM	Multi Criteria Decision Model
MCDA	Multi Criteria Decision Analysis
RI	Random Index

Chapter 1

Introduction

1.1 Background

Urbanization is the phenomenon of people moving from rural to urban regions, leading to the expansion and development of cities. This process encompasses alterations in land utilization, the establishment of infrastructure, and socio-economic shifts. It has impacts on the environment and agriculture as well. Substantial and forceful urban growth in urbanization is happening globally, primarily driven by factors such as industrialization, population increase, economic progress, and migration in pursuit of an improved life [1]. Urban expansion is a defining characteristic of the 21st century, driven by population growth, economic development, and changing societal needs. As cities worldwide grapple with the challenges of accommodating their expanding populations, finding suitable areas for future growth has become a paramount concern for urban planners, policymakers, and researchers. A thorough understanding of trends in urbanization and infrastructure development leads to discovering multiple social, environmental, and economic factors that can have long lasting results [2]. Identifying and mapping suitable areas for future urban growth complying with the current trends is important for directing development in the right direction [3]. Sustainable development is more important for the areas which are facing environmental threats due to urbanization and are more prone to overpopulation [4]. The United Nations (UN) defined 17 SDGs known as Sustainable Development Goals which are set to be achieved by the end of year 2030 [5]. The development of sustainable cities is one of the most important among the 17 SDGs [4].

Although, geospatial data for all defined SDGs can not be obtained but utilization of geospatial tools, such as GIS and RS, can assist in achieving various sustainable development goals [6]. Combining Remote Sensing with GIS is a powerful and efficient tool which has the potential to be used for developing urbanization within the economic limits [7]. Thoroughly analyzing and appraising current urban development and sprawl patterns can provide fundamental data for sustainable development. The data can be effectively utilized for future urbanization and for protection and management [8] for major Pakistani districts (Rawalpindi and Faisalabad). This study is an initiative of a small effort for sustainable urbanization of Rawalpindi which is a major metropolitan district and Faisalabad which is the industrial hub. The outcome of this research holds significant importance when it comes to regional planning and sustainable urbanization. It is the time when the authorities of these two districts need to face the challenges of overpopulation, and unplanned geographical growth. Policymakers can employ this study as a reference for the identification of the current trends in urban settlement, It will assist them in making effective policies to direct better land use in the long run. Not only sustainable expansion but smart and green cities can be built based on these policies and decisions.

1.2 Research Motivation and Problem Statement

Pakistan, as a developing country, grapples with a fragile economy and constrained natural resources. Its cities encounter significant energy crises and congestion due to the rapid population growth. The metropolitan districts, like Rawalpindi and Faisalabad, are challenged with uncontrolled and unplanned urbanization and have attracted millions of immigrants which led to problems related to housing, food, and natural disasters [9]. Every monsoon season, Pakistan faces huge flood destruction, and thousands of people are forced to migrate and left homeless. With the help of advanced technology, potential sites for natural disasters can be predicted to avoid and prepare against natural disasters. Therefore it is important to plan future settlements carefully and expand the current cities based on challenges. So, the problem statement for the study can be formulated as follows.

"Sustainable Urban development is relatively a new concept. Growth and development in urban areas have been increasing at a rapid rate for a few decades. Unplanned growth in urbanization is a challenge for a country's economy and resources. The current urbanization trends in Pakistan are alarming due to its haphazard and unplanned nature. With limited resources, Pakistan has not been able to address the issue of controlled and monitored regional expansions. The city and regional growth need to be controlled and planned carefully using innovative statistical methods and technological use."

1.3 Novelty

The novelty of this study lies in the fact that the integration of AHP and GIS has not been applied in the field of urban expansion in Pakistan. It has been applied in other countries but the criteria considered were mostly social to have a better impact on social life. A combination of AHP and GIS has found application in diverse countries. Its application in Pakistan is found in the mapping of soil erosion, and suitable sites for installing solar farms and dam sites.

1.4 Research Questions

- How can AHP be effectively integrated with GIS for urban expansion suitability mapping?
- What key criteria can be employed to map potential locations for infrastructure development?
- What are the future potential sites for urban expansion in the districts of Rawalpindi and Faisalabad?
- Is the integration of GIS with AHP technique an effective tool for city and urban growth?

1.5 Objective and Specific Aim

This study targets to identify suitable sites for future expansion using the key indicators. Obtaining suitability maps for future development and urban expansion by the wise and precise use of available resources and GIS is the foundation of this study.

"The specific aim of this MS Thesis is to map the characterized areas for the best suitability for their use for future settlements. It will help in expanding cities while meeting basic needs like safety, amenities, and transportation which is beneficial in the long run for creating green and smart urban areas"

1.6 Scope of Work and Study Limitation

After obtaining the datasets from the data sources listed in Table 1.1, the chosen criteria for the selected districts are examined. Ultimately, a suitability map for Future Urban development is generated for each district. This study, while insightful, must be viewed within the context of certain limitations that affect its ability to be fully substantiated in real-world scenarios. One primary limitation lies in the absence of sufficient resources and data for rigorous validation in practical settings. Due to a lack of access to comprehensive datasets, and limited resources, the validation of results is done through Google Maps.

Although AHP has no limit when it comes to dealing with a great number of multiple criteria, the dataset used in this research pertains primarily to the broader course level rather than offering a microscopic view of specific local ground conditions. This study is limited to only six criteria: Population proximity, Proximity to Road network, Land Value, Built-up areas proximity also referred to as proximity to developed areas, Proximity to water bodies, and hazards proximity.

In essence, this study serves as a valuable starting point and provides valuable insights into potential avenues for urban development and land utilization. However, its ultimate applicability and effectiveness in practical contexts will hinge on future efforts to obtain and incorporate more localized and detailed datasets.

1.7 Brief Methodology

Various criteria deemed crucial for urban development are chosen through a review of literature and recommendations from urban planners, as illustrated in Figure 1.1. The datasets are then gathered from specified sources, with Table 1.1 outlining the selected criteria for future urban development in the study area along with their respective dataset sources. The AHP method is applied to prioritize these criteria, and the ArcGIS weighted overlay tool is employed to analyze the integrated datasets based on AHP weights. Ultimately, the results are presented as a suitability map for future urban development, based on the selected criteria.

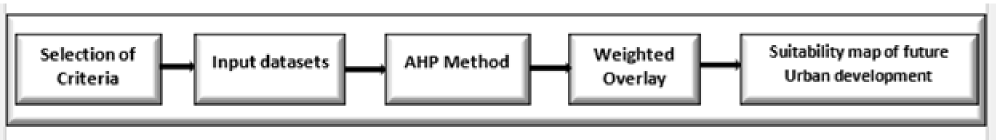

FIGURE 1.1: Brief Methodology

TABLE 1.1: Urban Expansion Criteria and Dataset Sources

Sr.	Criteria	Source of Data
1	Population proximity	WorldPop datasets
2	Road network proximity	OpenStreetMaps
3	Land Value	USGS Global Landuse dataset
4	Proximity to Built-Up areas	USGS Global Landuse dataset
5	Proximity to water bodies	OpenStreetMaps
6	Proximity to Hazard (Flood and Earthquake)	Geological Survey of Pakistan

1.8 Thesis Layout

There are 5 chapters in this study, each chapter serving a specific purpose. These chapters are designated as follows: Introduction, Literature, Research Methodology, Results and Analysis, and Discussion with Conclusion with Future Recommendations.

Chapter 1: This chapter gives a concise overview of the study, covering the research motivation, problem statement, ultimate goal, specific research aims, scope of work, novelty, and limitations. Additionally, it briefly touches upon the selected research methodology.

Chapter 2: This chapter covers a literature review, which consists of the most relevant studies, sustainability in regional and urban planning, and changes in land use and environment due to urbanization. Long-lasting construction based on accurate identification of sites is discussed in this chapter as well. This section introduces cutting-edge methods and tools for assessing urban growth and changes in land use related to urbanization. Additionally, it outlines the chosen vital criteria that hold particular relevance to urban development.

Chapter 3: Details the Study Area and the adopted research methodology, including data set collection within the study area. This chapter discusses various available techniques and methods, justifying the preference for the chosen approach.

Chapter 4: Provides an explanation of the results and analysis derived from the employed methodology. The suitability maps are presented with an explanation of potential urbanization sites. Validation of results is also discussed in this chapter.

Chapter 5: Summarizes all preceding chapters. Based on the research, this chapter provides recommendations for future studies. It also guides local authorities to address and minimize the urbanization impacts.

Chapter 2

Literature Review

2.1 Background

Urbanization means the concentration of people in a relatively small area [10]. It is driven by various factors, including large-scale migrations from rural to urban areas, rapid industrialization, and a rapidly growing population [11]. These elements underscore the importance of effective urban planning. The global trend toward urban living has resulted in 50% of the world's population residing in well-developed and urban and regions [12]. While the rural-to-urban area's shift has both positive and negative impacts, it has presented environmental as well as socio-economic challenges for urban authorities [13]. The conversion of fertile agricultural regions into housing and infrastructure developments, often due to inadequate urban management, is contributing to these challenges, placing additional strain on our existing resources. By fostering compact, efficient cities and promoting green infrastructure, we can mitigate the negative impacts of urban sprawl and ensure a healthier, more resilient future for generations to come.

2.2 Global Urbanization Trends and Challenges

In cities across the world, both industrial and metropolitan, there's a shared story of facing formidable challenges as rapid urban growth and urbanization sweep

through [14]. The migration of people from rural areas into cities in pursuit of better opportunities and a higher quality of life has brought about a slew of pressing issues. Cities are bursting at point of junctions, their infrastructure straining under the weight of a burgeoning population, and housing becoming increasingly scarce. This has led to the emergence of informal settlements and a lack of essential urban services, impacting public health, sanitation, and safety [15].
Moreover, the surge in industrial activities within these urban centers is generating environmental problems like pollution, congestion, and resource depletion. Striking a balance between economic growth and sustainable development is a complex task, demanding creative urban planning, substantial investment in infrastructure, and equitable resource distribution [16]. Solving these issues is not just about the well-being of city dwellers; it's also critical for global sustainability. These cities are economic powerhouses, but they also contribute significantly to greenhouse gas emissions [17]. Therefore, finding holistic solutions that prioritize urban populations' welfare while nurturing sustainable urban development is an urgent challenge for governments, urban planners, and communities worldwide.

2.3 Urbanization Challenges in Pakistan

Though urbanization is a global phenomenon reshaping the world's socio-economic landscape, nowhere is this transformation more prominent than in Pakistan. This influx places immense pressure on urban infrastructure, housing, and essential services, leading to overcrowding and inadequate living conditions in many urban areas. It is a country experiencing rapid urbanization driven by factors such as population growth, industrialization, and rural-to-urban migration [18]. Exploration of the complicated challenges posed by urbanization in Pakistan is crucial to understanding the growth trends. By examining existing research and studies, we seek to understand and explain the complexities of urbanization and address this issue with technological use.

Rural-to-urban migration is a defining feature of Pakistan's urbanization. Pull factors, including employment opportunities and better living conditions, draw people to cities, resulting in rapid urban population growth [19]. However, this influx places immense pressure on urban infrastructure, housing, and essential services, leading to overcrowding and inadequate living conditions in many urban areas. Moreover, this migration has led to the multiplication of informal settlements, commonly known as slums or katchi abadis [20]. These settlements lack basic amenities like clean water, sanitation, and healthcare, making residents vulnerable to eviction and displacement.

The concentration of industrial activities and transportation networks in urban areas contributes to pollution, congestion, and resource depletion[21]. Urban areas are vulnerable to extreme weather events, including floods and heatwaves, which are exacerbated by climate change[22]. Developing climate-resilient infrastructure and disaster preparedness strategies is essential for safeguarding urban populations. It is a country experiencing rapid urbanization driven by factors such as population growth, industrialization, and rural-to-urban migration

Urbanization in Pakistan presents both opportunities and challenges. While cities serve as engines of economic growth and innovation, they also face complex issues related to population growth, infrastructure deficits, housing shortages, environmental degradation, and socioeconomic disparities. Addressing these challenges requires a holistic approach that integrates sustainable urban planning, policy interventions, and community engagement. With careful planning and effective governance, Pakistan can harness the potential of urbanization to create vibrant, inclusive, and sustainable cities for its growing population.

2.4 Urbanization and its Impacts

Urbanization profoundly affects agriculture and the environment. The influence of urbanization on construction and precipitation intensity is evident in Figure 2.1, as demonstrated in a case study of China by Tian et al. in 2022. Interestingly, urbanization not only increases the land use for construction but also tends to increase the precipitation in these urban areas. It is essential to proactively forecast the impact of urbanization and predict precipitation to avoid the risk of flooding. Figure 2.1 shows that the precipitation intensity has increased from 15 mm/hr to 65 mm/hr due to the increment of constructed land from 15 km^2 to about 400

km^2 from the year 1985 to 2020. Such drastic changes are the primary source of urban hazards like flooding. It clearly shows that the population tends to move to urban areas.

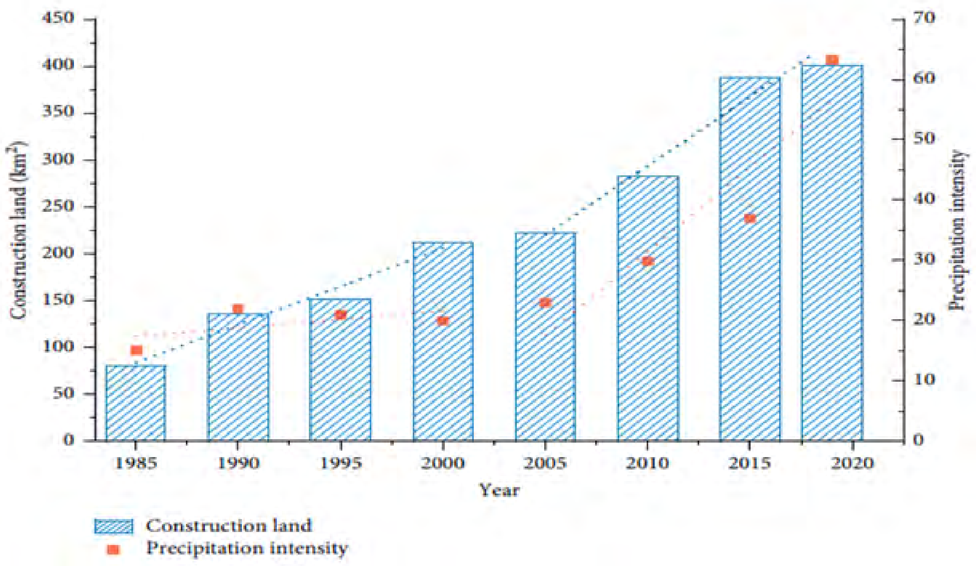

FIGURE 2.1: Urbanization and Precipitation Trends [23]

The acceleration of urbanization is consistently linked to rapid economic growth, primarily driven by population expansion [24]. This phenomenon has raised significant concerns about climate change [25]. Urbanization encompasses activities and such as deforestation, the clearing of natural vegetation for residential, industrial, road, and infrastructure development, all of which result from the migration of people from rural to urban areas [26]. Figure 2.2 illustrates the population increase both in urban and rural regions in Pakistan between 2005 and 2020. The urban population increased from 55 million to 80 million from the year 2005 to 2020. It clearly shows that the population tends to move to urban areas. The tendency to move to urban areas creates a need to address urban challenges and growth potential. An increase in population directly causes urbanization and alterations in land use and land cover (LULC) which profoundly impact local climate, rain cycle, floodplain dynamics, and environmental sustainability [27]. The rapidity with which these transformations are occurring worldwide in recent years is a source of concern. According to research conducted by the World Bank in 2007, developing countries are expected to host the majority of the world's mega cities by 2020. Urbanization converts previously unpaved rural areas, natural wetlands, and agricultural plains into impermeable urban zones [28].

