

**Assessing the Potential of Rainwater Harvesting through GIS and  
Remote Sensing Techniques in combating Urban Flooding in  
Lahore, Pakistan**



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## **Declaration**

This thesis is part of a research project conducted to identify flood-prone areas in the cities of Lahore, supported by a Wi GIS grant for professional or academic geospatial work. Ms. Aqsa Qalb is the principal investigator of the study, and Abdul Rauf and Sidra Tul Muntaha worked together as student assistants for their senior thesis. In addition, this research is supported by women in GIS organizations, and we thank ESRI for supporting our efforts.

We are also grateful to the Department of City and Regional Planning, Lahore University of Management and Technology for their assistance in participating in this funded research. During this event we learned about research methods, fieldwork, research writing and teamwork. The availability of these sources made our thesis a successful study.

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## **Acknowledgement**

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## **Dedication**

I dedicate this thesis to the city that witnessed my growth and ambitions. Lahore has been a constant source of inspiration for me throughout my academic career due to its vibrant culture, historical richness and indomitable character. My motivation to seek sustainable solutions was fueled by the city's difficulties in dealing with urban flooding. This thesis is dedicated to all the people living in Lahore whose experiences and stories have influenced my research and to the goal of improving the quality of life in this lovely city. Let this achievement be a tribute to the spirit of Lahore and its efforts to build a future that is both sustainable and flood-proof.

Furthermore, I also dedicate this thesis to my parents, whose undying love, support, and sacrifice have been the catalyst for my academic career. My main source of inspiration and motivation during this project was their belief in my abilities and unwavering support. They gave me advice and set ideals that influenced my character and academic goals, for which I will always be grateful. They have invested a lot of time and effort in helping me succeed, and my dissertation is a humble way for me to show them how much I appreciate and love them.

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## **Abstract**

Urban flooding is a major problem in cities around the world, including Lahore, Pakistan. The city is increasingly at risk of flooding due to heavy rainfall and poor management practices. This research explores rainwater harvesting (RWH) & bioswales as a possible sustainable solution to this problem, using geographic information systems (GIS) and remote sensing techniques for in-depth research. We use the Analytic Hierarchy Process (AHP) to examine various factors including land use/cover, slope, rainfall and drainage patterns to assess flood risk at different geographical scales, including union councils. The study identifies flood-prone areas, proposes RWH techniques, and evaluates the effectiveness of each strategy in reducing urban flooding. The results highlight the importance of integrating nature-based methodologies for sustainable urban development and contribute to flood management strategies and sustainable water solutions.

## **Keywords:**

Rainwater Harvesting, Urban Flooding, Bioswales

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# **CHAPTER 01: INTRODUCTION**



In every monsoon season million gallons of rainwater wastes and directly or indirectly merge with sewer. Saving rainwater or rainwater harvesting (RWH) is a concept that has been employed worldwide to address various water-related challenges, including urban flooding. RWH involves collecting and storing rainwater for future use, thereby reducing the demand for drinking water and reducing the negative effects of urban flooding.

The global concept of rainwater harvesting (RWH) means capturing and storing rainwater for future use instead of allowing it to flow down storm drains, wind and cause flooding. Several countries, such as Australia, India, and Singapore, have implemented large-scale RWH projects to tackle urban flooding. In Australia, the Water Sensitive Urban Design (WSUD) approach has been working to integrate RWH with other sustainable urban water management practices, such as green roofs, permeable pavements, and wetlands, to reduce size and speed of storm water runoff and enhance resilience of urban areas to flooding. (bin Zaman & Chowdhoree, 2022)

In India, the Central Ground Water Board has launched the "Jal Shakti Abhiyan" campaign to promote RWH and other water conservation measures across the country. The campaign involves creating awareness among communities, incentivizing the adoption of RWH systems, and integrating RWH with traditional water harvesting techniques, such as building check dams and percolation ponds, to recharge groundwater and prevent flooding. (PTI, 2019)

Singapore, a city-state with limited freshwater resources, has implemented an innovative RWH system that collects rainwater from rooftops and other surfaces, treats it to potable standards, and distribute it through a separate drinkable water network, for example for cleaning toilets and watering green spaces. The system, known as the "NEWater" system, has helped reducing the demand for drinking water, enhance the urban resilience to water scarcity, floods and promote sustainable urban development. (Bai et al., 2020)

Additionally, as climate change has the potential to worsen existing urban floods, it is strongly tied to it. Due to the abundance of impermeable surfaces, such as concrete and asphalt, which prevent precipitation from penetrating the ground, urban areas are particularly susceptible to floods. Instead, rainwater swiftly empties into storm water drains, which can overflow during periods of high precipitation and result in floods. In addition, urbanization frequently entails the destruction of natural vegetation, which can make floods worse by limiting the quantity of water absorbed into the ground and boosting runoff velocity and volume.

In this study we work on how to save rainwater with different techniques and how we use rainwater and what are their benefits in Lahore. Since rain is the purest form of water, "water when it falls" is a quick source to increase your water supply. Rainwater collected for direct use is stored in above-ground, underground or above-ground tanks and used for cleaning, washing, gardening and other purposes. Through wells, pits, ditches, revitalization of ditches, etc. In addition, the advantages of collecting water are less flooding in low-lying areas and on roads, less soil erosion, lower costs and easier maintenance, water and energy costs, etc.

Rainwater harvesting is a system that uses straightforward methods such as jugs and pots and more sophisticated methods such as subsurface check dams to collect and store rainwater from

roofs, soil or rocky soil. Water harvesting is of real benefit soil and water conservation in semi-arid drought conditions were primarily used. Reliability of both can be significantly increased.

The infrastructure of a city can be severely strained by urbanization and urban floods, which can result in traffic jams, damage to transportation systems, overloaded water supply and drainage systems, and a higher risk of natural disaster-related damage. The demand for infrastructure rises as more people come into a city, and if the infrastructure cannot keep up with the demand, it can cause a number of problems. Cities must make investments in resilient infrastructure that can resist the strains of urbanization and natural catastrophes in order to address these issues. This entails creating environmentally friendly transport networks, making investments in water supply and drainage systems, and putting catastrophe risk reduction strategies into action. Urban planning that considers the potential effects of urbanization on infrastructure and the environment is also a part of it.

For Example: Dhaka, the capital of Bangladesh with more than 18 million inhabitants, is one of the largest cities in the world. The rapid growth of the city has put a strain on its infrastructure, particularly in terms of transportation, housing, and sanitation. The city's roads are heavily congested, and public transportation is often overcrowded and poorly maintained. Illegal and informal settlements have arisen due to housing shortages, which often lack basic amenities such as sanitation and drinking water.

In response to these challenges, the government of Bangladesh has launched a number of initiatives aimed at improving the city's infrastructure. For example, the Dhaka Urban Transport Project is working to develop a more efficient and sustainable transportation system for the city, including new bus routes and bike lanes. The government has also invested in new housing projects and initiatives to improve access to basic services like clean water and sanitation. (Hamza, 2018)

## **Problem Statement**

Lahore is suffering from a water shortage, which is increasing day by day. The city relies on ground aquifers, which is also a concern due to excessive extraction. Rainwater harvesting, which is an important water supply for domestic, agricultural and industrial purposes, can relieve already overburdened municipal water supplies. Lahore has a poorly developed drainage infrastructure that fails to cope with heavy rainfall. Most of the city's drainage network is old and outdated, and many areas lack proper storm water management systems. Consequently, when it rains, water accumulates on the streets, causing flooding and damage to buildings and infrastructure. Lahore has witnessed rapid urbanization, resulting in the encroachment of natural waterways and wetlands. The unregulated construction of buildings, roads, and other infrastructure has significantly reduced the city's natural drainage capacity, exacerbating the risk of flooding during heavy rainfall. Lahore's sewerage system is in dire need of maintenance and up-gradation. Solid waste, including plastic and other waste, is often dumped down drains, clogging or clogging them. When it rains, the blocked sewerage system exacerbates the risk of flooding and can cause sewage to overflow onto the streets, posing health hazards to residents.

In Lahore, heavy rainfall often leads to flooding, particularly in low-lying areas and neighborhoods with inadequate drainage systems. This can disrupt the daily lives of residents, who may not be able to access their workplaces or schools due to flooded roads and streets.

The floodwater can also damage homes and businesses, leading to significant financial losses for local residents. Flooding is also a health hazard, as standing water can become a breeding ground for mosquitoes and other disease-carrying animals. Due to this, diseases like dengue and malaria are likely to prevail.

Urban flooding causes significant damage to lives, infrastructure and industry. Informal materials such as concrete and asphalt are common in urban areas and do not prevent rainwater from seeping into the soil. Instead, the water runs off and accumulates in low-lying areas, leading to flash floods and inundation of streets, buildings, and transportation systems. Floodwaters can damage buildings, roads, and other infrastructure, and can also cause power outages and disrupt transportation systems. In addition, urban flooding can have long-term environmental impacts, including the erosion of soil and sediment, the spread of pollutants, and the destruction of natural habitats.

## **Aims & Objective**

The aims & objectives of this topic are:

- i. To identify the hotspot urban flooded areas in Lahore especially urban elements
- ii. To conduct social economic survey for getting the perception of people regarding urban flooding.
- iii. To suggest rainwater recharge wells consists on nature based solutions to tackle urban flooding issues.

## **Research Question**

- i. In Lahore, at how many locations urban flooding occurs identified it through Hotspot analysis in ArcMap 10.2?
- ii. What is the perception of people regarding urban flooding?
- iii. What are the possible rainwater recharge well points to tackle urban flooding issue in Lahore?

## **Scope of Study**

This study aims to hold great significance for the city's sustainable development. Lahore, like many other cities in the world, is facing the challenge of increasing urbanization, which has resulted in rapid land-use changes and reduced permeable surfaces, leading to urban flooding during heavy rainfall events. This research can help identify the right location for RWH implementation, assess the effectiveness of different RWH techniques, and evaluate the economic feasibility and social acceptability of RWH systems. The study can provide valuable insights into the role of RWH in mitigating the adverse effects of urban flooding, reducing the demand for potable water, and promoting sustainable urban water management practices.

## **Justification**

It is crucial to combat urban flooding in Lahore by putting in place rainwater harvesting (RWH) systems for a number of reasons. First, because of its weak drainage systems and propensity for flash flooding, Lahore sustains serious harm to its infrastructure and property. Second, Lahore's population is expanding quickly, and the city's infrastructure is having trouble keeping up with the rising demand. By putting in place bioswales and RWH systems, the city's drainage system will be less taxed, and there will be more water available for non-potable purposes like irrigation and toilet flushing. These green infrastructure options can also improve the environment in other ways, such as by promoting biodiversity, lowering the effects of urban heat islands and improve water and air quality. Implementing RWH and bioswales is generally a good idea.

## **Limitations**

While this study contributes valuable insights to the field, it is important to acknowledge its limitations;

- Limited research material on urban flooding and rainwater harvesting in Pakistan which cause lack
- Lack of implementation on Rainwater Harvesting Techniques in Pakistan.
- Limited data available of urban flooding and RWH.
- Authorities didn't meet the time limit to complete the project of RWH.

## **Organization of thesis**

### **Chapter 1**

Chapter 1 based on introduction to the study which define the problems of the urban flooding in Lahore due to excessive rainfall and lack of management by authorities. RWH and bioswales are the two techniques which can help to reduce the risk of urban flooding just like other countries which are getting help from RWH to prevent urban flooding.

### **Chapter 2**

Chapter 2 is on literature review by which we get to know the international and national practices on how different countries handle urban flooding through rainwater harvesting and bioswales. And how these articles are related to our study especially in context of Lahore. And how we can implement their research in our study for getting efficient results.

### **Chapter 3**

Chapter 3 is based on research methodology in which we get the sample size for data collection of our questionnaires and create questionnaire from different articles. And this part also include all our data collection process which we gather during our study.

#### **Chapter 4**

In this chapter 5, we describe the data collection & data analysis procedure, which includes choosing a sample size for our study and distributing questionnaires based on relevant literature. The resulting data will then be analysis through GIS to provide useful information about the relationship between rainfall and urban flooding, as well as the potential effectiveness of bioswales and rainwater harvesting in reducing flood risk in Lahore.

#### **Chapter 5**

In this final chapter, we discuss the results of our research on urban flooding in Lahore and discuss Bioswales and rainwater harvesting as potential solution. The results of the GIS-based data analysis provide in-depth information on how well these strategies are working in flood risk mitigation. We also explore the implications of our research and make suggestions for future flood plans in Lahore.

## **CHAPTER 02: LITERATURE REVIEW**

## **Definitions of Keyword**

### **Urban Flooding:**

Urban flooding is an increased risk due to climate change, land use change and urbanization. (Sörensen et al., 2016)

Flooding of land or property in an urban setting, caused by an excess of storm water runoff or heavy rainfall, which exceeds the capacity of drainage systems and retention basins.(Aerts et al., 2018)

### **RWH:**

Rainwater Harvesting is a skill that allows you to collect and efficiently store rainwater from many underground regions, such as residential roofs, soil, rock pools, and more.(Pradhan & Sahoo, 2020)

The process of enhancing surface runoff or natural rainfall infiltration into the soil using a variety of technical techniques is known as rainwater harvesting.(Gupta & Chakraborty, 2021)

### **Bioswales:**

Using bioswales to reduce storm water runoff is one way to conserve our surface water. It is a gently sloping vegetation ridge designed to filter pollutants and slow storm water runoff.(Gibb, 2015)

To improve air quality, reduce the risk of earthquakes, and airborne members that depend on designated areas for painting infrastructure, bioswales, such as wall leaks, are a type of bio retention pathway. (Faraj & Hamaamin, 2023)

This article describes the alarming rate at which Lahore's water table is eroding at three stations per year. The main defense is that the recovery rate is slower than the groundwater lag. This script, groundwater isn't suitable to fulfill the unborn demand for water. Assessing rainwater harvesting potential in educational institutions located in Lahore. Analyze potential uses of GIS tools to assess storm water harvesting potential. To evaluate the potential benefits of rainwater harvesting in terms of water conservation and cost savings. Rainwater harvesting had the potential to provide a significant amount of water for the institutions, with an estimated average of 16.6 million liters of water per year. The researchers also identified suitable locations for the installation of rainwater harvesting systems using GIS mapping. It also concludes that the implementation of rainwater harvesting systems in educational institutions can contribute to sustainable water management and they provide a reliable source of water for non-potable purposes. Estimation of rainwater harvesting in educational institutions of Lahore. Effectiveness of GIS techniques in assessing rainwater harvesting potential. Potential benefits of rainwater harvesting for water conservation and cost savings in educational institutions in Lahore. Recommendations for implementing rainwater harvesting systems in educational institutions in Lahore, including required infrastructure, cost-benefit analysis, and potential challenges. This study methodology has significant contribution in building our strategy to tackle the ponding area in Lahore. Furthermore it relate with our topic by identifying areas for rainwater harvesting, which provides a framework for implementing the ponding area after rain solution in educational institutions in Lahore. This can help to alleviate water scarcity and reduce the demand for potable water, while also promoting sustainable water management practices. Also provides a valuable contribution to the field of sustainable water management by using GIS techniques to estimate the potential for rainwater harvesting in educational institutions in Lahore, which can help to promote the use of ponding areas after rain solutions in the region.(Siddiqui et al., 2020)

Another study which is conducted in Bangkok on the rainwater harvesting is also included in our literature. The objective of this study was to measure the feasibility of a rainwater harvesting system in Thailand. The RWH models were developed in the largest metropolitan area of Bangkok, Thailand using water modeling and financially sound assumptions. This rainwater harvesting system was a system of cost analysis, net present value or NPV. In short, depending on the methods used, the accumulated water in the water can reduce the volume of the water valve and the amount of water used in the water is reduced. Rainfall Statistics sponsor Thailand promotes tap water quality in a project implemented in Thailand. A case study that evaluated the potential for rainwater harvesting in a building in Bangkok, Thailand. Using a simulation model, this study evaluated storm water runoff from building construction and the benefits of using this water for non-conventional purposes. The researchers found that the building had a high potential for rainwater harvesting, with an estimated annual yield of over 1.2 million liters of water. In addition, they found that using this water for non-potable purposes, such as irrigation and flushing toilets, could reduce household water use and support sustainable water management. It concludes that rainwater harvesting can be a viable option for meeting the water needs of buildings in urban areas and can contribute to sustainable water management. In term of urban flooding in Lahore, rainwater harvesting could be one of several potential strategies to mitigate effects of urban flooding. Some other strategies include improved drainage system, green infrastructure such as rain gardens etc. (Monjaiang et al., 2018)

In another paper, researchers examine the installation of rainwater harvesting systems in residential areas of Lahore, Pakistan. We have identified the elements that influence the absorption of rainwater collection systems. Learn how rainwater harvesting technologies affect water quantity and quality in residential areas. Lahore, Pakistan's second largest city with a population of over 11 million, is a good example. During the survey, information was collected from 100 households in different districts of Lahore. The information was collected using a structured questionnaire, which asked about the population's demographic data, water consumption habits, and understanding and acceptance of rainwater harvesting equipment. According to the survey results, a rainwater harvesting system was installed in only 32% of the residences surveyed in the study. The expansion of storm water harvesting systems is determined by public education, awareness of the benefits of storm water harvesting and the costs of installation. Both the availability and quality of water in residential buildings have been improved with the installation of rainwater harvesting machines. It also emphasizes the importance of training and financial incentive programs to encourage the installation of rainwater harvesting systems in Lahore and other Pakistani cities with a similar climate. To solve the growing problem of water scarcity in large areas of Pakistan, it shows the potential of rainwater harvesting as sustainable water management. The results of this study can be used as a resource for urban climate because it provides information on the benefits of rainwater harvesting, its absorption patterns, and so on. This knowledge can be used to promote the widespread use of rainwater harvesting in buildings. (Nawaz, 2021)

Near the Pakistani model city of Lahore province, the study investigated the possibility of rooftop rainwater harvesting. In Model City, Lahore, data were collected on water use, roof area and rainfall conditions. To determine the soil capacity required for rooftop rainwater collection, the data was analyzed using a rainfall collection model. According to the report, Model Town has an average annual rainfall of 746 mm and an annual harvesting capacity of 2.22 million liters of rooftop rainwater. However, many variables, such as roof thickness, rainfall patterns, and water usage, affect the effectiveness of the system. The study demonstrates the potential of rooftop rainwater harvesting as a sustainable water management solution in urban residential areas in Pakistan and provides insightful information for policy makers and urban planners to support adoption. Harvesting rainfall mainly due to water scarcity, RWH is widely recognized in many parts of the world as an important source of water for domestic hydropower. The main problem in Pakistan is the scarcity of drinking water due to the increasing viscosity of the population and the decreasing number of permeable shells. In this article, precipitation can be used as a reliable source of fresh water. Geospatial methods were used to calculate the rainwater harvesting potential of the site's roof and found that average annual rainfall can produce up to 3.45 million liters of water per year. Using GIS maps, the researchers also identified areas that would be suitable for storm water harvesting systems. In addition, rainwater harvesting can reduce dependence on groundwater resources and support sustainable water management in major cities. The results of this study lead us to the following conclusion: promoting the use of rainwater harvesting systems in residential areas can be an effective strategy to solve the current water scarcity problem in urban areas in Pakistan. (Siddiqui & Siddiqui, 2018)

The terms "bioswales" and "sup inserts" are now popular in the field of environmental engineering. A U- or V-shaped depression in the landscape called a levee is intended to improve water quality by allowing pollutants to settle and reducing storm water ingress. The purpose of the concrete installation is to filter gypsum and solvents from the rainwater before it enters the sewer system. These are pollutant emission traps that are treated with positive pollutants that are placed in half of the network. The article "Evaluating the effectiveness of Bioswales and catch basin inserts for treating urban storm water runoff in Detroit, Michigan" describes a study that evaluated the effectiveness of biological treatment and drainage systems for urban storm water treatment in Detroit, Michigan. Contaminants such as trash, fertilizers, and metals can be removed from storm water using bio filters and traps. The researchers found that treatment effectiveness varied depending on the life or design of the bottom liner, as well as the characteristics of the storm water. These storm water management systems can improve urban rainfall and improve water quality in large cities, according to the study's findings. The results of the study shed light on the potential of green infrastructure, such as life buoys and fishing boats, to manage storm water runoff in a metropolitan environment. It provides information on how these solutions help improve water quality and reduce pollutants in storm water runoff. Using this data, recommendations can be made to promote the use of green infrastructure for storm water management in Lahore. (Tummala & Dittrich, 2019)