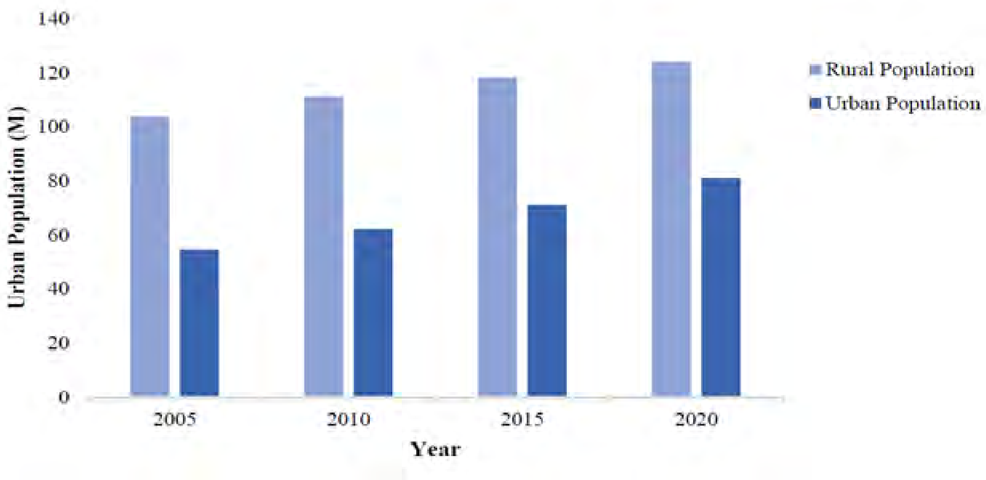

FIGURE 2.2: Urbanization Trend in Pakistan[29]

As urban areas grow, they frequently infringe upon agricultural lands, leading to the depletion of fertile soil and a decline in agricultural productivity. This trend has sparked concerns about food security and the sustainable fulfillment of the increasing needs of urban populations. Urbanization, marked by the shifting of agricultural regions into developed areas, contributes to the loss of fertile soil and farmland, impacting global food production and supply chains [30]. The expansion of urban areas diminishes arable land availability, affecting local and regional food production [31].

The rapid and unplanned growth of urban areas adversely affects suburban residents and their environment, posing challenges like an increase in population density, insufficient infrastructure along limited access to basic amenities. This results in affecting the quality of life well-being of urban communities. They rely on long-distance transportation and food imports, leading to carbon emissions and reduced food availability [32]. Water resources are also stressed due to urbanization. It leads to increased demand for water for domestic, industrial, and agricultural needs.

The water infiltration is being constantly reduced due to impervious surfaces in urban areas, causing increased surface runoffs leading to floods and decreased groundwater recharge [33]. Dealing with the influence of urbanization on agriculture requires essential strategies for building sustainable and smart cities. These strategies encompass land-use planning, zoning regulations, and the encouragement of urban and peri-urban farming. Urbanization alters hydrological processes, affecting patterns of stream flow, increasing flood risk, and reducing base flow in rivers [34]. Incorporating nature-based solutions and green infrastructure into urban planning improves resilience and helps alleviate climate risks [35]. Green building practices, energy efficient design, and sustainable construction materials are essential for sustainable urban development.

Implementing efficient transportation systems that encourage the use of public transportation, walking, and cycling can alleviate congestion, reduce air pollution, and decrease carbon emissions linked to urbanization. Empowering local communities and considering them as stakeholders in urban planning promotes social cohesion and aligns development initiatives with community requirements [36].

Despite its importance, urban development, especially in developing countries like Pakistan with limited resources, has not received adequate attention. This thesis employs Multi-Criteria Evaluation to map areas that has potential for future urban expansion, in Faisalabad and Rawalpindi.

2.5 Techniques for Sustainable Urbanization

Various techniques, including City Works (CW), Geographical Information System (GIS), Satellite images, Remote Sensing (RS), Transit-Oriented Development (TOD), and Multi-Criteria Decision Methods (MCDMs), can be employed for sustainable urbanization [37]. TOD supports the development of communities that are compact and diverse and located near public transportation centers [38]. By promoting walking, cycling, and the use of public transit options TOD helps reduce dependence, on vehicles, which in turn helps alleviate traffic congestion and air pollution. A study conducted by wid across 50 cities of China in 2017 showed that TOD can be implemented with more ease in second and third-class cities as compared to first-class cities in the coming 5 years which shows the potential use of TOD for city development.

The field of City Works covers the development, building, and upkeep of infrastructure. When approached from a sustainability perspective it involves the creation of parks and green areas effective transportation networks and strong utility systems. Implementing practices, in City Works can result in decreased resource usage and limited harm to the environment [40]. Satellite images offer a perspective of cities helping us track changes, in land usage, urban expansion, and vegetation [41]. By examining these images city planners can pinpoint locations, for developing infrastructure and evaluate the success of sustainability efforts. Multiple studies have been conducted using satellite images for city growth. A recent study was conducted in December 2023 by Xi et al. on 100 most populated US Cities using 25 sustainable indicators among which built environment and population were dominating indicators.

Remote sensing is an addition, to satellite imagery as it provides in-depth data about environments. It allows for the monitoring of factors such as air and water quality, temperature, and the health of vegetation [43]. This information can be used by decision-makers to gain insights, into the environmental condition and make decisions regarding development practices. Pham et al. identified an unusual urban growth pattern in Hanoi city of China by using Remote sensing and relevant special metrics. This information is useful for urban planners to control this growth and mold it into a normal growth pattern like a spread-out pattern.

2.6 Decision Making Methods and Tools

Decision-making is a complex process encompassing intricate economic challenges. Various factors play a role, either independently or in coordination, simultaneously or at different points in time. These factors significantly influence the decision-making methods employed, all geared toward supporting and improving managerial decision quality [45]. Over time, the methods used in decision-making fluctuate in response to changing objectives, circumstances, and anticipated outcomes. Evolution in decision-making strategies closely mirrors societal, economic, and scientific advancements, with scientific progress being a particularly influential factor [46].

Decision-making methods can be categorized into two distinct groups: intuitive methods and analytical methods [47]. The difference between these two approaches is fundamental and substantial [48]. Inituative methods are inclined towards personal feelings and instincts while analytical methods involve using data, logic, and analysis to make decisions. Decision-makers must take these differences into account to ensure effective decision-making.

Analytical methods in decision-making exert a positive impact on outputs and their performance. Decisions rooted in these methods aim to generate valuable outputs while efficiently utilizing limited resources. Important strategic decisions need careful thought because they require figuring out the best combination of projects within the limits of the resources the organization has. [49].

Furthermore, the influence of economic management in decision-making is noteworthy. It is regarded as a legitimate means of managing and reporting project activities to achieve stable and predictable financial results [50]. Practically, decision-making can affect a multitude of factors that sometimes conflict with each other. This complexity poses challenges for administrators and decision-makers, especially when the decisions have far-reaching implications for the future [51]. Decision-making problems come in various forms, each presenting unique challenges. Some problems have multiple potential solutions, while others require evaluation against several criteria. Additionally, multiple potential future scenarios may demand distinct optimal solutions. This intricacy necessitates an extended evaluation phase in decision-making processes [52]. Decision makers often encounter complex decisions, typically involving numerous stakeholders and variables [53]. These decisions require consideration of various criteria, some of which may be non-quantifiable but nevertheless significant. Experience often guides the decision-making process, although it may introduce uncertainty, especially in larger organizations and mega projects with elevated risk factors and environmental challenges. Ultimately, the interplay between intuition and analysis is crucial in effective decision-making [54].

Many decision-making methods are being used for different natures of studies. TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is a decision-making tool that involves ranking the alternatives based on their proximity to the ideal solution [55]. The ideal solution is defined as the alternative that maximizes the benefits and minimizes the negative impacts of urban growth [56].

The distance between each alternative and the ideal solution is calculated, and the alternatives are ranked based on their proximity to the ideal solution. The TOPSIS method involves using a set of weights to assign importance to each criterion [57]. IN 2020, Nasution et al. used TOPSIS to study 10 cities on the Island of Sumatra and recommended one city as a potential smart city. Four criteria used for this study are population, infrastructure, area, and economic level.

In the context of urban growth, TOPSIS can be used to evaluate the potential impact of urban development on various factors such as land use, transportation, and environmental quality [59]. The alternatives are then ranked based on their preference score. The weights obtained from TOPSIS are used to judge each alternative and extract the ideal solution. The alternatives are then ranked based on their proximity to the ideal solution [60].

Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) is a decision-making tool that involves ranking the alternatives based on their preference score [61]. The preference score is calculated based on the difference between the positive and negative impact of each alternative on each criterion. The alternatives are then ranked based on their preference score. PROMETHEE can be used to evaluate the potential impact of urban development on various factors such as land use, transportation, and environmental quality [62]. The alternatives are ranked based on their preference score, with higher scores indicating better alternatives [63]. Ranjan et al. conducted a study in India using 10 criteria to evaluate the performance of 20 smart cities. This study provided the influence of each criterion on the ranking of the smart cities [64].

Remote sensing technology, such as satellite imagery and aerial photography, provides valuable data for assessing land cover, land use changes, vegetation, and land suitability. Remote sensing helps monitor urban growth patterns over time and assists in identifying suitable areas for expansion [65]. Machine learning algorithms, including regression models, clustering, and neural networks, can be employed to analyze historical data and predict future urban growth trends [66]. These models can identify areas at risk of urban sprawl or prioritize regions with high growth potential. Beyond GIS, spatial analysis techniques like spatial autocorrelation, hot spot analysis, and spatial interpolation are used to identify spatial patterns and trends in urban growth [67]. These methods help in pinpointing areas with suitable characteristics for development.

Urban simulation models, such as cellular automata and agent-based models, simulate how cities evolve and expand over time based on various factors like transportation networks, land use policies, and socioeconomic trends [68]. These models allow for scenario testing and predicting future growth patterns. Land suitability models assess the suitability of land based on specific criteria like soil quality, slope, drainage, and environmental sensitivity [69]. These models help planners determine which areas are best suited for different types of development, such as residential, commercial, or industrial. Environmental Impact Assessment (EIA) is a systematic process for evaluating the potential environmental consequences of development projects [70]. It helps identify areas where development may have adverse environmental effects and suggests mitigation measures. EIA is an overlooked instrument for sustainable development in Pakistan [71].

Involving the public and relevant stakeholders in decision-making processes is essential for gaining insights into local preferences, needs, and concerns [72]. Public participation can inform decisions about suitable areas for growth and promote community buy-in for development projects [73]. Transportation studies help ensure that new urban development integrates seamlessly with existing infrastructure [74]. Evaluating the capacity and condition of existing infrastructure and utilities, including water supply, sanitation, and energy, is vital for determining whether an area can support future growth [75]. Economic impact analysis considers the potential economic benefits and drawbacks of urban expansion [76]. It assesses factors like job creation, tax revenue, and economic diversification when identifying suitable growth areas.

2.7 Importance of Integrating AHP and GIS in Urban Expansion Planning

Integrating the Analytic Hierarchy Process (AHP) and Geographic Information System (GIS) in urban expansion planning brings several crucial advantages and contributes to more informed and effective decision-making [77]. By integrating AHP and GIS, urban expansion planning becomes more powerful, transparent, and contextually sensitive. This integration harnesses the strengths of both tools i.e. AHP and GIS, and provides a comprehensive framework for sustainable and well-informed urban development. The importance of this integration can be summarized as follows:

- AHP provides a structured framework for decision-making by considering multiple criteria and their relative importance.
- AHP's pairwise comparison process enables stakeholders and experts to assign weights to different criteria based on their relative importance. This ensures that the decision-making process is transparent, systematic, and based on a consensus-driven approach.
- GIS offers powerful spatial analysis capabilities that enable the integration and manipulation of diverse geospatial data. By incorporating GIS into the urban expansion planning process, planners can perform overlay analysis, proximity analysis, and suitability modeling to identify areas that align with the defined criteria for expansion.
- GIS provides visual representations of spatial data, allowing for better visualization and communication of planning outcomes.
- AHP-GIS integration offers flexibility and adaptability in the urban expansion planning process. As criteria weights or data inputs change, the methodology can be easily adjusted to reflect new priorities or evolving circumstances.

2.8 AHP and GIS Integration

Among various techniques, GIS as a spatial tool, is globally recognized for its ability to manage, and analyze extensive spatial datasets and their attributes related to thematic layers. Despite its power, when offering overlay maps, GIS is limited to deterministic analysis [78]. To address limitations, Multi-Criteria Evaluations have been integrated to yield comprehensive and realistic outputs [79]. According to Weerakoon, Multi-Criteria Decision Models gather information from multiple criteria for alternatives, aiming to explore various choices considering conflicting objectives [81]. The synergistic use of GIS and MCDMs has the potential to create a unique tool, converting geographical data into decision outcomes. This approach has been applied in Pakistan to map potential areas for green energy produced by solar and wind energy [82].

Several research studies have investigated urban area expansion and changes in land use and land cover (LULC). Raziq et al. examined urban area growth and LULC changes in Peshawar City in Khyber Pakhtunkhwa, noting exponential growth in built-up areas and a rapid decline in agricultural and barren land from 1999 to 2016 [83].To address limitations, Multi-Criteria Evaluations have been integrated to yield comprehensive and realistic outputs. Similarly, a study in Lahore, Punjab assessed urban sprawl using multi-stage remote sensing data [84]. Another study has analyzed urbanization and sprawl through remote sensing and GIS in Faisalabad [85], and monitored urban expansion while analyzing changes in land use in Lahore and Bahawalnagar. [86].

In Faisalabad, Safder and Babar disclosed that over a research period spanning 30 years from 1980 to 2010, there was a substantial transformation in the landscape. Specifically, the area designated as "built-up land" increased by 44 percent, while, non-built-up or open areas decreased by 32 percent within the same time frame. Notably, this significant expansion of built-up areas came at the expense of fertile agricultural zones that were formerly on the periphery of Faisalabad city. To address limitations, Multi-Criteria Evaluations have been integrated to yield comprehensive. In Sindh, the province of Pakistan Mahboob et al. studied urbanization in the past year's areas in Karachi. Similarly, Butt et al. conducted a research on the urban sprawl of Islamabad using data from multiple resources and periods. The research period for Islamabad was 38 years spanning from 1972 to 2009, showing a tremendous increase of 78.31 km^2 [88]. Quetta has also faced an increase of 27.1 km^2 from 1998 to 2018. Khan et al. also predicted that there would be a decrease of 3.86 km^2 and 2.7 km^2 in open spaces and green areas in the next 10 years i.e. 2018 to 2028 [89].

A notable trend in city and regional planning is the concept of smart green cities. With rapid technological advancements, the blended use of technologies such as data analytics, and the Internet of Things (IoT) is significantly feasible and attractive for urban authorities [90]. Technological advancements enhance the efficiency and quality of many urban services such as transportation, energy management, citizen engagement, and maintenance in Smart cities [91]. Smart cities aim to optimize resource allocation, through the use of real-time data and infrastructure [92]. Recognizing the significance of citizen involvement in decision-making, participatory planning prioritizes engaging a range of stakeholders to shape urban policies and projects [93]. The research underscores the value of inclusive planning approaches that foster collaboration and ensure equitable outcomes [94]. Recent literature in transportation planning emphasizes the need of integrated approaches that promote public transit, cycling infrastructure, and designs that are friendly towards pedestrians [95]. In the US, [96] determined that a 10% increase in the city's initial highways caused an increase of 1.5% in employment over the period of 20 years [96].

2.9 Selection and Prioritizing of Criteria

There is no limit on selecting a specific number of criteria in AHP. AHP allows to use of as many criteria as possible and Prioritizes them as per the assigned comparison-wise weights. Table 2.1 shows some of the most cited studies using the integration of AHP and GIS. Mapping of Soil erosion of the Chitral River is done using AHP and GIS using 9 criteria among which slope is the most dominating factor. This concluded that 13 % of the Chitral River faces very high soil erosion [97]. Suitability maps for amenities have also been generated using AHP and GIS for the region of Srinagar, India by Parry et al.. The number of criteria is limited to 13 in this study [98]. Urban growth of a city is not limited to a specific number of criteria. It can involve environmental, economic, and social factors. Research conducted by Mohammed et al. for Malaysia developed suitability maps for urbanization using five criteria. Road network proximity is slightly more important to Population proximity [100] [101]. Table 2.1 clearly shows that integration of AHP and GIS is the most commonly used technique for mapping whether it is soil erosion or sites for groundwater recharge. Due to its acceptance and wide use, the integration of AHP and GIS is most suited for this study. Especially for the challenging economy of Pakistan, this integration offers an economical solution.

TABLE 2.1: Literature on AHP and GIS Integration

Sr #	Criteria	Author	City/-Country	Tool	Weightage	Field Application	Total Criteria
1	Land Use	Aslam et al.	Chitral, Pakistan	AHP and GIS	16.87	Soil Erosion	9
2	Built-Up	Parry et al.	Srinagar, India	AHP and GIS	6.58	Suitability maps for amenities	13
3	Agricultural Areas	Akbulut et al.	Beykoz district, Istanbul	AHP and GIS	13.7	Sustainable urban and environmental planning	6
4	Land Availability	Chandio et al.	Larkana	AHP and GIS	-	Public Parks	45
5	Drainage Facility	Sayyadi and Awasthi	Montreal, Canada	AHP	15.7	Location planning for pedestrian zones	15
6	Access to public facilities	Lee and Chan	Hong Kong	AHP, Respondents, 3 groups	3.7	Assessment of Urban Renewal Proposal	18
7	Precipitation	Al-Ruzouq et al.	UAE	AHP and Fuzzy with AHP. Machine learning is incorporated at the end.	20	Dam Site Suitability	10
8	Distance from Road	Park et al.	South Korea	RS and GIS with Frequency Ratio, AHP, LR, and ANN Model	3.12	Prediction of Urban Growth	9
9	Proximity to water bodies	Mohammed et al.	Malaysia	AHP and GIS	23	Urban Development	5
10	Distance from Settlements	Günen	Kahramanmaras Turkey	AHP and GIS	-	Installation of Solar PV Farms	14

Chapter 3

Research Methodology

3.1 Background

This chapter presents the methodology employed to map suitable areas for future city growth, providing an overview of the key steps, data sources, and analytical tools utilized in this process. It serves as a bridge between the conceptualization of suitable areas for future city growth and the practical implementation of this concept. Mapping suitable areas for future city and regional growth is a multi-dimensional task that requires a combination of geospatial analysis, data integration, and decision support systems. By adopting a systematic and data-driven approach, urban planners and policymakers can make informed decisions about where and how to expand urban areas, ensuring that growth aligns with long-term goals of sustainability. The methodology for mapping suitable areas for future city growth encompasses several key components.

The process begins with the acquisition and compilation of diverse data sets, including information on land use, land cover, transportation networks, population demographics, environmental conditions, and existing infrastructure. These data sets serve as the foundational information for the analysis.

Geographic Information Systems (GIS) and spatial analysis techniques play a pivotal role in assessing the suitability of areas for urban expansion. GIS enables the integration of spatial data layers, facilitating the identification of patterns and trends that inform decision-making. Analytical Hierarchy Process (AHP), a Multiple Criteria Decision Analysis (MCDA) method is utilized to establish a systematic framework for evaluating and prioritizing potential growth areas based on multiple criteria. These criteria include proximity to developed areas, population proximity, Road network proximity, proximity to water bodies and hazards, and land use.

By following this methodology, urban planners and policymakers can navigate the complex challenges of urban expansion while fostering sustainable, vibrant, and resilient cities.

3.2 Study Area

Rawalpindi and Faisalabad are both major districts of the province of Punjab, Pakistan. The current study involves applying GIS-based Multi-Criteria Evaluation (MCE) to identify suitable areas for urban growth. The investigation takes into account the geographic and demographic features of both cities to comprehend the distinct challenges and opportunities for promoting sustainable urban development. Figure 3.1 shows the study area map of the present research.

3.2.1 Rawalpindi

Rawalpindi, a historic and rapidly evolving district located in the north of Punjab province of Pakistan, presents a compelling study area for the study of suitable areas for future urban growth. The district covers an area of 5,285 square kilometers and is made up of seven tehsils: Rawalpindi, Taxila, Gujar Khan, Kalar-Syedan, Kahuta, Kotli Sattian, and Murree. It is located at approximately 33.4095°N latitude and 72.9933°E longitude, having a diverse landscape, with elevations ranging from 300 to 2,790 meters above sea level. This geographical diversity contributes to a different climates across different parts of the district which significantly increase urbanization and population growth in recent decades. The current population of Rawalpindi city is 2,377,000, a 2.15% increase from 2022 [109]. This, in turn, has increased the need for proper urban planning and expansion strategies to ensure a

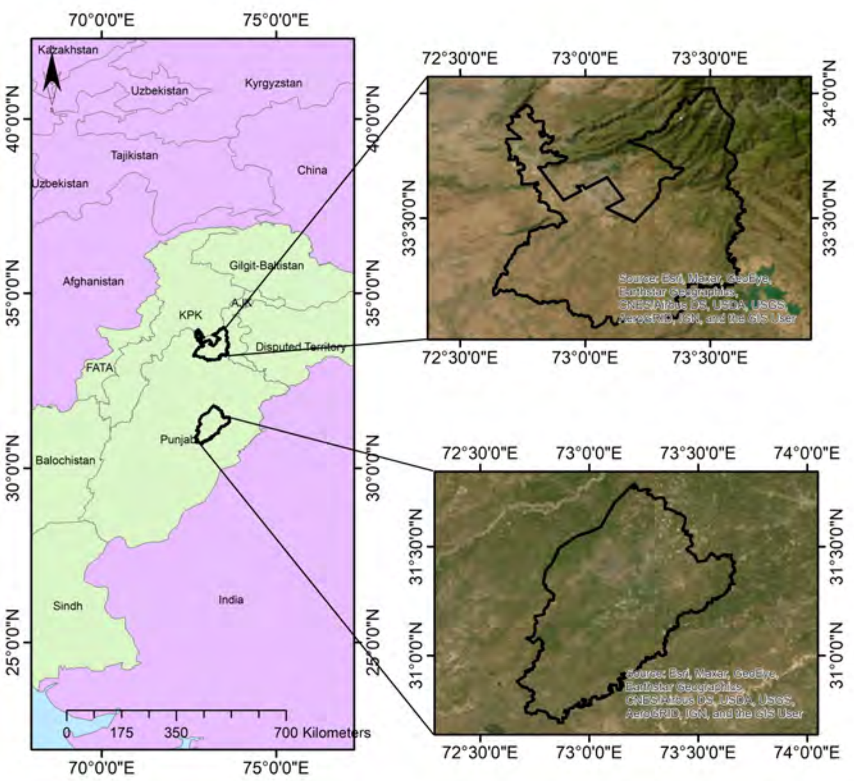

FIGURE 3.1: Study Area of Research

sustainable and well-organized development. Rawalpindi occupies a strategically important geographic location within Pakistan. It is positioned in the northern part of the country, against the Margalla Hills and adjacent to the federal territory of Islamabad. This geographical context places Rawalpindi at the crossroads of regional connectivity, with well-established road and transportation networks connecting it to other major cities in Punjab. The district of Rawalpindi has a remarkable transformation over the years, from the cities of Taxila to Muree, evolving from a historic and culturally rich urban center to a dynamic metropolitan area. Urbanization, driven by factors such as population growth, economic development, and migration, has led to an expansion of the city's boundaries and infrastructure. Understanding the dynamics of this growth is paramount for effective urban planning and sustainable development. As with many rapidly urbanizing regions, Rawalpindi faces a host of challenges and opportunities. Balancing the demands of urban expansion with environmental conservation, infrastructure development, and the provision of essential services is a complex task. This study area provides a unique opportunity to explore innovative approaches to address these challenges while harnessing the city's potential for economic development, improved quality of life, and enhanced livability.

3.2.2 Faisalabad

Faisalabad city, often referred to as the "Manchester of Pakistan" due to its historic significance in the textile industry, is a captivating study area for the exploration of suitable areas for future city growth [110]. Faisalabad district is situated in the heart of the Punjab province, It is located between 30.70° to 31.79° latitude East and 72.64° to 73.41° longitude North. The area of Faisalabad District is 5,856 km^2 out of which 1,326 km^2 is controlled by the FDA. This area includes urban, and suburban zones, and extends into the surrounding agricultural and industrial areas. The current population of Faisalabad cit]y is 3,711,000 with an increment of 2.37% from 2022 [111]. In this district, Faisalabad is the biggest city and has evolved into one of Pakistan's major urban and economic centers. The selected study area is a dynamic city offering information on existing trends, challenges, and opportunities in urbanization. With a rich industrial heritage and a thriving textile sector, the city has attracted investments and skilled labor from across the country. As a result, it has experienced substantial economic growth and industrialization. Understanding how these socio-economic factors intersect with urban expansion is a focal point of this study.

The city's economic vibrancy has also driven population growth and urbanization. Faisalabad's rapid transformation from a historical market town to a developing urban center fosters urbanization challenges faced by many developing cities. Investigation of urban growth's dynamic is crucial for addressing issues related to housing, infrastructure, and land use planning. Faisalabad's urban landscape is characterized by a variety of land use patterns. This spatial complexity offers an intriguing context for mapping suitable areas for future growth, as it requires careful consideration of existing land use and its compatibility with sustainable development goals.

The city's infrastructure, including transportation networks and utility services, plays a pivotal role in shaping urban expansion. As Faisalabad continues to grow, assessing the adequacy and adaptability of these critical systems is essential for determining suitable areas for future development. The city's strategic location within the Punjab region and its role in the national economy makes it a focal point for policymakers and urban planners.

3.3 Rationale for Same AHP Values and Weights for both Districts

oThe decision to apply the same AHP values and weights to two different districts, Faisalabad and Rawalpindi, can be justified for several reasons. Firstly, the districts share similar characteristics for the selected criteria that make the AHP criteria and their relative importance comparable. Mohammad et al. used the same AHP analysis for 2 different districts of Isfahan city in Iran. In urban planning and development studies, districts within the same region or having similar socioeconomic profiles can exhibit analogous patterns and priorities in terms of infrastructure, environmental considerations, and population needs [112]. Limited resources and data limitations are a concern, using the same AHP values and weights can simplify the decision-making process. Collecting district-specific data for every criterion and sub-criterion can be resource-intensive and time-consuming. Furthermore, if the study's focus is on broader regional planning or policy recommendations, rather than district-specific details, using uniform AHP values and weights is justifiable. It allows decision-makers to identify general trends and prioritize actions that benefit multiple districts simultaneously. The only difference between these two districts is terrain which is not considered as a criterion in this study which is a justification for using the same AHP values and weights for both districts.

3.4 Algorithm for Deriving the Suitability of an Area

Integration of AHP and GIS presents a robust approach for suitable mapping of areas for urban expansion. AHP, serving as a decision making tool, establishes a framework for selection of criteria, pairwise comparison, and obtaining the weights of criteria. Concurrently, GIS facilitates in integrating the data for spatial analysis, and visualization [113]. The methodology initiates with the selection of criteria that are relevant to urbanization followed by the collection and preparation of relevant datasets. Table 3.1 displays the selected criteria for this study along with their sources. Consistency checks are employed for ensuring the reliability of judgments, which enhances the precision of the decision-making process. Subsequently, GIS holds the capability of combining various data layers, employing spatial analysis techniques and weighted overlay tools to assign weights to criteria. Through the overlay and combination of calculated weights from AHP, suitability maps are generated. The suitability maps highlight the areas that are most conducive to future urbanization.

3.5 Criteria Selection and Definition

The selection and definition of criteria constitute a pivotal step in the Analytic Hierarchy Process (AHP) methodology for analyzing urban expansion. Selecting appropriate criteria requires a comprehensive understanding of the factors that influence urban expansion decisions. A comprehensive literature is shown in Table 2.1 which led to the selection of criteria for this study. These criteria capture the key dimensions and objectives of urban development, considering economic, social, environmental, and infrastructural aspects [114]. Once the criteria are selected, the next step is to define each criterion clearly and precisely. This helps ensure that decision-makers have a shared understanding of the criteria and can make consistent judgments during the decision-making process.

The selected Criteria and their source of data are as follows.

3.5.1 Population Proximity

In the AHP framework for city expansion planning, "Population Proximity" serves as a crucial criterion. This criterion evaluates the spatial relationship between potential expansion areas and existing population centers [115]. The degree of closeness or distance to established communities influences accessibility, social interactions, service provision, and economic opportunities in the expanding city. As an essential factor in urban planning, population proximity helps optimize resource allocation and infrastructure development for sustainable growth. To quantify population proximity, data from WorldPop as shown in Figure 3.2, a comprehensive research initiative, offers high-resolution gridded population datasets. WorldPop is globally accepted for population datasets [116].

FIGURE 3.2: WorldPop as a Source of Population

3.5.2 Road Network Proximity

In the context of the AHP for city expansion planning, "Road Network Proximity" emerges as a fundamental criterion. This criterion assesses the connectivity of potential expansion areas to existing road infrastructure. The accessibility and efficiency of transportation systems play a pivotal role in shaping urban growth patterns, impacting mobility, economic activities, and overall development of the country [117]. That is why it is an important criteria for the current study to plan the urbanization of cities by identifying the trend of population growth and suitability. By considering road network proximity, urban planners can identify expansion sites that ensure convenient access, reduced travel times, and improved connectivity for residents and businesses alike. For the analysis of road network proximity, OpenStreetMap (OSM) as shown in Figure 3.3, a valuable source of geospatial data. OSM provides up-to-date and collaboratively information.

3.5.3 Proximity to Water Bodies as an AHP Criterion for City Expansion

In the AHP framework of city expansion planning, "Proximity to Water Bodies" emerges as a significant criterion. This factor evaluates the distance between potential expansion areas and natural water bodies, excluding groundwater due to data limitations and complexity [118]. Considering proximity to surface water bodies, such as rivers, lakes, and ponds, informs decision-making regarding sustainable urban growth. Expansion into areas near water bodies can contribute to environmental sustainability, enabling access to water resources for various urban needs. OpenStreetMap (OSM) as presented in Figure 3.3, serves as a valuable source of geospatial data to assess proximity to water bodies, offering insights into their locations and distributions. By utilizing OSM data, urban planners can identify expansion zones that strike a balance between urban development and ecological preservation, facilitating a resilient and water-conscious city expansion strategy.

3.5.4 Land Use

Land use dataset is obtained from datasets like the USGS Global Land Use dataset [119] shown in 3.4, stands as a critical criterion in the assessment of suitable areas for future city growth. It offers a comprehensive understanding of how land is currently utilized within the study area, categorizing it into various classes such as residential, commercial, industrial, agricultural, and natural areas [120].
This data aids in the identification of existing urban footprints, outlining the boundaries of built-up areas, infrastructure networks, and urban centers. By analyzing land use data alongside other criteria, urban planners can evaluate the suitability of different land use types for future growth, facilitating informed decisions about potential redevelopment and infrastructure investment. Moreover, it assists in assessing the environmental impact of urban expansion, highlighting ecologically sensitive regions for preservation. Land use data also informs infrastructure planning by pinpointing areas with high demand for services and helps ensure compliance with zoning regulations and land use policies. Ultimately, land

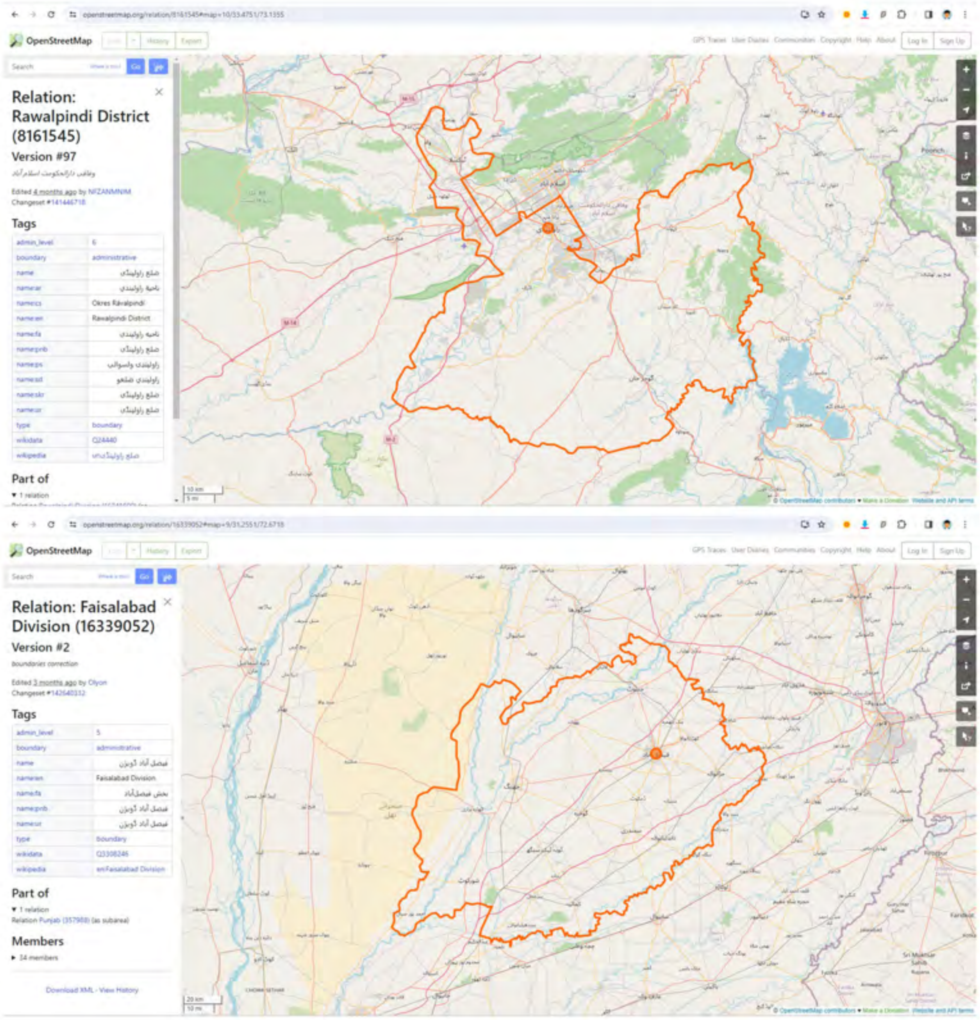

FIGURE 3.3: Open Street Map for Proximity to Road Network and Water Bodies

use data plays a pivotal role in guiding sustainable and equitable urban development while preserving valuable natural resources and ecosystems.