This article evaluates the possibilities of using rainwater at home, taking into account the area of the pool and the need for water use. Analysis of the relationship between water demand for pools and final domestic use. To determine the factors that determine the possibilities and efficiency of domestic rainwater use. The study area, which consists of five residential areas with different social characteristics, is located in Bandung, Indonesia. We collected 85 households in the basin of the studied area, the amount of precipitation and the need for used water. In order to determine the possibilities of domestic use of rainwater, we analyzed the data using the rainwater collection model. The results of the study showed that different variables, such as the catchment area, the amount of precipitation and the final water demand, influenced the possibilities of households to utilize rainwater. The catchment area is positively correlated with the possibility for using rainwater, while end-use water demand is negatively correlated. Furthermore, it says that rainwater utilization is feasible and efficient in households with larger catchment areas and lower end-use water demand. In conclusion, the article highlights the possibility for using rainwater in households as a sustainable water management strategy in Bandung, Indonesia. This research provides valuable insights for policymakers and urban planners to promote the implementation of rainwater harvesting systems in households, particularly in areas with high rainfall and low access to safe water supply. The Findings can help identify potential barriers to the use of technologies for collecting rainwater in households in Lahore. Policy makers could encourage greater use of rainwater harvesting systems by removing these barriers, potentially reducing the impact on municipal water delivery systems. (Takagi et al., 2018)

The six strips of Parindini desert from the cities of Dakos (Bangladesh) and Mumbai (India) are socially and economically prosperous. They employ a mixed methods approach that includes both qualitative and quantitative data collection methods. Focus groups, interviews with key informants and community members, senior government officials and other stakeholders were used for qualitative data, and household surveys for quantitative data. It shows urban flooding has a significant impact on the livelihoods, health, and well-being of communities in both cities, often leading to displacement and loss of property. Coping strategies adopted by the communities were found to be primarily reactive. The researcher identified several potential measures for adapting to urban flooding, including improving drainage systems, increasing the capacity of local authorities to respond to flooding, enhancing community preparedness and resilience, and promoting sustainable urban planning and development. Finally, this study highlights the critical need for rapid adaptation strategies to address the increasing risk of urban flooding in South Asia. To understand how urban flooding affects the socio-economic status of residents of two South Asian cities. To investigate current urban flood control mechanisms. To find possible solutions to the flooding of the two cities. This study was conducted in Mumbai, India and Dhaka, Bangladesh, both cities in South Asia. Both cities are crowded and often flooded, especially during the monsoon season. Using a mixed methods strategy that included qualitative and quantitative data collection methods. Focus groups and key informant interviews with community residents, local government representatives and other stakeholders were used to collect qualitative data. Both sites are run with representative positions of households to collect quantitative data conducted from household surveys. The coping strategies adopted by the communities were found to be primarily reactive, rather than proactive. These included measures such as sandbagging, moving to higher ground, and seeking assistance from neighbors and local authorities. This research identified several potential measures for adapting to urban flooding in the two cities. These included improving drainage systems, increasing the capacity of local authorities to respond to flooding, enhancing community preparedness and resilience, and promoting sustainable urban planning and development. The findings of this study can be used by highlighting the importance of adapting to urban flooding in order to reduce its impact. It provides data on the strategies used in Dhaka and Mumbai to adapt to urban flooding, including infrastructure improvements, land use planning, and community participation. This information used to develop recommendations for promoting adaptation to urban flooding in Lahore. (Pervin et al., 2019)

In another paper, we explore the use of smart storm water harvesting devices as a potential means of reducing urban flooding. The location of the study was the city of Newcastle-upon-Tyne in the United Kingdom. The aim of the research was to find out whether it is possible to use intelligent rainwater storage systems to reduce the consequences of flooding in metropolitan areas. To conduct this research, the researchers used a combination of data collection methods. They used smart rain gauges to collect real-time rainfall data and monitor the inflow and outflow of rainwater from the storage tanks. In addition, sensors were used to measure the water quality and the level in the tanks. The researchers concluded that smart rainwater storage systems could be an effective solution to mitigate urban flooding. They found that the use of these systems could reduce the volume of runoff that enters the drainage system during periods of heavy rainfall. This would reduce the risk of flooding in populated areas. The researchers also found that the performance of storm water harvesting devices can be improved through real-time monitoring and control. The use of sensors and monitoring systems would

allow for the collection of real-time data, which could be used to inform decision-making and optimize the operation of the rainwater storage systems. Overall, this study suggests that the use of smart rainwater storage systems could be an effective solution to mitigate the impact of urban flooding. The effectiveness and efficiency of these systems in reducing flood risk in urban areas can be improved through real-time monitoring and control. The results highlight the potential of smart rainwater storage systems as a solution to the problem, providing information on the effectiveness of the system in reducing flood risk and improving water management during heavy rains. This data can be used to make recommendations to promote the deployment of smart rainwater harvesting systems in Lahore. (Liang et al., 2019).

Furthermore this article author examines impact of paving front gardens in urban flooding in residential areas in the city of Manchester, United Kingdom. Study area for this research was residential areas with front gardens in the city of Manchester. To assess the effect of different types of pavement on surface water flow, the researchers examined the front gardens in the study area. A hydrological model has also been created to simulate the effect of paved forecourts on urban flooding. Survey data was analyzed using statistical analysis to evaluate the effectiveness of various mitigation strategies to reduce the impact of paved front yards on urban flooding. Researchers found that paved front gardens can significantly increase surface water runoff and urban flooding, both in the present and in the future. This study revealed that the percentage of paved front gardens in study area had increased from 26% in 2001 to 46% in 2016, with a corresponding increase in surface water runoff. The research also showed that climate change and population growth will exacerbate the problem of urban flooding in the future. It also found that proper mitigation techniques are needed to reduce the impact of paving front yards on urban flooding. To reduce the negative effects of concrete front gardens on surface water flow, the researchers recommended the use of permeable pavement and green infrastructure. This study highlights the need for appropriate mitigation strategies and the impact of front yard paving on urban flooding. The combination of survey data, hydrological modeling, and statistical analysis provides a comprehensive analysis of the problem and potential solutions. The study can be applied to designing policies and interventions to mitigate the impact of urban flooding in residential areas. (Kelly, 2016)

Civilian flooding is a major problem in China due to the rapid expansion of large cities, which affects both public safety and people's quality of life. Urban flooding has recently received more and more attention. We analyze and summarize the frequency, extent and losses of recent urban flood data, and generalize the causes and current status of China's civil flood problems in terms of civil climate change, civil planning, civil construction, civil operation and civil policy. This article focuses on the metropolitan regions of China. The research focuses on the evolution of flooding in China's cities from 1949 to 2017. The data analysis method used in study was a statistical analysis and a collection of literature, reports and policies related to urban flooding in China. The researchers collected and analyzed data on the frequency, duration and intensity of flooding. Infrastructure development, urbanization and climate change are also seen as urban flooding. The researcher used a combination of quantitative and qualitative data to thoroughly examine the evolution of urban flooding in China. The study focuses on how urban flooding in China changed between 1949 and 2017. The researchers collected and analyzed data on flood frequency, duration, and intensity over time. They also analyzed factors contributing to urban flooding, including urbanization, climate change, and infrastructure development. The article on the evolution of urban flooding in China could be a

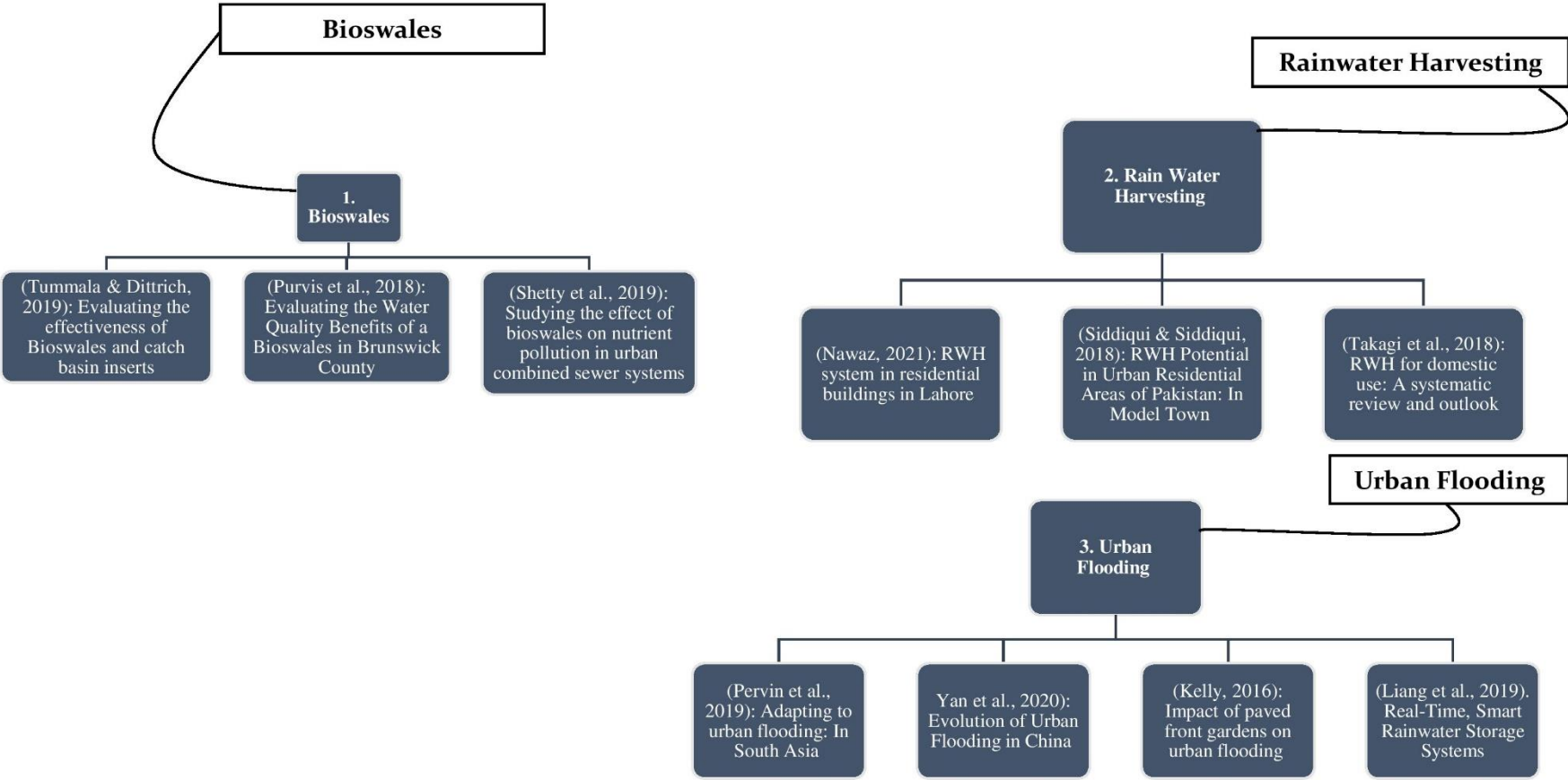
useful resource urban flooding in Lahore, helping to identify key issues, best practices, and potential solutions to the problem of flooding in rapidly growing urban areas. (Yan et al., 2020)