3.5.5 Proximity to Developed Areas as an AHP Criterion for City Expansion

Proximity to built-up areas serves as a pivotal criterion in the AHP framework for city expansion planning [121]. This criterion considers the spatial relationship between potential expansion areas and existing urban developments, and its significance cannot be overstated. Figure 3.4 shows that the USGS Global Land Use dataset enhances the precision of this evaluation [119]. Firstly, it directly correlates with infrastructure availability and accessibility. Areas located near established urban centers tend to benefit from well-developed transportation networks, utilities, and public services. By identifying land areas that can be integrated into the existing urban sprawl, encourages efficient land utilization, maximizes land value, and curtails urban sprawl, thus adhering to the principles of sustainable urban development. Lastly, proximity to built-up areas has a significant bearing on environmental considerations. In essence, considering the proximity to built-up areas as an AHP criterion provides a well-rounded perspective for sustainable and informed city expansion decisions, balancing accessibility, land use efficiency, and environmental conservation.

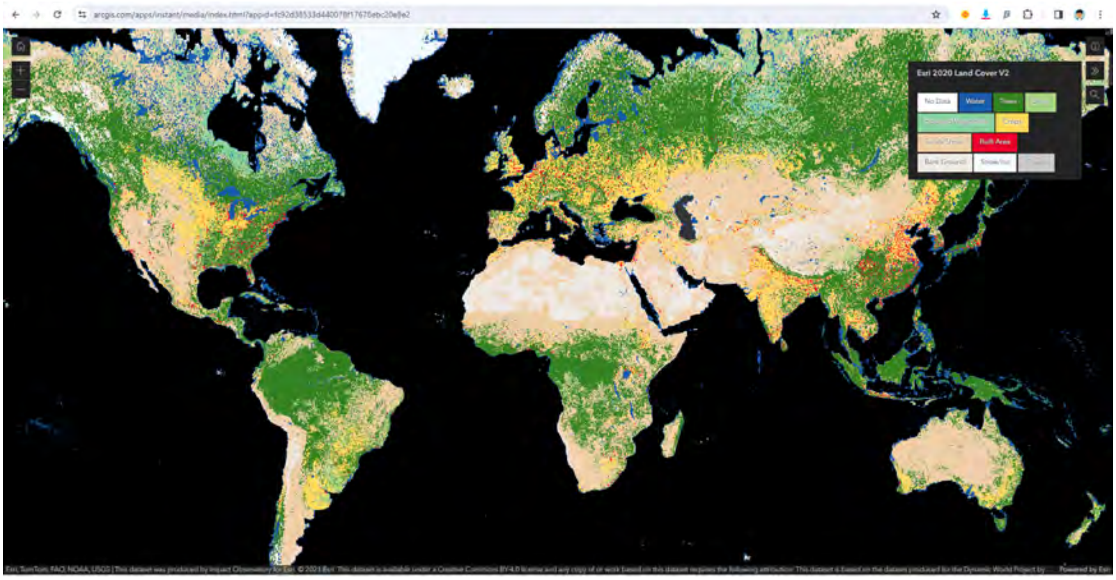

FIGURE 3.4: USGS for Land Use and Proximity to Developed Areas (Built Up Areas)

3.5.6 Proximity to Hazard Vulnerability as an AHP Criterion for City Expansion

This criterion evaluates the potential exposure of expansion areas to two significant hazards: floods and earthquakes. The hazard map of Pakistan has been published by the Geological Survey of Pakistan. That map serves as the foundation for the hazard dataset for this study. The map is characterized by different colors to show the nature and intensity of the hazard. The data for selected districts is extracted from that map and employed in ArcGIS. Table 3.1 shows all the criteria along with its sources and resolution in meters.

TABLE 3.1: Criteria and Data Sources Along with Resolution of Datasets

Sr#	Criteria	Source of Data	Resolution in meters (m)
1	Population proximity	WorldPop datasets	100
2	Road network proximity	OpenStreetMap	30
3	Land Value	USGS global Landuse dataset	30
4	Proximity to Developed areas	USGS global Landuse dataset	30
5	Proximity to water bodies	OpenStreetMap	30
6	Proximity to Hazard Vulnerability (Flood and Earthquake)	Geological Survey of Pakistan	30

3.6 Explanation of Analytic Hierarchy Process (AHP) Methodology

The Analytic Hierarchy Process (AHP) is a decision-making and ranking alternatives tool introduced by Thomas Saaty [122]. The AHP methodology provided a structured and systematic approach to decision-making to handle complex problems with multiple criteria. It provided a structured framework for evaluating and prioritizing factors based on multiple criteria. AHP simplifies a complicated decision problem by breaking it down into a hierarchical structure [123]. The hierarchy of this study consists of the overall goal or objective at the top, followed by criteria (Level 1) and sub-criteria (Level 2) which contribute to achieving the goal [122]. The criteria are further divided into more specific sub-criteria, forming a tree-like structure that captures the interrelationships and dependencies among the elements.

The AHP methodology employs pairwise comparisons to assess the relative importance of criteria and alternatives. Decision-makers compare each criterion with every other criterion, assigning preference or dominance values based on their judgment [124]. These values are typically represented on a numerical scale, such as Saaty's 1 to 9 scale, where 1 indicates equal importance and 9 indicates extreme dominance as shown in table 3.2 [125].

To driven meaningful weights from the pairwise comparisons, the judgments undergo mathematical calculations.

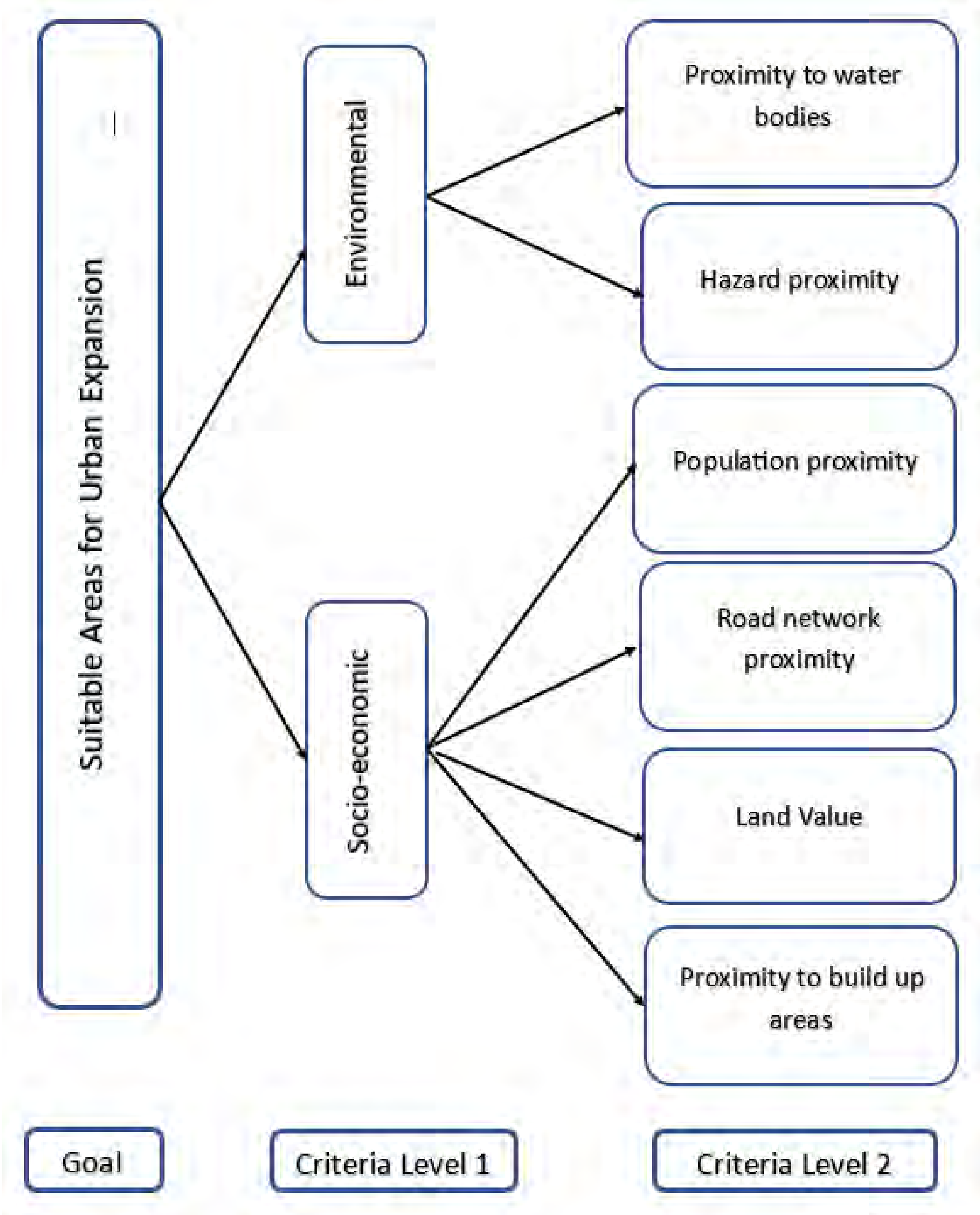

FIGURE 3.5: Hierarchical Map of Criteria for Sustainable Urban Growth

TABLE 3.2: Rating Scale for Pair Wise Comparison of Criteria

Importance Ratings								
1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely Less Important	Very	Strongly	Moderately	Equally Important	Moderately	Very	Strongly	Extremely More Important

Ensuring consistency in pairwise comparisons is a critical aspect of the AHP methodology. Decision-makers are asked to assess the consistency of their judgments by comparing the values assigned to different pairs of criteria. Consistency checks are performed to verify the reliability of the judgments. In case inconsistencies are identified, decision-makers are advised to review and adjust their judgments or participate in group discussions to attain a consensus. There were inconsistencies with this study. It was adjusted by multiple iterations.

3.6.1 Pairwise Comparison and Criteria Weighting Process

The pairwise comparison and criteria weighting process is a fundamental step within the Analytic Hierarchy Process (AHP) methodology for urban expansion analysis. This process enables decision-makers to systematically compare criteria and derive their relative importance, which is essential for effective decision-making [126]. During pairwise comparisons, decision-makers evaluate each criterion in relation to every other criterion and establish their relative priorities or preferences. These judgments are typically expressed on a numerical scale, Saaty's 1 to 9 scale, where 1 indicates equal importance and 9 indicates extreme indicated in 3.2.

The pairwise comparison shows the relative importance of each criterion in comparison to the other. For instance, Proximity to Hazard is strongly important i.e. 7 in comparison to Population proximity [127]. These weights are important for quantifying the contributions of each criterion to the overall evaluation of urban expansion alternatives. Table 3.3 is the pairwise comparison matrix of the chosen criteria. The literature review is one strong support behind these relations. The higher the weight assigned to a criterion, the greater its influence on final decision.

TABLE 3.3: Criteria Comparison Matrix

Criteria	**Population Proximity**	**Road Network Proximity**	**Land Value**	**Proximity to Developed Areas**	**Proximity to Water Bodies**	**Proximity to Hazard**
Population Proximity	1	$\frac{1}{5}$	5	3	2	$\frac{1}{3}$
Road Network Proximity	5	1	9	5	3	3
Landuse Value	$\frac{1}{5}$	$\frac{1}{9}$	1	$\frac{1}{3}$	$\frac{1}{7}$	$\frac{1}{7}$
Developed Areas	$\frac{1}{3}$	$\frac{1}{5}$	3	1	$\frac{1}{5}$	$\frac{1}{5}$
Water Bodies	$\frac{1}{2}$	$\frac{1}{3}$	7	5	1	$\frac{1}{3}$
Hazard	3	$\frac{1}{3}$	7	5	3	1
Total	10.03	2.18	32.00	19.33	9.34	5.01

Once the comparison-wise matrix is completed, the next is to normalize it. Normalizing ensures that values represent a consistent scale and sum up to 1. Equation 3.1 is the formula for normalizing the pairwise matrix.

$$N_{ij} = \frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}} \tag{3.1}$$

Where

N_{ij} is the normalized value in row i and column j.

a_{ij} is the original value in row i and column j

$\sum_{j=1}^{n} a_{ij}$ is the sum of all elements in row i.

This formula is applied to the whole matrix and the normalized matrix is obtained as shown in Table 3.4.

Criteria weights that reflect the relative importance of each criterion as shown in the last column of table 3.4. In this study, Road Network Proximity is ranked first with its weight of 40.3%, Hazard proximity is Ranked number two with its weight of 24.2%, Proximity to water is number third with a weight of 14.2%, Population Proximity is ranked number fourth weighting 13.1%, closeness to Developed areas as number fifth with the weight of 5.5% and sixth and the last is Land value with being least importance of 2.7%. The same kind of pattern of weights is observed by Mohammed et al., Mohammad et al., Kumar et al. and Bamrungkhul and Tanaka. Ensuring the consistency and reliability of pairwise comparisons is crucial. The judgments were carefully reviewed so they could be in compliance with consistency checks. Consistency checks in urban planning can be conducted using both the consistency index and the random consistency index. This approach allows for a more objective and data-driven assessment of criteria for urban expansion, supporting well-informed decision-making.

3.6.2 Consistency Checks in AHP

Consistency checks are integral to the AHP method for urban expansion and its analysis. Its evaluates the reliability and consistency of pairwise comparisons matrix made during criteria evaluation [129], these checks play a crucial role. The

Table 3.4: Normalised Pairwise Comparison Matrix with Priority Weights of Each Criterion

	Population Proximity	**Road Network Proximity**	**Land Value**	**Proximity to developed areas**	**Proximity to water bodies**	**Proximity to Hazard**	**Average**	**Weight Percentage**
Population Proximity	0.100	0.092	0.156	0.155	0.214	0.067	0.131	13.1
Road Network Proximity	0.498	0.459	0.281	0.259	0.321	0.599	0.403	40.3
Land Value	0.020	0.051	0.031	0.017	0.015	0.029	0.027	2.7
Developed Areas	0.033	0.092	0.094	0.052	0.021	0.040	0.055	5.5
Water Bodies	0.050	0.153	0.219	0.259	0.107	0.067	0.142	14.2
Hazard	0.299	0.153	0.219	0.259	0.321	0.200	0.242	24.2
							1	100

process of pairwise comparison carries the inherent risk of inconsistent judgments or subjective biases. Consistency checks ensure the validity and reliability of the process.

Upon normalizing the matrix and estimating the criteria weights, a critical assessment of matrix consistency is conducted. The primary objective is to ascertain the coherence of the assigned weights when applied to the geospatial database. This assessment hinges on the determination of two key parameters, namely the consistency index (C.I) and the consistency ratio (C.R). For this step, a consistency matrix is formed demonstrated in Table 3.5 which is the product of each value from a pairwise comparison matrix and criteria weight obtained from the normalized matrix [130]. The calculation of the C.I rely on the λ value, representing the matrix's largest eigenvalue.

In this study, the computed C. I add up to approximately 0.101. Subsequently, the CI value is divided by the random index value, which is determined based on the number of criteria, following the approach outlined by Saaty and Shang.

$$CI = \frac{\lambda_{\max} - n}{n - 1} = \frac{6.505 - 6}{6 - 1} = 0.101 \tag{3.2}$$

Where λ is the Maximum Eigen Value.

n represents the number of criteria.

TABLE 3.5: Consistency Matrix

							Sum	**Ratio** $=\frac{Sum}{Weight}$
Population Proximity	0.131	0.081	0.136	0.166	0.285	0.081	0.878	6.726
Road Network Proximity	0.653	0.403	0.245	0.277	0.427	0.725	2.729	6.774
Land Value	0.026	0.045	0.027	0.018	0.020	0.035	0.171	6.299
Developed Areas	0.044	0.081	0.082	0.055	0.028	0.048	0.338	6.108
Water Bodies	0.065	0.134	0.190	0.277	0.142	0.081	0.889	6.250
Hazard	0.392	0.134	0.190	0.277	0.427	0.242	1.662	6.875 Average 6.505

The last and final step of the AHP matrix is a calculation of Consistency ratio. The random matrix is as follows in table 3.6. consistency ratio is the quotient of the consistency index and the random index. For a weight distribution to be consistent, the resulting consistency ratio should fall below 0.1. If this is not met, the weights undergo necessary adjustments to change consistency.

The random consistency index (RI) is a reference value determined based on the matrix size. The globally accepted values of the Random Index are presented by Saaty demonstrated in Table 3.6. In this study, the number of criteria is six, so the value of RI is 1.25 extracted from Table 3.6.

TABLE 3.6: Random Index (Saaty, 1980)

Number of Criteria	**Random Index (RI)**
3	0.52
4	0.89
5	1.11
6	1.25
7	1.35
8	1.40
9	1.45

The Consistency Ratio (CR) is a commonly used metric to assess the degree of consistency in judgments, comparing it to a random consistency index. It helps to assess the reliability and coherence of the decision-making process. Calculating the Consistency Ratio involves dividing the CI by RI as shown in Equation 3.3.

$$C.R = \frac{\text{Consistency Index}}{\text{Random Index}} = \frac{0.101}{1.25} = 0.081 \tag{3.3}$$

If the CR is higher than the standard value i.e 0.1, it shows inconsistency and the pairwise comparisons matrix is are revised [131]. For this study, the pairwise comparison was revised multiple times to attain the CR value within the accepted limit i.e. less than 0.1. Consistency ratio table 3.7 is shown below:

TABLE 3.7: Consistency Check

(Max) eigenvalue	**6.570**
CI	0.101
R1	1.25
CR	0.081

C.R Values came around 0.081 which makes the weights in alliance to the thematic layers. Consistency checks offer decision-makers an opportunity to carefully assess their judgments and adjust pairwise comparisons if necessary. Results should be integrated obtained from the AHP process into the GIS analysis. This can be achieved by assigning the weights derived from AHP to the corresponding criteria and applying them in the GIS analysis. The CR helps decision-makers assess whether the judgments they provided are consistent enough to be reliable for decision-making. The integration ensures that the GIS analysis reflects the relative importance and priorities assigned to different criteria during the AHP process.

The AHP-derived weights were employed in the overlay analysis through a weighted linear combination process. In this procedure, all 6 thematic layers are individually multiplied by their respective assigned weights and subsequently summed, yielding the resulting overlay map. Moreover, within the context of overlay analysis, each class within the thematic layers is assigned weights based on their suitability. The outcome of this overlay analysis conducted in the GIS environment results in the production of the ultimate suitability maps, exemplified in Figure 4.11 and Figure 4.12 in the next chapter. This can be achieved by assigning the weights derived from AHP to the corresponding criteria and applying them in the GIS analysis. These final suitability maps, resulting from the overlay analysis, are subsequently displayed as proposed areas for future city and regional growth or expansion to achieve sustainability. This categorization process ultimately yields the conclusive suitability assessment of potential zones.

GIS visualizes and communicates the results of the integrated analysis by creating maps, charts, and other visual representations that effectively communicate the spatial patterns, impacts, and implications of the urban expansion analysis. Visualization helps in understanding the outcomes and facilitates communication with stakeholders, decision-makers, and the public.

3.7 Suitability Map Generation

After obtaining the datasets from the data sources mentioned in Table 3.1 and weighted criteria through the Analytical Hierarchy Process (AHP) calculated in Table 3.4, the next critical phase in methodology involves the generation of suitability maps using Geographic Information Systems (GIS) [132]. This phase serves as the link where the quantitative assessments from AHP are translated into spatial representations, providing a comprehensive overview of suitable areas for future city and regional growth in the study area.

3.7.1 Data Integration and Preparation

To initiate the process, spatial datasets of six selected criteria pertinent to this study were collected and integrated into the GIS environment. These datasets encompass land use information, road networks, proximity to water bodies, population distribution, hazard zones, and built-up areas. The data underwent thorough analysis to ensure consistency and compatibility within the GIS framework.

3.7.2 Thematic Layer Creation and Over Lay Analysis

Each criterion, armed with its respective weighted values derived from the AHP, was transposed into thematic layers within the GIS [133]. For instance, a thematic layer representing land use suitability was crafted, as were layers for road network suitability, proximity to water bodies, population distribution suitability, hazard zone suitability, and suitability related to built-up areas. These layers served as the building blocks for the subsequent analysis. The crux of the suitability mapping process was the overlay analysis executed within the GIS platform. This analysis represents the individual thematic layers while considering the weighted values assigned through AHP. Employing mathematical techniques, and weighted linear combination, the GIS software computed the comprehensive suitability scores for each location across the study area. Figure 3.6 demonstrated the interface of GIS where the overlay tool is being applied on all datasets along with the AHP Weights.

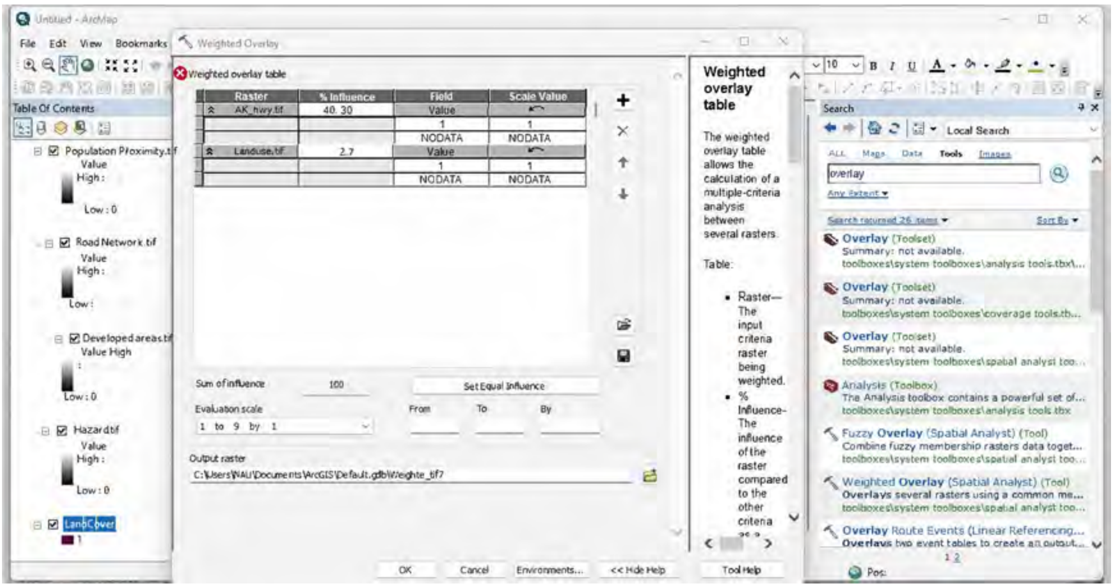

FIGURE 3.6: Application of Overlay Tool of arcGIS

Once all the datasets are uploaded and AHP Weights are added, the overlay tool provides a final suitability map of the study area which is presented in the next chapter. These maps provide a visual representation of the areas' potential for future city and regional expansion, graded from low to high suitability.

3.8 Summary

In this chapter, the methodological approach is outlined systematically, which forms the basis of this study. Integration of GIS and AHP, a powerful toolkit to tackle the complexities of mapping suitable areas for future city growth in the study area is equipped successfully. Spatial analysis and decision-making methodology ensure that this research is not only theoretical but deeply involved in practical applicability. This study adds to the next phase of results and analysis, making a comprehensive understanding of urban expansion and its sustainable management in the cities of Faisalabad and Rawalpindi.

Chapter 4

Results and Discussion

4.1 Background

In the preceding chapters, the chosen geographical area and the methodology are extensively explained. This is done with a keen awareness of the paramount importance of the problem statement and the specific aim of the study, with urbanization and its prospective growth serving as the pivotal influencing factors. All the selected factors are defined along with justification of their selection for this study. The selected criteria are evaluated based on subjective judgments supported by the extensive literature review. Table 3.4 reflects the most commonly selected criteria for different studies along with the origin of the study. The weights assigned to those criteria are mentioned as well. The final weights of the criteria are checked for baseness with consistency checks as per standards. This chapter not only showcases the quantitative data but also delves into qualitative insights gleaned from participant interviews. Each figure is meticulously explained, providing readers with a comprehensive understanding of our findings. Furthermore, statistical analyses are employed to validate the significance of our results across various parameters. Through this detailed analysis, we aim to offer a nuanced perspective on the implications of our research, paving the way for further discussion and exploration in the field. These figures are generated by GIS, a powerful tool for representing geospatial datasets. The sources of these datasets are mentioned in Table 2.1. To have a better and clearer understanding, the results are analyzed and explained making the two major cities, Faisalabad and Rawalpindi of the Faisalabad district and Rawalpindi district respectively.

4.2 Criteria Maps for Rawalpindi and Faisalabad

4.2.1 Land Use and Built Area Map

Land Use and Built Area are two different criteria, but they are merged to have one consolidated map for both. Faisalabad is a plain area having a well-established canal irrigation system. Figure 4.1 shows the existing land use incorporating built-up areas in Faisalabad. The district is divided into 5 categories, bare areas, built-up areas, agriculture, natural vegetation, and water. The Land Use and Built-Up

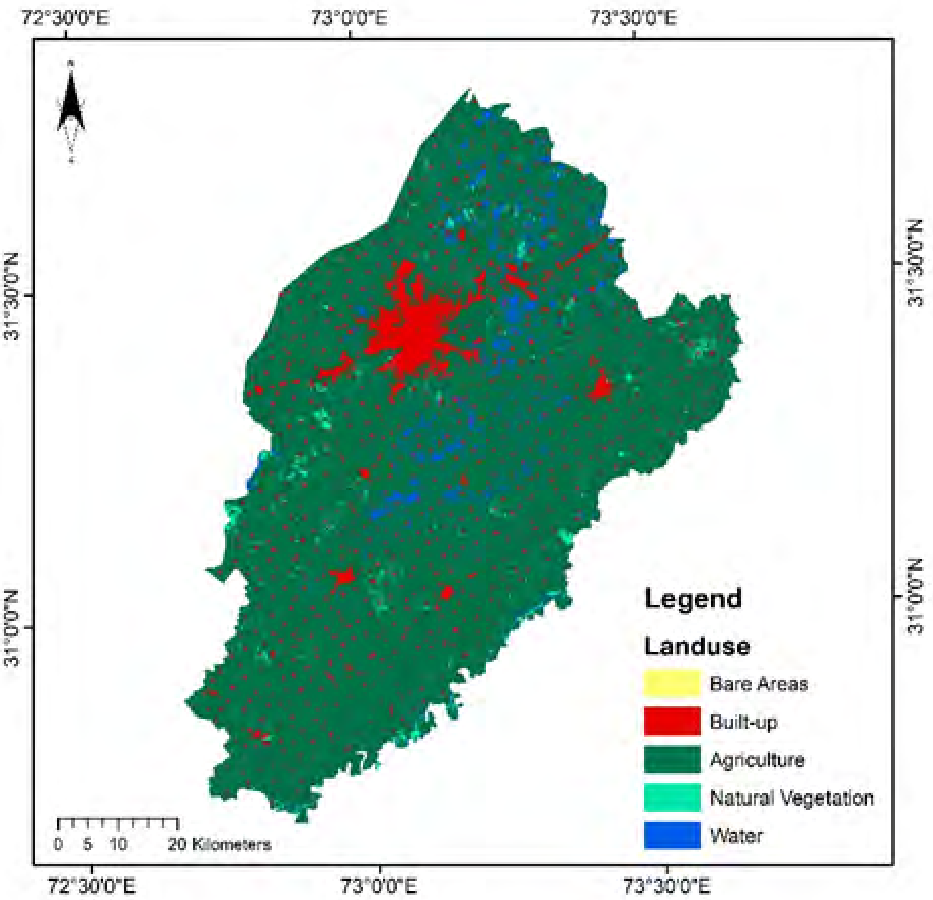

FIGURE 4.1: Land Use and Built-Up Areas of Faisalabad

Areas map for Faisalabad portrays that the district has experienced significant urban expansion over the years. Within the city boundaries, extensive built-up areas dominate, reflecting the city's role as an industrial and economic hub. Residential neighborhoods, commercial zones, and industrial areas are well-defined, contributing to the city's functional organization. The presence of educational institutions, healthcare facilities, and recreational spaces is also evident. Faisalabad's land use pattern indicates a city that has evolved to accommodate the diverse needs of its residents and industries. Figure 4.1 clearly shows that agricultural area dominates the region along with scattered natural vegetation which puts a responsibility on urban planners to conserve agricultural land for future generations. Faisalabad district has a small area of barren lands indicated as Bare areas.

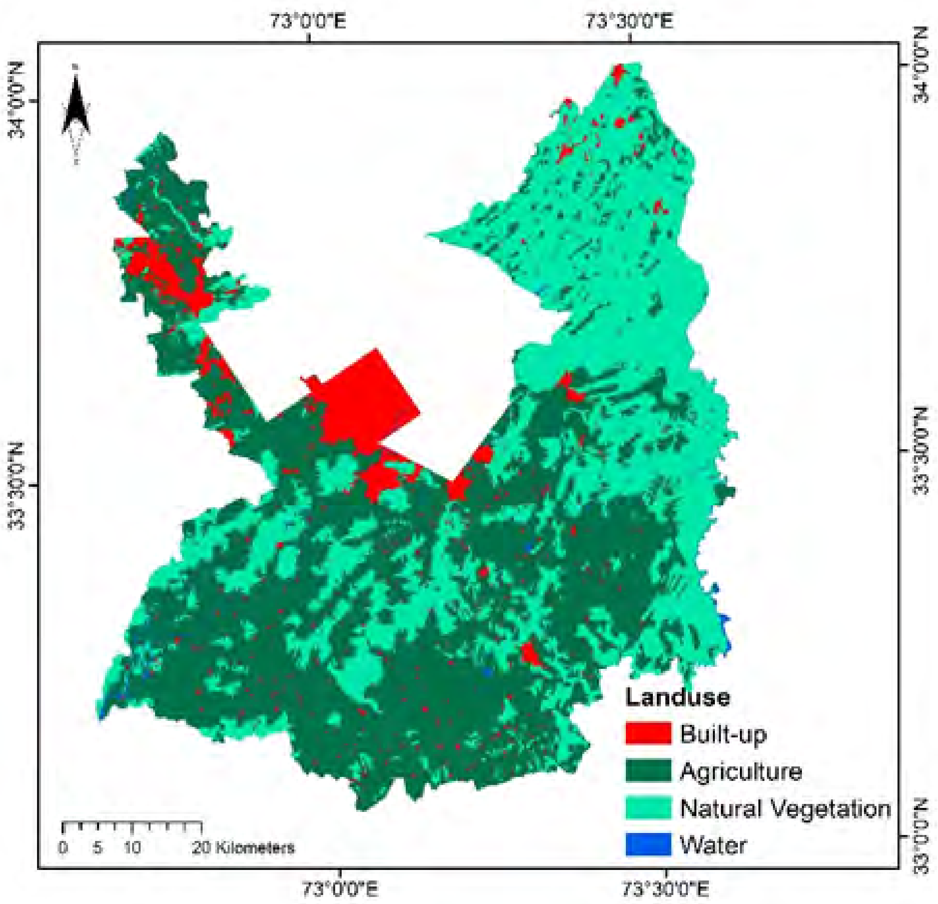

FIGURE 4.2: Land Use and Built-Up Areas of Rawalpindi

In contrast, the Land Use and Built-Up Areas map for Rawalpindi reveals a city characterized by a mix of land uses and a unique spatial layout. While the urban core exhibits substantial built-up areas as shown in Figure 4.2. Rawalpindi features a balance between agricultural and natural vegetation areas. The topography of this district makes it insignificant, including parks and forested areas such as the

Margalla Hills National Park. The city's proximity to Islamabad is evident in the well-planned road networks and residential areas that cater to both commuters and residents. The presence of government offices, educational institutions, and healthcare facilities underscores Rawalpindi's administrative significance within the region. The area has more natural vegetation as compared to the agricultural land.

4.2.2 Population Proximity

This criterion holds a significant behavior on the quality of life, accessibility, and efficiency of both cities. The Population Proximity maps, generated through GIS, offer a pictorial presentation of the distribution of the population and its implications for future city growth.

The population is categorized into five based on the number of people living per square kilometer. For Faisalabad, densely populated areas have more than 24000 people per km^2 while Rawalpindi's densely populated areas have more than 13000 people living per square kilometer. In both Faisalabad and Rawalpindi, we observe a concentration of population in the central urban core which is the case in most past studies [134]. Upon careful observation of Figure 4.3 and 4.4, it is evident that the population density in Faisalabad is more condensed while Rawalpindi has a scattered population. Rawalpindi has more areas of medium population range, i.e. 3000 to 7000 people per square kilometer. These areas are the cities of Muree, Taxila, and the surrounding core of Rawalpindi. Makhamreha and Almanasyeha described that there is a correlation between areas' demographic behavior and topography. This is indicative of well-established residential areas and the presence of key services, such as schools, healthcare facilities, and commercial centers, which tend to attract residents. Additionally, both cities exhibit corridors of high population density along major transportation routes, underscoring the significance of accessibility in influencing settlement patterns.