This study evaluated the effectiveness of a bioswales in treating storm water runoff. The bioswales, located in a parking lot in Brunswick County, NC, was designed to capture and filter storm water before it enters the nearby waterways. The study describe that the bioswales was effective in removing pollutants such as suspended solids, nutrients, and metals from the storm water. The researchers also found that the bioswales was able to retain most of the storm water during small to moderate storm events. Study area was a 2,800-square-meter bioswales located on the campus of Brunswick Community College, Brunswick County, North Carolina. The bioswales was designed to capture and treat storm water runoff from the surrounding area and improve water quality in the adjacent stream. As part of the study's data collection technique, water samples were collected and analyzed at the entrance and exit of the bioswales. Water samples were taken every two weeks for ten months, from October 2017 to July 2018. Water samples were tested for a number of characteristics such as total suspended solids, total nitrogen, total phosphorus and fecal coliforms. The examination of the study's data revealed that bioswales were successful in enhancing water quality by lowering the amounts of TSS, TN, TP, and fecal coliform bacteria in the storm water runoff. The study found that the bioswales was able to remove an average of 62% of TSS, 56% of TN, 63% of TP, and 84% of fecal coliform bacteria from the storm water runoff. The article demonstrates the potential of bioswales as a low-cost and effective storm water management practice for improving water quality in urban areas. The study provides valuable information for policymakers, planners, and practitioners who are interested in implementing bioswales or other green infrastructure practices for storm water management. The research concludes that bioswales can be effective storm water treatment practices and can provide water quality benefits for urban areas. The findings can be relevant by highlight the potential of bioswales as a solution to the problem of poor water quality in urban areas impacted by flooding events, which provides data on the effectiveness of the bioswales in removing pollutants from storm water runoff, which can be used to develop recommendations for promoting the adoption of bioswales in Lahore. (Purvis et al., 2018)

The article "Studying the Effects of Bioswales on Nutrient Pollution in Urban Combined Sewer Systems" describes research looking at how well bioswales worked to reduce nutrient pollution in cities with combined sewer systems. According to the paper's study, bioswales are excellent at removing nutrients from storm water, including nitrogen and phosphorus, which are among the leading causes of nutrient pollution in urban waterways. The researchers also found that the effectiveness of bioswales varied depending on the design and location of the bioswales, as well as the characteristics of the storm water runoff. This research concludes that bioswales can be an effective tool for reducing nutrient pollution in urban areas and improving water quality. Moreover, this article aimed to reduce pollutants from the urban combined sewer system. This article advances our understanding the role that bioswales can play to reducing nutrient pollution in urban environments, and provides guidance for the design and implementation of bioswales in combined sewer systems. By achieving these objectives, the article has the potential to inform policy and practice in the field of storm water management and contribute to the development of more sustainable and resilient urban environments. The data analysis method used in the research was a combination of field measurements and laboratory analyses. The researchers collected water samples from various locations in the

bioswales and adjacent sewage system and analyzed them for nutrients. They then compared nutrient levels between different sampling sites to assess the effectiveness of bioswales in removing nutrients from runoff. Statistical analysis was also performed to test the significance of the results. The findings can help to identify potential challenges and barriers to the adoption of bioswales in urban areas of Lahore. By addressing these challenges, policymakers can promote the widespread adoption of bioswales, which help to reduce nutrient pollution and mitigate impact of urban flooding in Lahore. (Shetty et al., 2019)

# Literature Map



## **CHAPTER 03: METHODOLOGY**

## Study Area

The study area for this thesis will focus on the city of Lahore and its surrounding areas. Lahore is located in the Punjab province of Pakistan. Its latitude and longitude are 31.2504°N & 74.3587°E, respectively. The research will involve identifying the area's most vulnerable to urban flooding, analyzing the potential for rainwater harvesting in these areas, and assessing the effectiveness of using rainwater collection as a method for combat urban flooding. This study also involve examining the existing policies and regulations related to rainwater harvesting in Lahore and proposing recommendations for their improvement.

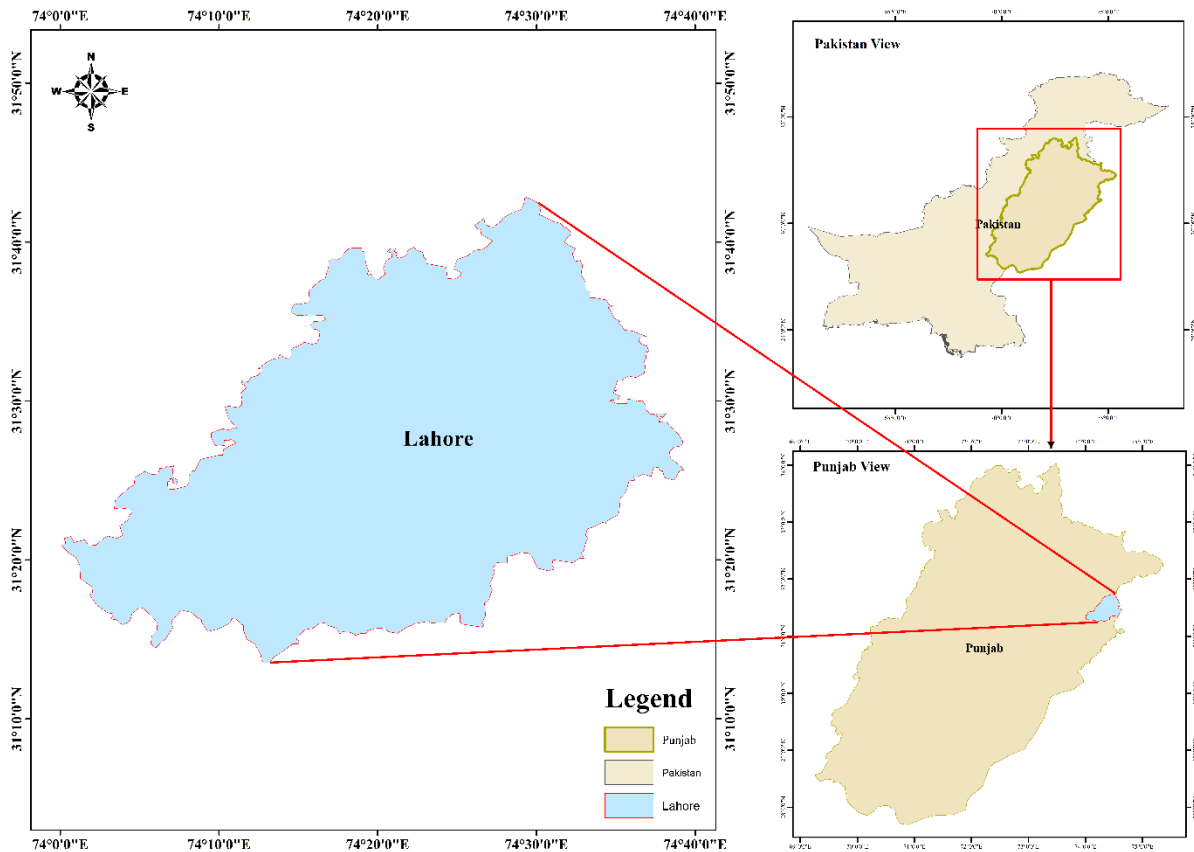


Figure 1. Study Area Map (Lahore)

## Sample Size Calculation

The formula for calculating sample size:

$$n = (Z^2 * p * (1-p)) / E^2$$

Where:

n is the sample size

Z is the Z-score corresponding to the desired level of confidence (e.g., 1.96 for 95% confidence)

p is the estimated proportion of the population with the characteristic of interest

E is the desired margin of error as a proportion

To apply this formula to our scenario, where the population size is 13,979,000 and the desired level of confidence is 95% with a margin of error of 5%, we would need to estimate the proportion of the population with the characteristic of interest. Let's assume that this proportion is 50% (for simplicity).

Plugging these values into the formula, we get:

$$n = (1.96^2 * 0.5 * 0.5) / (0.05^2) = 384.16$$

Rounding up to the nearest whole number, we get a sample size of 385.

Therefore, to achieve a 95% confidence level with a 5% margin of error, we would need to collect data from a sample size of 385 individuals from the population of 13,979,000.

## Questions and Questionnaire

Sr. No	Questions	Scale	Source
<b>Urban Flooding</b>			
1.	In your perspective, who is responsible for urban flooding in your community?		(Rainey et al., 2021)
2.	Do you feel that in this time of flood, the support of Govt. was good?	1 - 5	(Gandhi & Agnihotri, 2022)
3.	Is the cleaning of the area (sewer cleaning before monsoon) was better than the earlier?		(Gandhi & Agnihotri, 2022)
4.	Have you ever face damages from urban floods?		(Gandhi & Agnihotri, 2022)
5.	Is the damage from flooding is on a lesser than the earlier?		(Gandhi & Agnihotri, 2022)
6.	Have you ever see the roads damages by urban flooding?		(Gandhi & Agnihotri, 2022)
7.	Is the recovery period in post flooding has been reduced due to Self Help Groups (Self-help groups are informal associations of people who meet regularly to discuss common problems)?		(Gandhi & Agnihotri, 2022)
8.	Do you feel that SHGs are essential for flood management activities?		(Gandhi & Agnihotri, 2022)
9.	Do you think that the recovery period in post flooding has been reduced due to government actions?		(Gandhi & Agnihotri, 2022)
10.	Do you feel that due to SHGs the damaged has been reduced?		(Gandhi & Agnihotri, 2022)
11.	Do you feel that due to governmental action in urban flooding the damaged has been reduced?		(Gandhi & Agnihotri, 2022)
12.	In your perspective, which one of the following is chief causes of Urban Flooding?		
13.	In your perspective, which one of the following is a major impact of Flooding on communities in the city?		(Mboma, 2021)
14.	In your perspective, which one of the following is a prominent diseases spread after flooding?		(Leandro et al., 2022)
15.	In your perspective, which one of the following is a major impact of flooding on city infrastructure?		(Mboma, 2021)

<b>Rainwater Harvesting</b>			
1.	Do you have any idea about rainwater harvesting tank in your house?		(Al-Batsh et al., 2019)
2.	Is your plan in future for giving a rainwater tank in your house?	1	(Al-Batsh et al., 2019)
3.	If, Yes than what is your current Rainwater Tank Capacity (In Liters)?	-	(Al-Batsh et al., 2019)
4.	Uses of Rainwater?	5	(Donohue et al., 2017)
5.	Do you clean your water tank regularly?		(Donohue et al., 2017)
6.	Name any one road which you have observed urban flooding during monsoon?		(Gandhi & Agnihotri, 2022)
7.	Water in a rainwater catchment system should be tested regularly?		(Donohue et al., 2017)
8.	Proper Drainage Pattern Provided in the city?	1	(Naik et al., 2022)
9.	Were the members of SHGs were friendly with you?	-	(Gandhi & Agnihotri, 2022)
10.	Were the members of SHGs were easily accessible to you?	5	(Gandhi & Agnihotri, 2022)
11.	Were the government support easily accessible to you during flooding?		(Gandhi & Agnihotri, 2022)
12.	Have you ever been relocated from your residence by the government in case of flooding damage?		(Gandhi & Agnihotri, 2022)
13.	What should be the possible solution to handle urban flooding?		(Gandhi & Agnihotri, 2022)

*Table 1. Questionnaire*

## Framework

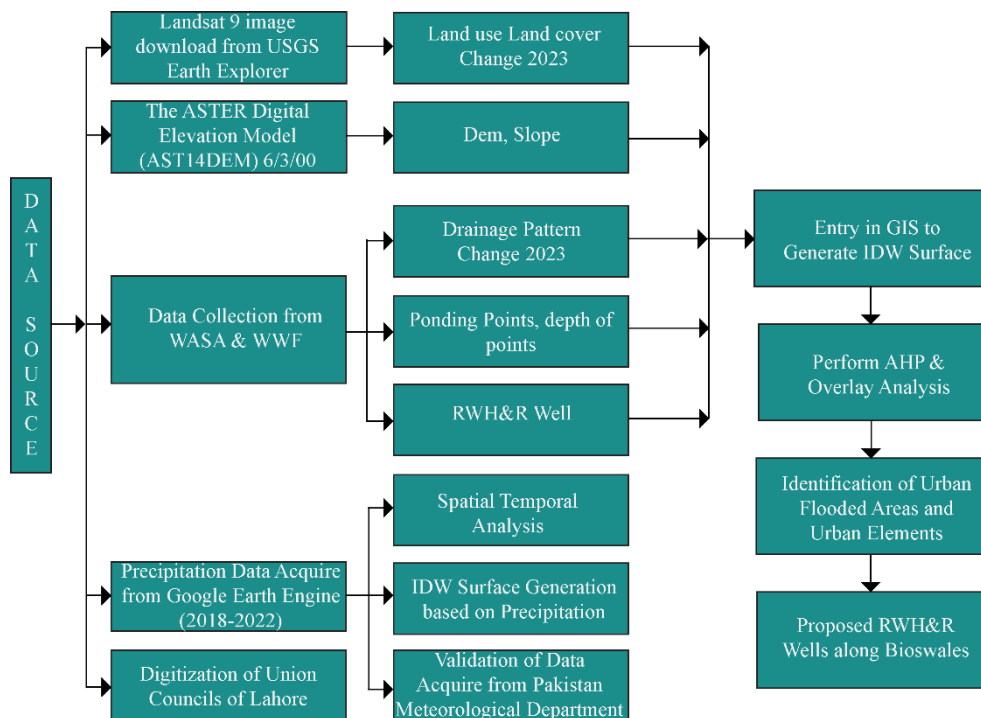


Figure 2. Research Framework

### Land use Land cover Change

The term "Land Use Land Cover Change" (LULCC) describes how human activities or natural processes that alter the Earth's physical, chemical, or biological characteristics can alter or transform the Earth's surface.

### Drainage Pattern

Drainage pattern refers to the arrangement or layout of natural streams, rivers, and other watercourses within a drainage basin or watershed. It is determined by the topography and geology of the area, as well as by the climatic and hydrological conditions that affect water flow.

### Spatial Temporal Analysis

Spatial-temporal analysis refers to the study of how spatial patterns and relationships change over time, and how temporal patterns and relationships vary across different spatial scales. It involves the integration of spatial and temporal data, and the use of analytical methods to explore, visualize, and model complex spatiotemporal phenomena.

### Overlay Analysis

Overlay analysis is a GIS (Geographic Information System) technique involves a composite layer to create new layers of geographic information. This analyzes interaction between the spaces and to identify areas where different features overlap or coincide.

### **IDW Surface**

IDW Surface refers to the "Inverse Distance Weighting" surface, which is a type of interpolation technique used in geographic information systems (GIS) to extrapolate the values of a variable from values recorded at adjacent sampling locations to unsampled locations.

### **Engine for Google Earth**

Using the cloud, Google Earth Engine provides a platform for analyzing and visualizing geospatial data. It provides access to a vast archive of data and powerful computing resources, enabling users to explore and study the earth's surface and changes over time. It is useful for applications such as environmental monitoring, disaster response, and planning. The platform allows users to run complex geospatial analyses using a simple web-based interface and a powerful set of tools and algorithms.

### **Analytical Hierarchical Process**

A decision-making framework and a mathematical method called Analytic Hierarchy Process (AHP) are used to methodically analyze and rank multiple criteria or options. Pairwise evaluation of criteria and options based on relative importance or preference involves breaking down complex questions into a hierarchical framework. AHP's methodical approach to quantify and summarize subjective judgments enables decision makers to reach consensus and make informed decisions, taking into account both qualitative and quantitative aspects.

### **Euclidean Distance**

Euclidean distance is a simple way to calculate the distance between two spaces. It determines the straight-line distance between two places, which is comparable to the length of a straight line walk. It is a typical method of determining the separation between two places or things, which helps us understand their spatial interaction and proximity.

## **CHAPTER 04: DATA COLLECTION & ANALYSIS**

## Flood Risk Assessment

	<b>Factors</b>		<b>Class</b>	<b>Descriptive Level</b>
1	<b>LULC</b>	Build-up Area	Build-up Area	Very High
		Barren Soil	Barren Soil	Low
		Vegetation	Vegetation	Very Low
		Water Body	Water Body	High
2	<b>Slope</b>	0 - 89.011673	5	Very High
		89.011673 - 89.405840	4	High
		89.405840 - 89.792007	3	Moderate
		89.792007 - 89.966164	2	Low
		89.966164 - 89.999741	1	Very Low
3	<b>RWRW</b>	0.167091 - 0.25567	5	Very High
		0.119782 - 0.167091	4	High
		0.083546 - 0.119782	3	Moderate
		0.047309 - 0.083546	2	Low
		0 - 0.047309	1	Very Low
4	<b>RWHW</b>	0.221252 - 0.318752	5	Very High
		0.170001 - 0.221252	4	High
		0.118751 - 0.170001	3	Moderate
		0.06625 - 0.118751	2	Low
		0 - 0.06625	1	Very Low
5	<b>Rainfall</b>	65.685318 - 68.465508	5	Very High
		63.323231 - 65.685318	4	High
		60.672089 - 63.323231	3	Moderate
		56.766445 - 60.672089	2	Low
		50.394932 - 56.766445	1	Very Low
6	<b>Road Network</b>	0 - 657.748162	5	Very High
		657.748162 - 1775.920037	4	High
		1775.920037 - 3091.41636	3	Moderate
		3091.41636 - 4801.561581	2	Low
		4801.561581 - 8353.401654	1	Very Low
7	<b>Ponding Sites</b>	0 - 0.054819	5	Very High
		0.054819 - 0.109637	4	High
		0.109637 - 0.163238	3	Moderate
		0.163238 - 0.220493	2	Low
		0.220493 - 0.31064	1	Very Low
8	<b>Drainage Network</b>	11198.249196 - 17736.357422	5	Very High
		7929.195083 - 11198.249196	4	High
		4868.803998 - 7929.195083	3	Moderate
		2017.075942 - 4868.803998	2	Low

		0 - 2017.075942	1	Very Low
9	<b>DEM</b>	134 - 199	5	Very High
		199 - 204	4	High
		204 - 209	3	Moderate
		209 - 215	2	Low
		215 - 256	1	Very Low
10	<b>Area Under Water</b>	0 - 893.306348	5	Very High
		893.306348 - 1786.612695	4	High
		1786.612695 - 2815.26849	3	Moderate
		2815.26849 - 4033.413509	2	Low
		4033.413509 - 6902.821777	1	Very Low

Table 2. Flood Risk Assessment

## LULC

LULC influence the interaction between land surfaces and water during rainfall. To assess the flood risk of the study area, AHP analysis was used. The study included four categories, each with a different level of flood risk: Buildup, Barren Land, Vegetation and Water Body. Due to significant urban expansion and insufficient natural drainage, the Buildup area is classified as Very High, indicating a high risk of flooding. Because barren land cannot hold water, they are considered to be at very low risk of flooding. Due to their ability to absorb and delay runoff, vegetated areas were assigned a low classification, indicating a significantly reduced risk of flooding. Waterbody are considered natural resources because they can increase water accumulation during heavy rains, which pose an acceptable risk of flooding.(Nsangou et al., 2022)