There are distinct differences manifest in the Population Proximity maps of Faisalabad and Rawalpindi. Notably, Rawalpindi, being the neighboring city of the capital Islamabad, exhibits a more dispersed pattern of population density portrayed

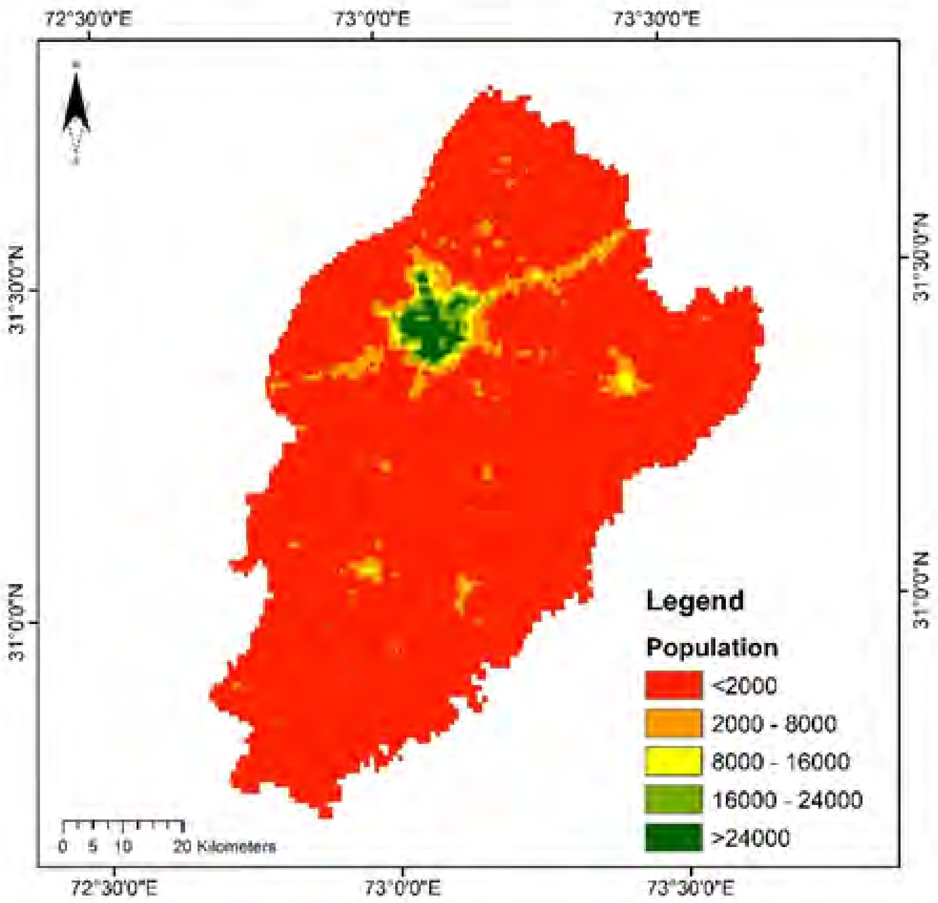

FIGURE 4.3: Population Distribution Map of Faisalabad

in Figure 4.3 This reflects its role as a commuter city, with residents seeking employment and services in the capital city. In contrast, Faisalabad's population distribution is relatively more concentrated within its boundaries, indicative of its historical role as an industrial and economic hub as shown in Figure 4.4

Moreover, the population density gradients in Faisalabad tend to extend more uniformly outward from the city center, whereas Rawalpindi's density varies, with the highest concentrations closer to Islamabad and diminishing as one moves further away. This unique population distribution in Rawalpindi underscores the city's role in the broader metropolitan region.

4.2.3 Road Density

Being an industrial city, the center of the city is saturated with road network. The city is full of potential for expanding the road network on the outer territory.

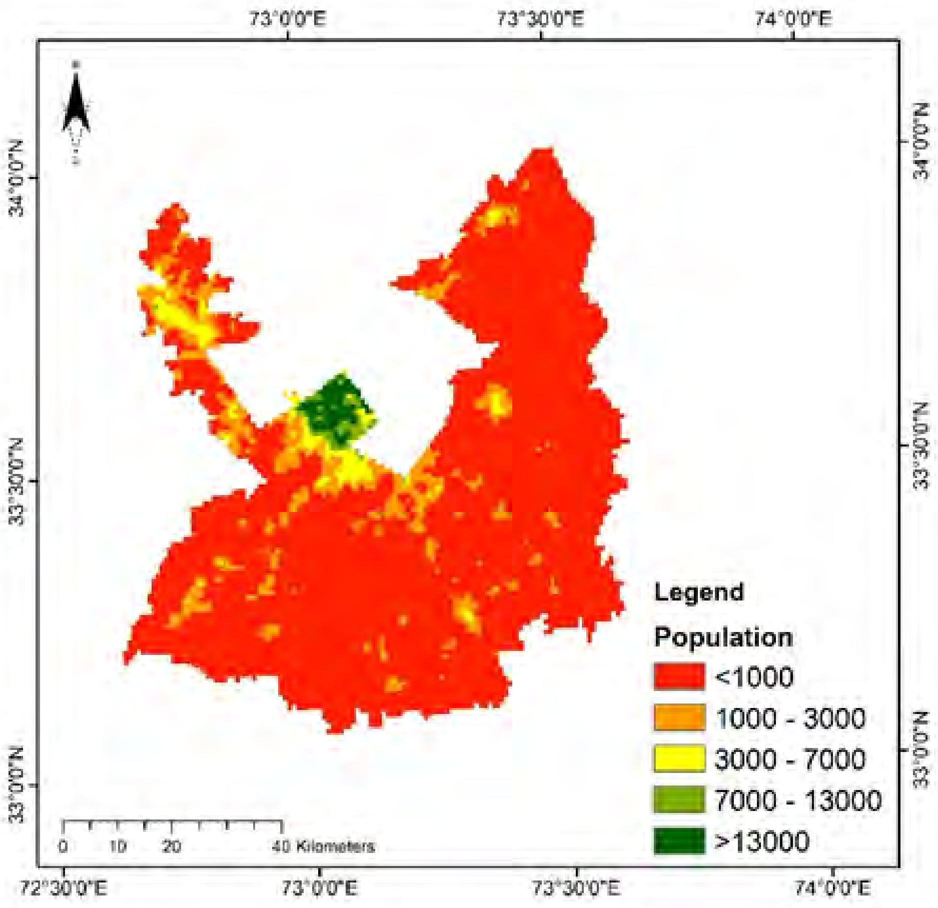

FIGURE 4.4: Population Distribution Map of Rawalpindi

The first category includes areas where the road density is less than 350 meters per square kilometer. These areas have relatively lower road infrastructure or connectivity. 350 - 700: This range covers areas with a moderate road density, where the road network is more developed than in the first category but not extremely dense. 700 - 1000: In this range, road density is higher, indicating that the area has a well-developed road network with more roads or longer road segments. 1000 - 1300: This range represents even higher road density, suggesting that the area is densely populated with roads and likely has excellent connectivity >1300: This category includes areas with the highest road density, indicating an extremely dense road network or a high concentration of roads, possibly in urban or densely populated regions which is in the core of Faisalabad city.

Figure 4.6 shows that Rawalpindi district has more areas covered by road as compared to Faisalabad. The core of the city has more than 2000 meters per square kilometer covered by the roads which is 700 more more than Faisalabad.

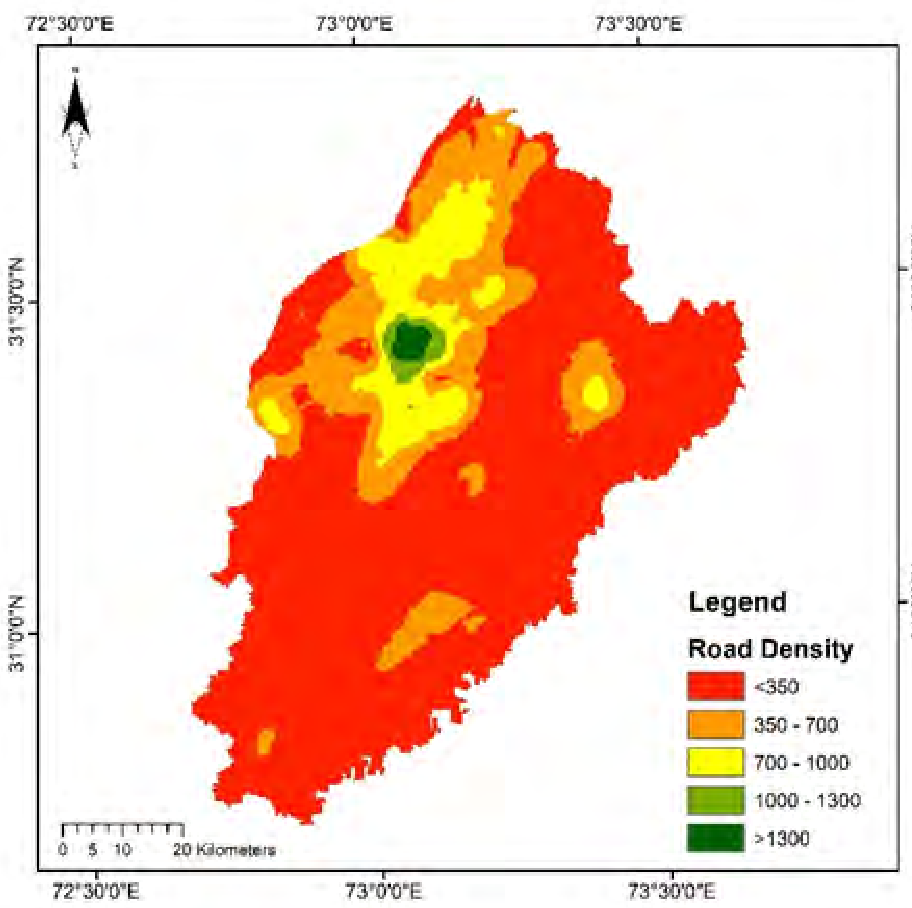

FIGURE 4.5: Road Density Map of Faisalabad

One striking similarity apparent in the Road Density maps for both cities is the prevalence of higher road densities in the urban cores. This phenomenon reflects the well-developed road networks within the city centers, accommodating the transportation needs of residents and businesses. Additionally, major arterial roads radiate from the city centers, facilitating efficient mobility within and beyond city boundaries. Rawalpindi has more major arterial roads as indicated by the range of 500 - 1000 meters in Figure 4.6. These similarities align with research on urban road networks, emphasizing the importance of high road infrastructure in urban areas.

While both cities exhibit a concentration of road density in their urban centers, differences emerge in their respective layouts. Rawalpindi, as a neighboring city to Islamabad, displays a road network that is well-connected with the capital shown in Figure 4.6. This is indicative of its role as a key transit hub for commuters traveling to and from Islamabad. In contrast, Figure 4.5 shows that Faisalabad's road network is more centralized within its boundaries, reflecting its historical identity as an industrial and commercial center. Another notable difference lies in the distribution of road density within residential areas. In Faisalabad, residential neighborhoods tend to be connected by a network of smaller roads. Rawalpindi, on the other hand, displays a more irregular layout, with residential areas connected by a mix of larger arterial roads.

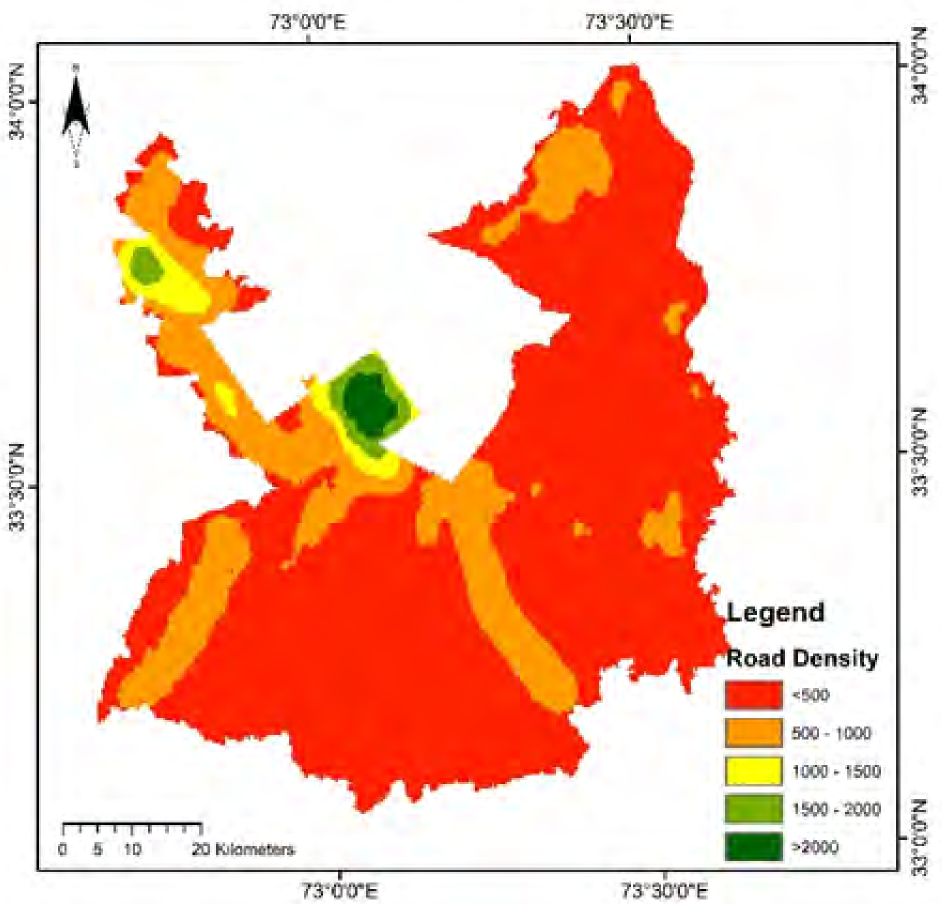

FIGURE 4.6: Road Density Map of Rawalpindi

4.2.4 Proximity to Water Bodies

Figure 4.7 and Figure 4.8 show the proximity to water bodies for the Faisalabad region. Proximity to water bodies, as analyzed using Geographic Information Systems (GIS), provides critical insights into the spatial relationships between geographic features and water resources. In this study, proximity to water bodies refers to the measurement of how close or distant specific locations are from natural water sources, such as rivers, lakes, or oceans. GIS tools enable the calculation of distances between each point of interest and the nearest water body, allowing for a precise understanding of spatial relationships. This analysis is invaluable in various fields, including environmental science, urban planning, and ecology, as it helps assess factors like accessibility to water resources, potential flood risks, and the ecological impact of land development.

Analyzing the Proximity to Water Bodies criterion in the cities of Faisalabad and Rawalpindi provides valuable insights into the accessibility and utilization of water resources within these urban areas. These GIS maps offer a visual representation of the relationship between the cities and their proximity to water bodies, shedding light on the implications for urban planning and environmental considerations.

In the Proximity to the Water Bodies map for Faisalabad, several noteworthy observations emerge. The city exhibits a relatively moderate proximity to water bodies, primarily owing to its location in the fertile plains of the Punjab province. The Chenab River, a significant waterway in the region, flows in proximity to the city. This proximity provides opportunities for water-based recreational activities and can support agricultural activities in the surrounding areas. However, the city's proximity to water bodies appears to be relatively consistent across its urban and suburban zones, with limited variations in proximity within the city boundaries as shown in Figure 4.7. It can be observed that the study area is divided into 5 divisions, <5, 5-15, 15-25, 25-35, and ¿35. It shows that red areas are close to water bodies so these are the most suitable areas for urban expansion while ¿35km shows that water bodies are to far to initiate the sustainable urbanization here.

In contrast, the Proximity to Water Bodies map for Rawalpindi unveils a distinct pattern. The city's proximity to water bodies appears more limited, with a notable absence of major rivers or large bodies of water within the immediate vicinity of the urban core. Instead, Rawalpindi's water resources predominantly consist of smaller streams and tributaries. Figure 4.8 shows that the city's proximity to water bodies is generally lower compared to Faisalabad, reflecting the region's topography and natural water distribution. While Rawalpindi may have limited access to major water bodies, its proximity to smaller water sources highlights the importance of managing local water resources effectively.