Classes	Description (Mia et al., 2023)
Vegetation	Open Spaces, Parks,
Buildup	Infrastructure, Road Network, Residential, Commercial, Industrial, Institutional, Mixed-Use
Barren Land	Soil, Desert, Sand, Rocks,
Water Body	River, Lake, Pond, Canal, Nullah,

## Slope

Slope is an important component in flood risk assessment because it influence the movement of water during rainfall. The analysis identified five slope categories: very high, high, moderate, low and very low. Areas with very high (5) slopes have steep topography, which increases the of rapid water flow. Areas with high (4) slopes have a relatively steep topography, which also increases water flow and decrease the risk of flooding. Areas with a moderate (3) slope have low ground and a low risk of flooding. Low (2) slope areas represent gently sloping terrain that reduces water flow and generally increase the risk of flooding. Areas with very low (1) slopes have an almost flat topography, which potentially increase the risk of flooding.(Mia et al., 2023)

## RWHW

Rainwater Harvesting Wells influence on water management and flood mitigation in flood risk reduction are evaluated using AHP analysis. While wells classified as high (4) reduce flood risk at a lower level, wells classified as very high (5) indicate limited capacity to reduce flood

risk. While shallow (2) wells reduce the risk of high flooding, (3) wells mitigate the risk of flooding with them. Very low level wells (1) provide the best in reducing the risk of flooding.(Veerappan & Sayed, 2020)

### **RWRW**

Rainwater recharge wells influence water management and flood mitigation strategies. AHP analysis performed to assess the flood risk of the study area. On a scale of 1 to 5, where 5 represents the highest level of flood risk (very high) and 1 represents the lowest level of flood risk (very low), the scale is used in the analysis. The effectiveness of rainwater harvesting wells in reducing flood risk is analyzed using AHP analysis. While wells classified as high (4) reduce flood risk somewhat lower, wells classified as very high (5) indicate limited effectiveness in reducing flood risk. Shallow (2) wells greatly reduce the flood risk, moderate (3) wells moderately reduce the flood risk. Wells with a very low (1) level give the best results in reducing the risk of flooding. (Veerappan & Sayed, 2020)

### **Rainfall**

Rainfall directly influence the volume and intensity of the water, which can cause flooding. The rainfall-related flood risk of the study area was assessed using the Analytic Hierarchy Analysis (AHP). The level of flood risk used in the analysis is measured on a scale of 1-5, where 5 represents the highest level (Very High) and 1 the lowest level (Very Low). The impact of rainfall intensity on flood risk is assessed using AHP analysis. While a high (4) amount of precipitation means a slightly increased risk of flooding, a very high (5) amount of precipitation indicates a much higher probability of flooding. Low (2) rainfall helps reduce the risk of flooding, while moderate (3) rainfall indicates a moderate level of flood risk. A very low (1) rainfall rating indicates a low chance of flooding.(Y. O. Ouma & Tateishi, 2014)

### **Road Network**

Road network is important in flood risk assessment because it affects flood connectivity, accessibility and water flow. The AHP study assesses how vulnerable the road network is to flooding and how it affects this risk. Roads rated very high (5) are extremely vulnerable to flooding and pose a high risk of disruption and damage during a flood. While moderate (3) roads indicate moderate flood susceptibility, high (4) roads indicate significantly increased flood risk. Low (2) tracks indicate reduced flood risk and lower vulnerability, while very low (1) tracks indicate little or no flood risk and high resilience.(Y. Ouma & Tateishi, 2014)

### **Ponding Sites**

Ponding sites are important in flood risk assessment because they directly affect local water dynamics and cause flooding. AHP analysis conducted to access the flood risk associated with ponding sites on a scale of 1-5, where 5 represents the highest level (Very High) and 1 the lowest level (Very Low). The AHP study examines how vulnerable lake sites are and how they affect flood risk. Ponds rated very high (5) have a high accumulation potential and a higher risk of flooding, making them particularly vulnerable to flooding. While moderate (3) levels indicate a level of flood vulnerability, high (4) levels indicate significantly increased flood risk. Low (2) basins indicate reduced flood risk and lower vulnerability, while very shallow (1) basins indicate very low flood risk and high resilience.(Veerappan & Sayed, 2020)

### **Drainage Network**

Drainage Pattern directly affects the transport and management of water during storms and floods, the runoff pattern is critical to flood risk assessment. AHP analysis conducted to assess the flood risk associated with drainage pattern on a scale of 1-5, where 5 represents the highest level (Very High) and 1 the lowest level (Very Low). The AHP study assesses the impact of the drainage network on flood risk and its sensitivity. Drainage networks rated very high (5) are highly vulnerable, increasing the risk of both inadequate drainage and flooding. While high (4) drainage networks indicate significantly increased flood risk. Moderate (3) drainage networks indicate moderate flood susceptibility, while low (2) drainage networks indicate reduced flood risk and relatively lower vulnerability and very low (1) drainage networks indicate negligible flood risk and high resilience. (Nsangou et al., 2022)

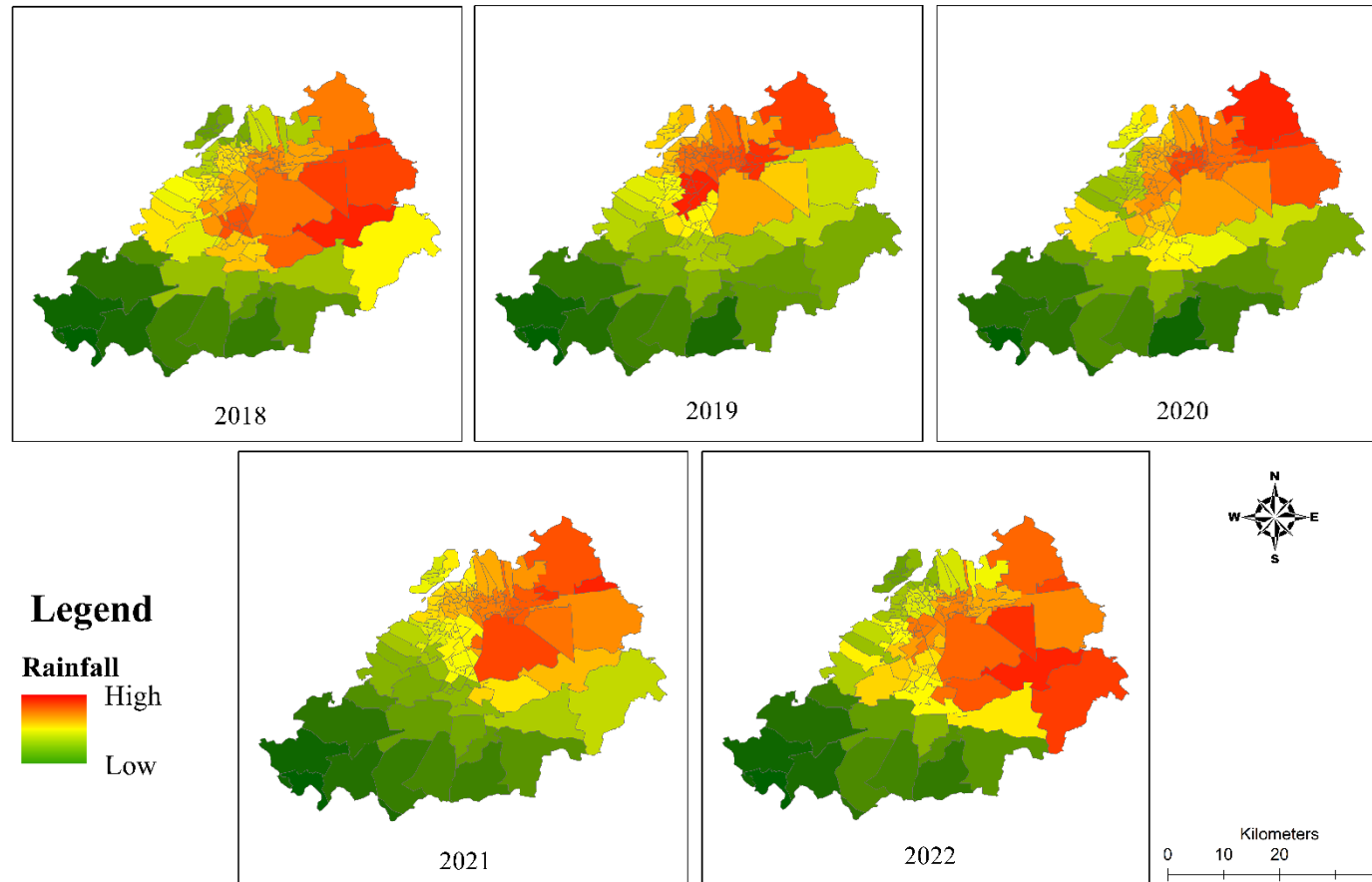
### **DEM**

Digital elevation model (DEM) that provides useful data on the topography and elevation of the study area is crucial for flood risk assessment. AHP analysis has been conducted to assess the flood risk associated with DEM (Digital Elevation Model) on a scale of 1-5, where 5 represents the highest level (Very High) and 1 the lowest level (Very Low). The AHP study assesses how the DEM affects flood risk and how vulnerable it is. A DEM with a very high (5) rating indicates areas that are at low elevations or are susceptible to significant flooding. While a moderate (3) DEM indicates a moderate level of flood vulnerability, a high (4) DEM indicates a significantly increased flood risk. While a very low (1) DEM indicates negligible flood risk and strong resilience, a low (2) DEM indicates reduced flood risk with relatively lower vulnerability. (Mia et al., 2023)

### **Area Under Water**

Area Under Water (AUW) is important in determining the magnitude and severity of flooding in a given area, making it a key factor in flood risk assessment. AHP analysis has been conducted to assess the flood risk associated with AUW (Area Under Water) on a scale of 1-5, where 5 represents the highest level (Very High) and 1 the lowest level (Very Low). The AHP study assesses the exposure of the underwater area and the impact on flood risk. Areas rated very high (5) have a high risk of flooding, indicating that large areas are vulnerable to flooding. While moderate (3) areas indicate a level of flood vulnerability, high (4) areas indicate a significantly increased flood risk. Low-lying (2) areas have lower flood risk and vulnerability, while very low-lying (1) areas have very low flood risk and high resilience. (Mia et al., 2023)

## Five Year Rainfall Analysis in Lahore UCs Wise



This GIS-generated map shows the five-year rainfall patterns of Lahore Union Council wise from 2018 to 2022. The map uses many categories to show different rainfall levels in a city, from high to low. The different boundaries of each union council provide a local overview of rainfall trends over five years period.

Sr. No.	Name	2018	2019	2020	2021	2022
1	Rehman Pura, UC 107	59.0075	70.63958	74.82167	76.20975	66.15542
2	Sodiwal, UC 92	57.72108	66.99742	72.777	73.93258	64.56575
3	Rashidpura, UC 43	59.12783	70.26944	75.60533	80.92653	65.68414
4	Bhangali, UC 61	60.34958	67.60892	74.74983	80.891	68.315
5	Ghaziabad, UC 56	59.18483	70.22392	75.93533	80.83833	66.05108
6	Sultan Mehmood, UC 38	59.18483	70.22392	75.93533	80.83833	66.05108
7	Muhammad, UC 37	57.36725	69.82158	74.656	78.01717	63.935
8	Darogha Wala, UC 42	59.12783	70.26944	75.60533	80.92653	66.05108
9	Muslim Abad, UC 39	56.88033	68.7085	74.86525	79.10992	64.3225
10	Salamat Pura, UC 40	59.01383	70.3605	74.94533	81.10292	65.50067
11	Bhaseen, UC 52	59.06617	68.88992	76.08383	81.91258	65.3095
12	Hadiara, UC 65	57.70683	58.4745	69.68158	73.40333	68.18425
13	Gulgasht Colony, UC 88	57.72108	66.99742	72.777	73.93258	64.56575
14	Barki, 62	61.88564	65.23589	72.90036	77.96494	68.46561
15	Minhala, UC 53	60.14167	65.54014	75.88833	79.59636	65.89128
16	Dograi Kalan, UC 51	60.80833	69.52342	78.53175	82.96883	68.16
17	Bhaseen, UC 50	59.35633	70.33175	78.54108	81.40392	66.38075
18	Mujahidabad, UC 47	59.18483	70.22392	75.93533	80.83833	66.05108
19	Angori Bagh, UC 46	59.18483	70.22392	75.93533	80.83833	66.05108
20	Baghbanpura, UC 36	59.18483	70.22392	75.93533	80.83833	66.05108
21	Crown Park, UC 33	59.18483	70.22392	75.93533	80.83833	66.05108
22	Muhammad Colony, UC 35	57.36725	69.82158	74.656	78.01717	63.935
23	Madhu Lal Hussain, UC 34	59.18483	70.22392	75.93533	80.83833	66.05108
24	Rizwan Park, UC 91	57.72108	66.99742	72.777	73.93258	64.56575
25	Gujjar Pura, UC 16	57.36725	69.82158	74.656	78.01717	63.935
26	Bhaghat Pura, UC 15	54.7995	68.13792	73.3545	76.23908	62.80783
27	Shad Bagh, UC 23	58.50917	70.1785	74.32167	78.00475	64.11325
28	Begum Pura, UC 18	59.18483	70.22392	75.93533	80.83833	66.05108
29	Rehmatpura, UC 17	59.18483	70.22392	75.93533	80.83833	66.05108
30	Chah Miran, UC 19	59.18483	70.22392	75.93533	80.83833	66.05108

31	Bilal Park, UC 20	58.95961	70.20878	75.39744	79.89381	65.40514
32	Makhanpura, UC 21	58.50917	70.1785	74.32167	78.00475	64.11325
33	Kot Khawaja Saeed, UC 22	58.73439	70.19364	74.85956	78.94928	65.40514
34	Wassanpura, UC 24	58.50917	70.1785	74.32167	78.00475	64.11325
35	Babu Sabu, UC 90	57.68628	66.69178	72.30781	73.526	64.11542
36	Faiz Bagh, UC 25	58.50917	70.1785	74.32167	78.00475	64.11325
37	Farooq Ganj, UC 26	58.50917	70.1785	74.32167	78.00475	64.11325
38	Jia Musa, UC 8	53.91383	67.36692	73.07325	73.91375	61.39517
39	Kot Mohibbu, UC 2	53.91383	67.36692	73.07325	73.91375	61.39517
40	Aziz Colony, UC 3	53.91383	67.36692	73.07325	73.91375	61.39517
41	Qaiser Town, UC 5	53.91383	67.36692	73.07325	73.91375	61.39517
42	Shahdara, UC 7	54.50428	67.88092	73.26075	75.46397	62.33694
43	Dhair, UC 6	54.7995	68.13792	73.3545	76.23908	62.80783
44	Kot Begum, UC 1	56.98392	67.63942	72.81767	76.58525	63.40942
45	Kot Begum, UC 1	54.93719	67.45775	72.98806	74.80425	62.06658
46	Abu Bakar Siddique Colony, UC 84	56.98392	67.63942	72.81767	76.58525	63.40942
47	Fruit Mandi, UC 10	54.7995	68.13792	73.3545	76.23908	62.80783
48	Siddique Pura, UC 11	54.7995	68.13792	73.3545	76.23908	62.80783
49	Bangali Bagh, UC 12	57.27261	69.49831	73.99928	77.41619	63.67811
50	Siddiqia Colony, UC 13	54.7995	68.13792	73.3545	76.23908	62.80783
51	Bhamman, UC 14	54.7995	68.13792	73.3545	76.23908	62.80783
52	Qila Lachhman Singh, UC 9	58.50917	70.1785	74.32167	78.00475	64.11325
53	Androon Texali Gate, UC 30	58.50917	70.1785	74.32167	78.00475	64.11325
54	Androon Bhatti Gate, UC 29	58.50917	70.1785	74.32167	78.00475	64.11325
55	Rang Mahal, UC 28	58.50917	70.1785	74.32167	78.00475	64.11325
56	Aandroon Dehli Gate, UC 27	58.50917	70.1785	74.32167	78.00475	64.11325
57	Gulshan-e-Ravi, UC 89	57.72108	66.99742	72.777	73.93258	64.56575
58	Faisal Park, UC 5	53.91383	67.36692	73.07325	73.91375	61.39517
59	Tajpura, UC 58	59.01383	70.3605	74.94533	81.10292	65.50067
60	Shamke Bhattian, UC 123	44.41942	47.82617	61.91042	51.76958	52.31858
61	Lakhodher, UC 49	56.88033	68.7085	74.86525	79.10992	64.3225

62	Ichhra, UC 100	59.0075	70.63958	74.82167	76.20975	66.15542
63	Samanabad, UC 106	59.0075	70.63958	74.82167	76.20975	66.15542
64	Shah Kamal, UC 102	59.0075	70.63958	74.82167	76.20975	66.15542
65	New Samanabad, UC 101	59.0075	70.63958	74.82167	76.20975	66.15542
66	Bahawalpur House, UC 93	59.0075	70.63958	74.82167	76.20975	66.15542
67	Bostan Colony, UC 134	60.109	67.15342	73.45283	74.8215	64.94567
68	Ismail Nagar, UC 135	60.109	67.15342	73.45283	74.8215	64.94567
69	Farid Colony, UC 137	58.742	64.26908	73.28017	72.19742	64.6585
70	Green Town, UC 139	57.52067	62.46275	72.87533	69.773	64.95992
71	Maryam Colony, UC 140	58.742	64.26908	73.28017	72.19742	64.6585
72	Chandrai, UC 143	58.742	64.26908	73.28017	72.19742	64.6585
73	Haloke, UC 144	55.10767	58.36081	69.32889	66.51456	61.26775
74	Sittara Colony, UC 136	58.5835	63.07833	73.12533	76.661	66.24583
75	Attari Saroba, UC 141	58.5835	63.07833	73.12533	76.661	66.24583
76	Kamahan, UC 63	59.69283	62.93933	73.01575	76.44517	66.57883
77	Nawan Kot, UC 105	57.72108	66.99742	72.777	73.93258	64.56575
78	Dullo Khurd Kalan, UC 142	58.742	64.26908	73.28017	72.19742	64.6585
79	Keer Kalan, UC 138	58.742	64.26908	73.28017	72.19742	64.6585
80	Dhaloke, UC 66	53.89533	55.33925	65.36108	66.06242	61.24192
81	Hair, UC 64	55.90167	56.94858	67.73567	72.87083	64.85517
82	Pandoki, UC 150	48.33642	49.09992	60.62567	59.63442	58.46311
83	Kahna Nau, UC 146	53.30192	53.39725	65.82667	66.39575	61.016
84	Gajju Matta, UC 145	54.8835	59.04342	70.537	68.38925	62.79658
85	Jia Bagga, UC 147	50.767	53.34633	65.77117	62.00775	59.80717
86	Awan Town, UC 110	57.72108	66.99742	72.777	73.93258	64.56575
87	Hanjarwal, UC 117	57.61667	66.0805	71.36942	72.71283	63.21475
88	Sham Nagar, UC 87	56.98392	67.63942	72.81767	76.58525	63.40942
89	Niaz Beg, UC 118	57.75333	64.35908	73.33992	70.35892	64.67975
90	Johar Town, UC 116	59.09883	67.257	74.04592	72.48058	65.1345
91	Sabzazar, UC 112	57.65147	66.38614	71.83861	73.11942	63.66508
92	Saidpur, UC 111	57.72108	66.99742	72.777	73.93258	64.56575