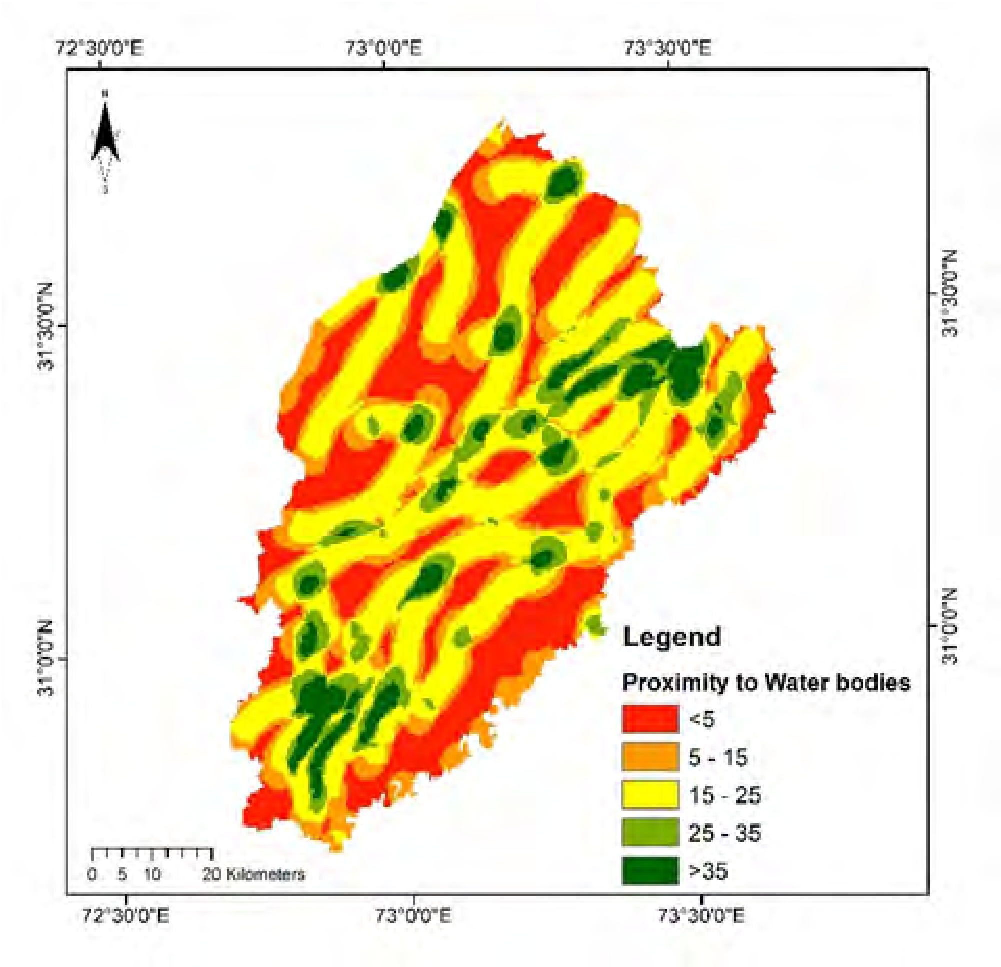

FIGURE 4.7: Proximity to Waterbodies Map of Faisalabad

4.2.5 Proximity to Hazard

Faisalabad is more prone to Flood as a hazard due to its plain geography. The hazard map for Faisalabad in terms of more susceptibility to floods is represented in Figure 4.9. The Proximity to Hazard map for Faisalabad portrays the city's exposure to various hazard-prone areas. Faisalabad's proximity to hazardous zones primarily encompasses regions susceptible to natural hazards such as flooding due to its proximity to the Chenab River and surrounding low-lying areas. Figure 4.9 indicates that the core of the city has a very low susceptibility to the hazard of flood while the borders of the district are more prone to flooding risks. Additionally, urban expansion has encroached into zones prone to industrial hazards, urban planning and necessitating careful zoning and disaster management planning. The map in Figure 4.10 showcases that areas in the southern part are more prone and susceptible to flood hazards while the core of the city has very low chances of flooding.

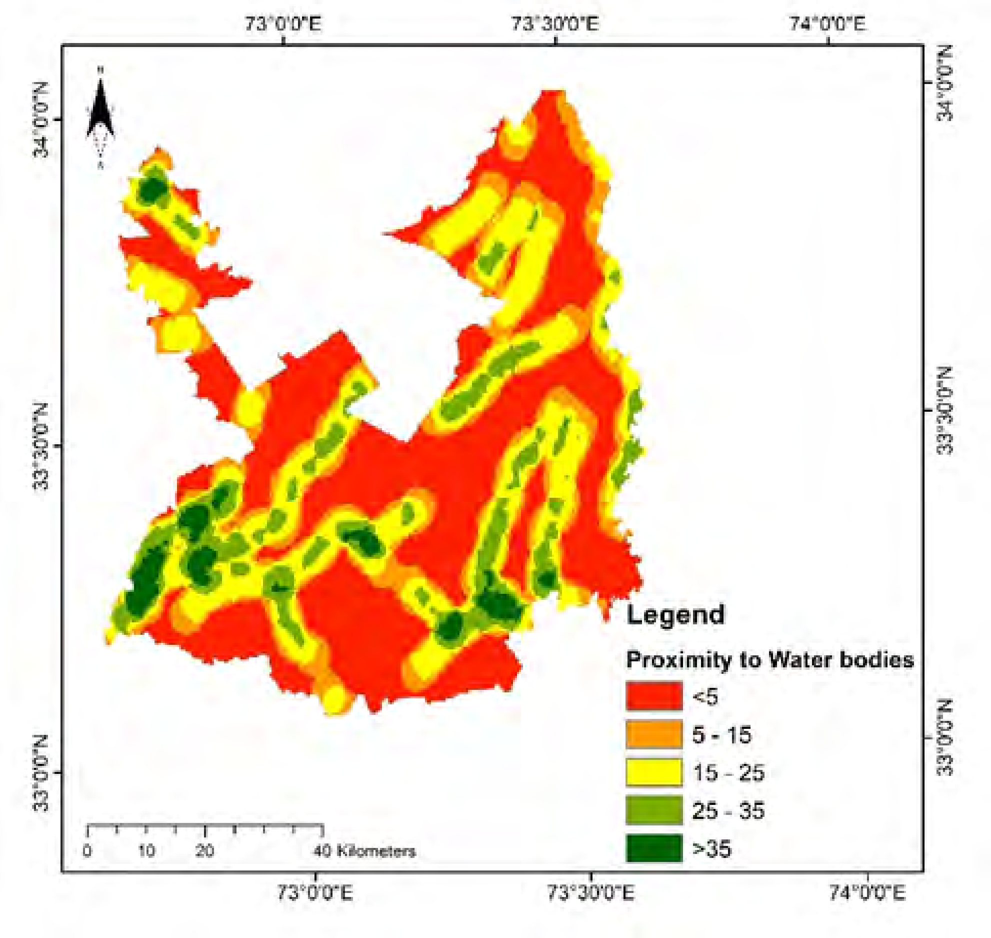

FIGURE 4.8: Proximity to Waterbodies Map of Rawalpindi

In Rawalpindi, the Proximity to Hazard map paints a distinct picture. Despite its lower susceptibility to flooding, Rawalpindi's geography presents distinct risks, including landslides and seismic events, necessitating tailored mitigation strategies. Effective urban planning and building regulations are crucial to minimizing the impact of these geological hazards. In addition to geological hazards, rapid urbanization in Rawalpindi has led to challenges such as traffic congestion and inadequate waste management. Efforts to address these issues must incorporate community engagement and sustainable development practices. By investing in infrastructure resilience and disaster preparedness, the city can better withstand natural disasters and safeguard the well-being of its inhabitants. Collaboration between government agencies, local communities, and international partners is essential to effectively address these multifaceted challenges and build a safer, more sustainable urban environment for all residents. The map in Figure 4.10 showcases that the city is under the medium level of Earthquake Hazard.

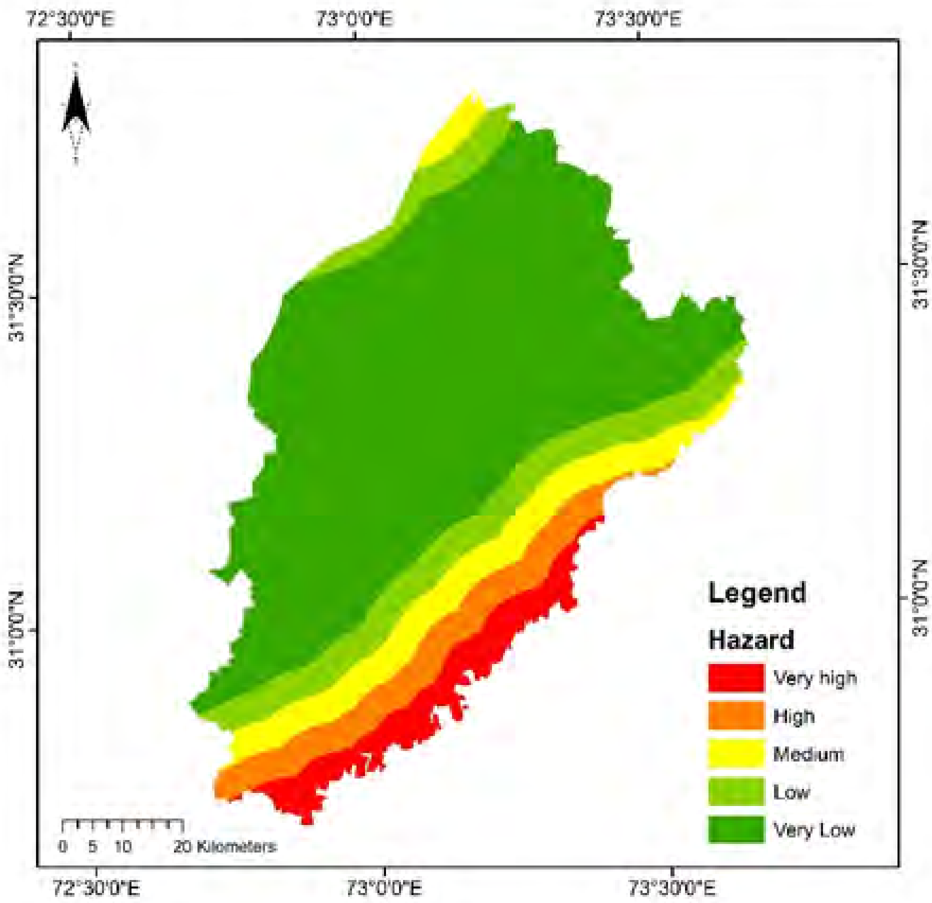

FIGURE 4.9: Proximity to Hazard Map of Faisalabad

4.3 Result and Analysis: Mapping Faisalabad's Prospective Growth Zones

After extensive geospatial analysis and data integration, the unveiling of the Final Suitability Map, Figure 4.11, for Faisalabad offers a strategic vision for the city's forthcoming expansion. This map serves as a guiding beacon for urban planners and policymakers, illuminating the path to accommodate Faisalabad's growing population and economic ambitions. The Final Suitability Map for Faisalabad divulges pivotal insights that are instrumental in shaping the city's urban fabric.

To begin, it highlights the high-suitability regions primarily situated within the urban core. Recognizing these zones as engines of growth is paramount for accommodating Faisalabad's increasing population and fostering economic activities. A noteworthy aspect of the map is its emphasis on Faisalabad's proximity to the

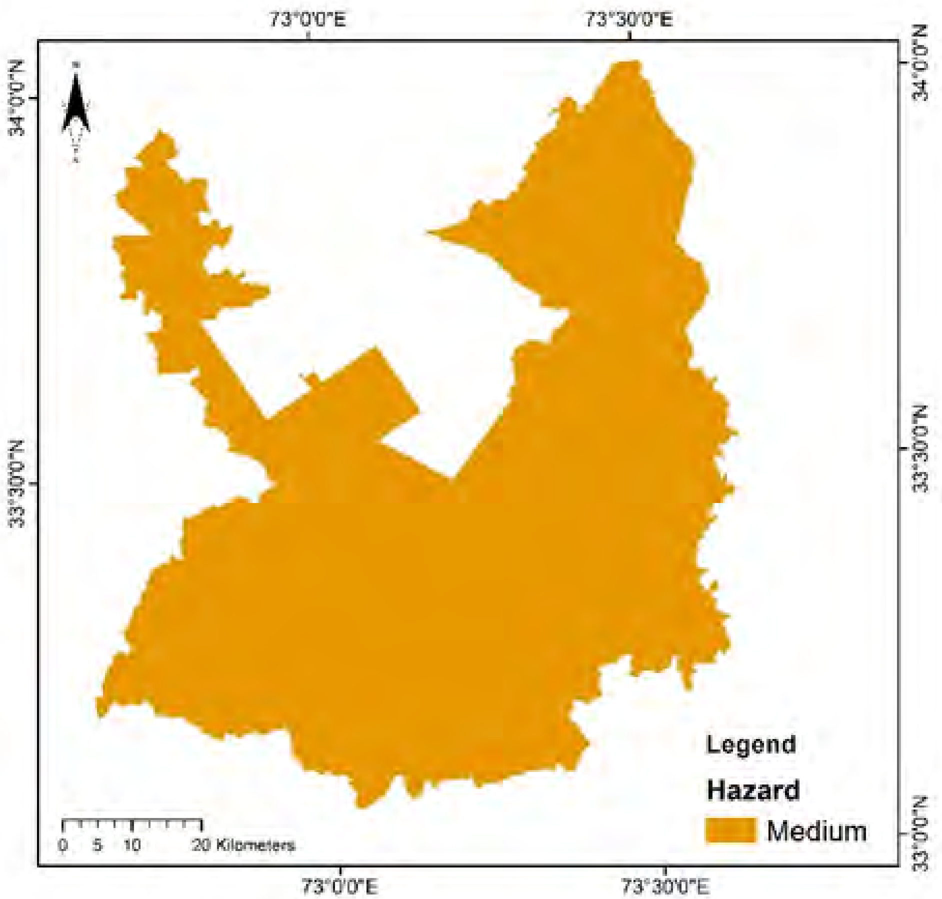

FIGURE 4.10: Proximity to Hazard Map of Rawalpindi

Chenab River. The high-suitability zones along the riverbanks not only offer picturesque vistas but also provide an opportunity for well-considered riverfront development. Nevertheless, the map underscores the necessity for careful flood-plain management and sustainable urban design in these areas. Integrating green spaces, recreational zones, and flood mitigation measures will be instrumental in harnessing this potential.

Conversely, the less suitable areas on the outskirts of Faisalabad require strategic planning. These regions may presently lack robust infrastructure, but they harbor immense potential for greenfield development. Prudent investments in road networks, utilities, and hazard resilience can metamorphose these areas into the expansion zones of the future, accommodating the city's growth while ensuring responsible land use.

In summary, the Final Suitability Map for Faisalabad shows that 28% percent of the area is suitable for future sustainable growth which serves as an encompassing tool for directing urban development strategies. This approach emphasizes the importance of sustainable growth, balancing economic development with environmental conservation. By focusing on these key elements, cities can enhance livability, attract investment, and foster a high quality of life for residents and visitors alike. Faisalabad stands at a critical juncture, well-positioned to embrace sustainable growth while preserving its distinct character and fortifying itself against environmental challenges, offered by this map.

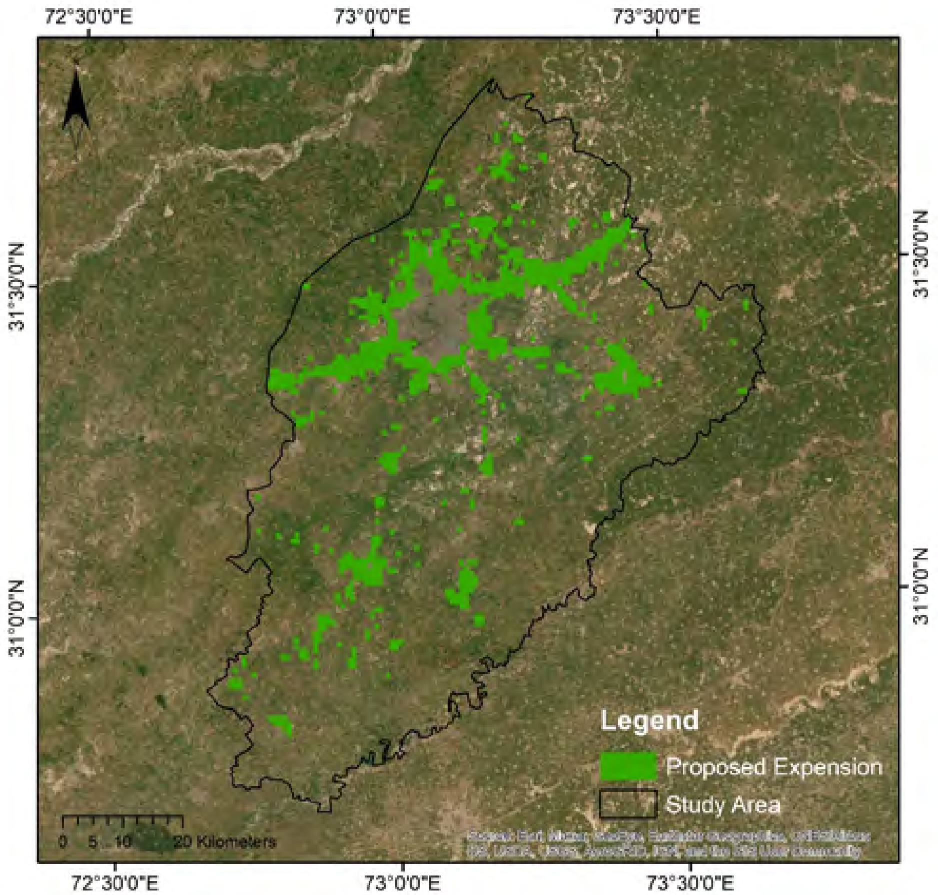

FIGURE 4.11: Area Suitability Map of Faisalabad

4.4 Result and Analysis: Mapping Rawalpindi's Growth Zones

The conclusion of extensive geospatial analysis and data integration has yielded a Final Suitability Map for Rawalpindi, showing that 23% of the area is best suitable for future urban expansion, offering a roadmap for the district's future expansion. This map shown in Figure 4.12 is an invaluable resource for urban planners and policymakers, as it identifies areas with the highest potential for accommodating Rawalpindi's flourishing population and economic activities.

The map reveals several key findings that are important in shaping Rawalpindi's urban development trajectory. Areas adjacent to parks, forests, and the iconic Margalla Hills National Park are designated as highly suitable [135]. While these regions may not be suitable for traditional urban development, the map underscores the significance of conserving Rawalpindi's natural beauty and offering residents access to recreational amenities. In conclusion, the Final Suitability Map for Rawalpindi provides that the area is suitable and the extension pattern of the district is more diverse and serves as a comprehensive guide for informed urban development decisions. Rawalpindi stands as an important economic hub, poised to embrace sustainable expansion while safeguarding its environmental treasures.

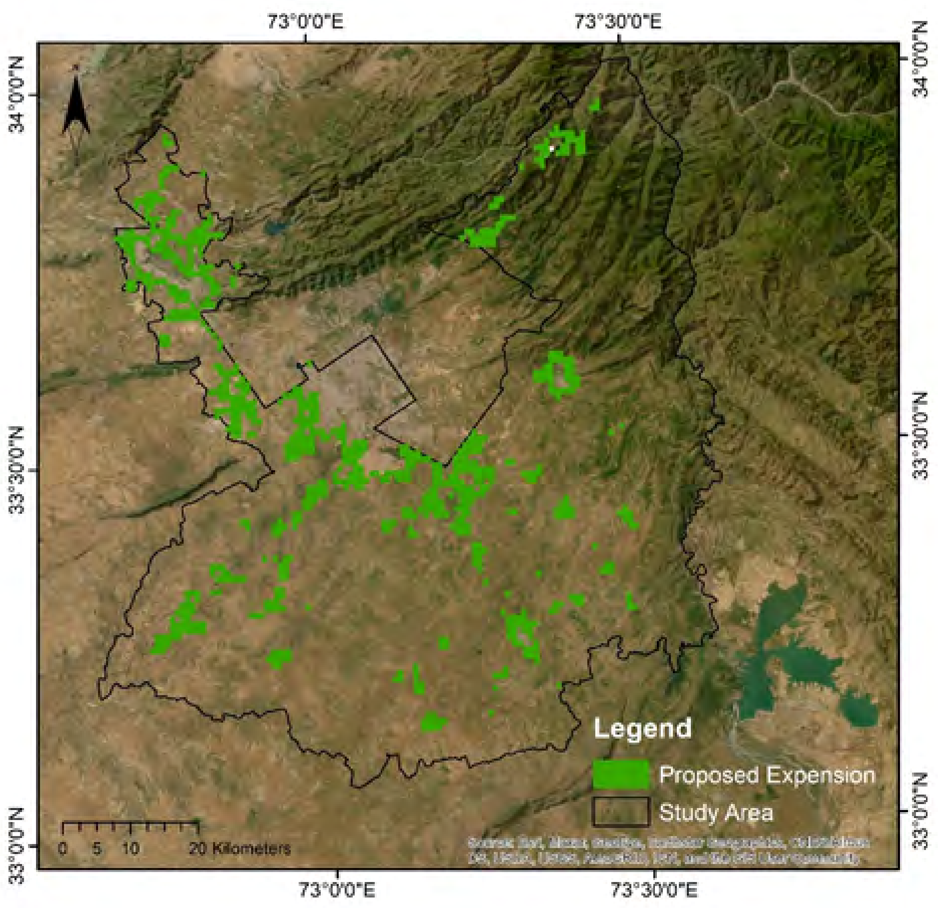

FIGURE 4.12: Area Suitability Map of Rawalpindi

4.5 Validation of Results

The final suitability maps have pointed out the potential suitable areas for future urban growth and expansion. To check the ground realities, an effort is made using Google Maps to validate if the potential sites are available for expansion. Three different patches are taken as samples from the identified areas as shown in Figure ?? indicated by Red, Blue, and Green rectangles. The areas indicated by Red and Blue rectangles show that the settlement trend is spreading in the indicated areas while the green box is still untouched by urbanization and it is a good potential site for urban expansion.

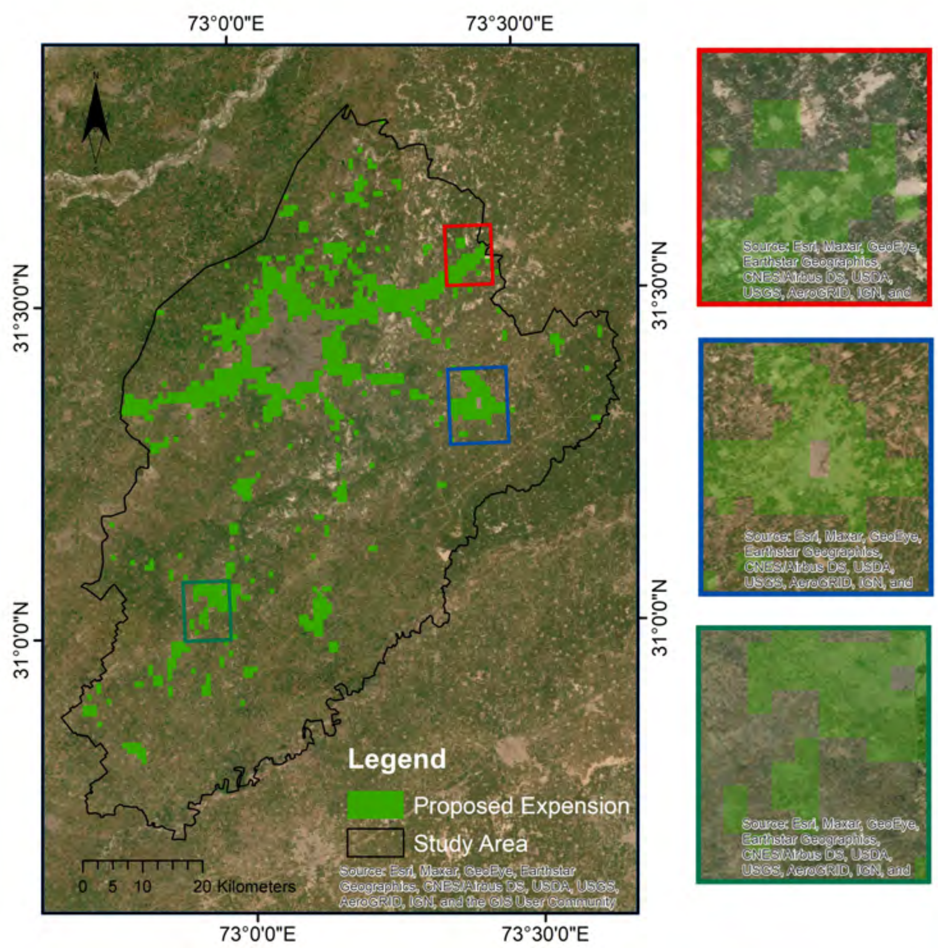

FIGURE 4.13: Ground Reality of Potential Suitable Sites in Faisalabad

The same is the case with Rawalpindi District. Figure 4.14 shows that out of all the mapped potential suitable sites, only 3 random sites were selected indicated by Red, Blue, and Green rectangles, to validate the outputs. Among the 3 selected sites, the Red and Blue Rectangle sites are vacant and completely available for urban expansion. The 3rd site within the green rectangle is slightly populated showing the urban expansion trend is being already followed in the area. This area has more potential for accommodating urbanization.

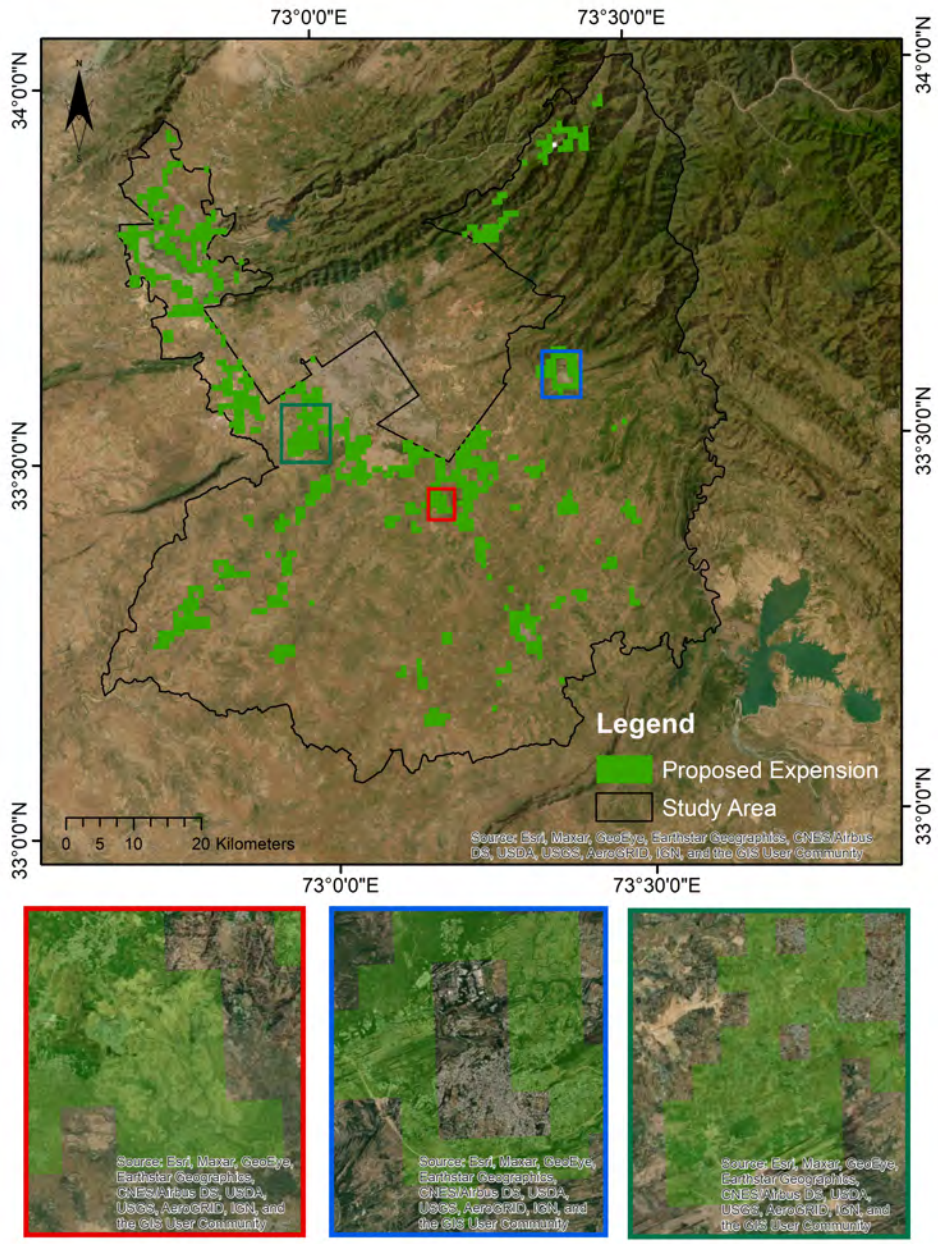

FIGURE 4.14: Ground Reality of Potential Suitable Sites in Rawalpindi

4.6 Conclusion

This chapter primarily focused on the maps of individual criteria representing the salient features and existing conditions of the study area. Spatial analysis including the similarities and differences in both cities is discussed. Suitable sites for the future growth of two cities Faisalabad and Rawalpindi are proposed with the help of suitability maps. The integration of GIS and AHP methodologies was used to come up with proposed sites for the future construction and expansion of these cities.

Faisalabad, with its closeness to the urban core, closeness to Chenab River, and diverse land use, demanded a sustainable approach, while Rawalpindi's high-suitability urban core, environmental aspects, and geological challenges need a balanced strategy. The final suitability maps are the essence of the results. The Suitability Maps are not just visual representations but strategic blueprints. These maps guide urban planners and policymakers toward informed decisions that lead to balanced growth, preservation, and resilience.

Chapter 5

Conclusion and Future Recommendations

5.1 Background

This study is motivated by a deep concern and an ambitious goal: to outline a trajectory for the sustainable growth and development of two dynamic districts, Faisalabad and Rawalpindi. The objectives driving this motivation are rooted in the challenges these districts encounter as a result of rapid urban expansion.

The motivation lies in the fact that urbanization is an irreversible global phenomenon, accelerating at an unprecedented pace. With this growth comes a multitude of intricacies and complexities, ranging from infrastructure demands to environmental preservation and hazard susceptibility. Faisalabad, renowned as the "Manchester of Pakistan," and Rawalpindi, with its strategic significance as a neighboring city to the country's capital, Islamabad, stand at the forefront of this progressive wave.

The significance of this study resonates not only locally but also within the broader context of urban planning and city growth. As urbanization continues to reshape our world, the lessons learned from Faisalabad and Rawalpindi districts extend far beyond their boundaries. They serve as a sample of the challenges and opportunities faced by cities worldwide, where sustainable development is the most important goal. Through geospatial analysis, data integration, and the application of advanced tools like GIS and the AHP, an effort is made to provide a solution-oriented approach to the complex puzzle of urban growth. This study aimed not only to map suitable areas for future expansion but also to contribute knowledge in urban planning, offering insights that can guide policymakers, planners, and stakeholders not only in Pakistan but also in cities around the globe.

5.2 Conclusion

The overall purpose of this study is to map out the suitable areas for future urban growth in the districts of Faisalabad and Rawalpindi. In the course of this study, a comprehensive exploration of the field of mapping suitable areas for future urban growth, drawing from local and global literature was conducted. Based on the selected six criteria, the following conclusions can be made.

- Out of the total area of 5,856 km^2, only 28% of the area of Faisalabad district is suitable for sustainable urban expansion.
- 23% area out of the total area of 5,286 km^2 of Rawalpindi district is best for future urban expansion.
- The priority weights rank the criteria in the following order with number one being the most important and number six being the least important. Closeness to the road network, proximity to hazards, distance from water bodies, Population proximity, Proximity to developed areas, and land value with the weight of 40.3, 24.2, 14.2, 13.1, 5.5 and 2.7 respectively.
- Out of the selected criteria, the most important is proximity to road network which conveys that areas that are closer to well-developed road networks are highly unsuitable for future expansion. The second most important criterion for selecting sites for urban expansion is hazard vulnerability followed by distance from waterbodies, population, developed areas, and land value.
- The sites suggested as suitable for future urban expansion are a blend of all six criteria.

- These zones, predominantly concentrated within the existing urban cores and along well-connected transportation networks, emerged as focal points of growth potential.
- The suitability maps underscored the importance of conserving green spaces, preserving the unique character of Faisalabad and Rawalpindi.
- A few samples selected on the suitability maps highlight the urbanization trends complying with the predicted results.

Navigating this intricate web of data and analysis, the results unveiled a variety of high-suitability areas and critical challenges [136]. Challenges, encompassing geological hazards and infrastructure demands, came into focus, emphasizing the need for a balanced and resilient approach to urban development.

The suitability maps generated through the methodology transcend visual representations; they serve as strategic blueprints guiding urban planners and policymakers [137]. These maps empower decision-makers to navigate the rapid journey of urbanization with wisdom, and foresight along with commitment to sustainable development. Faisalabad and Rawalpindi are on the verge of urban growth, ready to embrace change while protecting their individuality and becoming more resilient.

5.3 Future Research Directions

There are various avenues for future research and enhancement which can be accomplished using AHP and GIS. Potential directions for future studies, not limited to only AHP as Multi-criteria decision making model, include:

- Future research could delve into integrating dynamic elements like population growth, economic trends, and infrastructure development into GIS-based MCE analysis.
- Involvement of stakeholders is pivotal in urban planning. Stakeholder preferences and feedback can be incorporated into GIS-based MCE analysis.

Methods like surveys or workshops can be utilized to ensure that the decision-making process considers the varied needs and perspectives of the community.

- Future research could center on evaluating the outcomes of implementing GIS-based Multicriteria Evaluation (MCE) recommendations in actual urban development projects. Strengths and limitations of the approach can be obtained which may lead to its use in a different research field.

- The updated version of GIS, new statistical tools, and data availability are all opportunities. Future research might investigate how these advancements, including real time data, machine learning, and advanced visualization tools, can enhance the accuracy GIS based MCE in urban and regional planning process.

Opportunities and challenges, both emerge from the expansion of sustainable urban development. The case study of the Faisalabad and Rawalpindi districts illustrates the potential of this integration to deal with the complexities of urban development. Nevertheless, there is still space for enhancement and additional research to fine-tune methodologies, integrate dynamic factors, involve stakeholders, assess policy implementation, conduct comparative studies, and leverage technological advancements.

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