93	Raiwind, UC 113	57.72108	66.99742	72.777	73.93258	64.56575
94	Bakar Mandi, UC 114	57.72108	66.99742	72.777	73.93258	64.56575
95	Town Ship, UC 132	60.109	67.15342	73.45283	74.8215	64.94567
96	Township Sector A, UC 133	58.742	64.26908	73.28017	72.19742	64.6585
97	Ali Raza Abad, UC 120	57.52067	62.46275	72.87533	69.773	65.05353
98	Shahpur, UC 119	57.75333	64.35908	73.33992	70.35892	63.44217
99	Pakki Thatti, UC 103	57.72108	66.99742	72.777	73.93258	64.56575
100	Chung, UC 121	52.08567	54.99267	69.239	62.4835	59.30775
101	Maraka, UC 122	46.46967	51.0465	64.58225	55.16275	54.4185
102	Manga, UC 125	41.16217	45.10392	58.4805	47.33642	50.39217
103	Sultanke, UC 124	45.73681	49.21511	63.50922	53.13486	53.62708
104	Dholanwal, UC 149	46.43758	50.03958	61.48208	52.96392	56.91733
105	Paji, UC 148	49.29739	52.393	65.79414	58.36556	60.33175
106	Model Town, UC 127	60.109	67.15342	73.45283	74.8215	64.94567
107	Bibi Pak Daman, UC 75	58.50917	70.1785	74.32167	78.00475	64.11325
108	Zaman Park, UC 96	59.18483	70.22392	75.93533	80.83833	66.05108
109	Daras Barey Mian, UC 32	59.18483	70.22392	75.93533	80.83833	66.05108
110	Muslim Town, UC 115	59.0075	70.63958	74.82167	76.20975	65.75217
111	Railway Colony, UC 31	58.95961	70.20878	75.39744	79.89381	65.40514
112	Garrhi Shahu, UC 76	59.18483	70.22392	75.93533	80.83833	66.05108
113	Al-Hamra, UC 95	59.0075	70.63958	74.82167	76.20975	65.85244
114	Gulberg, UC 97	58.81725	67.21125	73.79733	80.93767	65.2465
115	Makkah Colony, UC 98	59.60061	67.02542	72.95867	78.88333	65.76072
116	Naseer Abad, UC 99	60.109	67.15342	73.45283	74.8215	64.94567
117	Kot Lakhpat, UC 130	60.109	67.15342	73.45283	74.8215	64.94567
118	Liaqatabad, UC 129	60.109	67.15342	73.45283	74.8215	64.94567
119	Pindi Rajputan, UC 131	60.109	67.15342	73.45283	74.8215	64.94567
120	Faisal Town, UC 128	60.109	67.15342	73.45283	74.8215	64.94567
121	Sikandar Block, UC 109	59.09883	67.257	74.04592	72.48058	65.1345
122	Faisal Town, UC 126	59.0075	70.63958	74.82167	76.20975	66.15542
123	Riwaz Garden, UC 81	58.50917	70.1785	74.32167	78.00475	64.11325

124	Islam Pura, UC 82	56.98392	67.63942	72.81767	76.58525	63.40942
125	Jinnah Hall, UC 80	58.50917	70.1785	74.32167	78.00475	64.11325
126	Anarkali, UC 72	58.50917	70.1785	74.32167	78.00475	64.11325
127	Mozang, UC 79	58.50917	70.1785	74.32167	78.00475	64.11325
128	Shadman, UC 94	59.0075	70.63958	74.82167	76.20975	66.15542
129	Race Course, UC 78	59.0075	70.63958	74.82167	76.20975	66.15542
130	Qila Gujjar Singh, UC 77	58.50917	70.1785	74.32167	78.00475	64.11325
131	Kasur Pura, UC 67	56.98392	67.63942	72.81767	76.58525	63.40942
132	Kashmir Block, UC 104	57.72108	66.99742	72.777	73.93258	64.56575
133	Sare Sultan, UC 74	58.50917	70.1785	74.32167	78.00475	64.11325
134	Gawalmandi, UC 73	58.50917	70.1785	74.32167	78.00475	64.11325
135	Bilal Gunj, UC 71	58.50917	70.1785	74.32167	78.00475	64.11325
136	Sanda Khurd, UC 86	57.49233	68.48578	73.319	77.05842	63.64403
137	Sanda Kalan, UC 85	56.98392	67.63942	72.81767	76.58525	63.40942
138	Chohan Park, UC 83	56.98392	67.63942	72.81767	76.58525	63.40942
139	Ganj Kalan, UC 70	56.98392	67.63942	72.81767	76.58525	63.40942
140	Kareem Park, UC 69	56.98392	67.63942	72.81767	76.58525	63.40942
141	Ameen Pura, UC 68	58.50917	70.1785	74.32167	78.00475	64.11325
142	Cantonment, UC 152	59.46225	68.21992	74.54522	81.48089	66.4315
143	Gulshan-e-Iqbal, UC 108	57.72108	66.99742	72.777	73.93258	64.56575
144	Mustafa Abad, UC 55	59.18483	70.22392	75.93533	80.83833	66.05108
145	Mian Meer, UC 54	59.18483	70.22392	75.93533	80.83833	66.05108
146	Al-Faisal Town, UC 59	59.78475	68.72425	74.91917	81.7525	67.024
147	Guldast Colony, UC 60	59.01383	70.3605	74.94533	81.10292	65.50067
148	Taj Bagh, UC 57	59.01383	70.3605	74.94533	81.10292	65.50067
149	Harbanspura, UC 41	59.01383	70.3605	74.94533	81.10292	65.50067
150	Fateh Garh, UC 44	59.18483	70.22392	75.93533	80.83833	66.05108
151	Fateh Garh, UC 44	59.01383	70.3605	74.94533	81.10292	65.50067
152	Nabipura, UC 45	59.18483	70.22392	75.93533	80.83833	66.05108
153	Mughalpura, UC 48	59.18483	70.22392	75.93533	80.83833	66.05108

Table 3. UC's Annual Rainfall 2018-2022

## UC's with Highest Rainfall

<b>Sr. No.</b>	<b>UCs Name</b>	<b>Rainfall Precipitation</b>
1	Dograi Kalan, UC 51	71.99846667
2	Bhaseen, UC 50	71.20276667
3	Ghaziabad, UC 56	70.4467
4	Sultan Mehmood, UC 38	70.4467
5	Mujahidabad, UC 47	70.4467
6	Angori Bagh, UC 46	70.4467
7	Baghbanpura, UC 36	70.4467
8	Crown Park, UC 33	70.4467
9	Madhu Lal Hussain, UC 34	70.4467
10	Begum Pura, UC 18	70.4467

*Table 4. UC's with Highest Rainfall*

## UC's with Lowest Rainfall

<b>Sr. No.</b>	<b>UCs Name</b>	<b>Rainfall Precipitation</b>
1	Kahna Nau, UC 146	59.98751667
2	Chung, UC 121	59.62171667
3	Jia Bagga, UC 147	58.33988333
4	Paji, UC 148	57.23636667
5	Pandoki, UC 150	55.23190556
6	Maraka, UC 122	54.33593333
7	Dholanwal, UC 149	53.5681
8	Sultanke, UC 124	53.04461667
9	Shamke Bhattian, UC 123	51.64883333
10	Manga, UC 125	48.49503334

*Table 5. UC's with Lowest Rainfall*

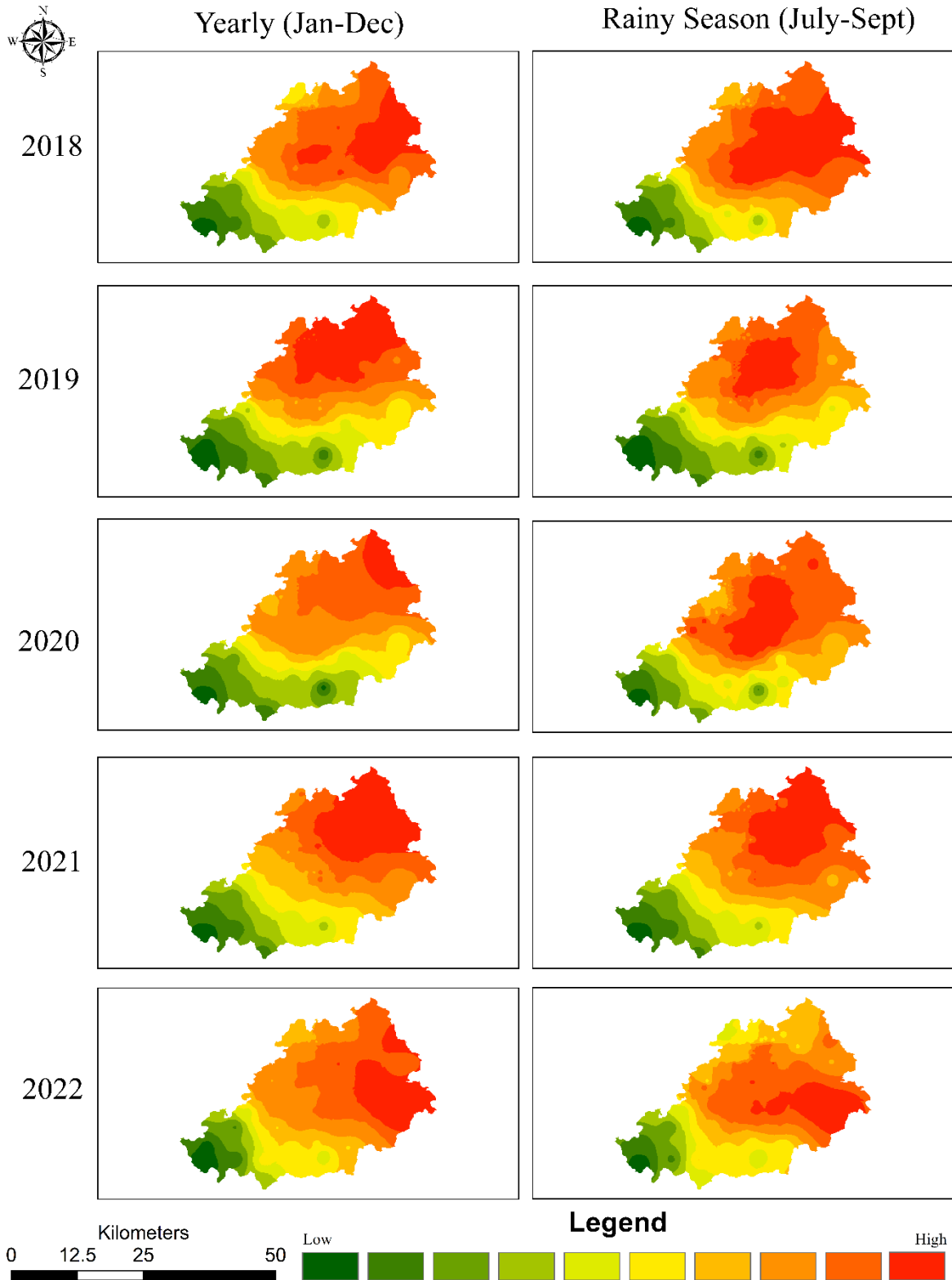
## Flood Affected UC's

UC's Name	
Bhaghat Pura, UC 15	Very High
Sham Nagar, UC 87	Very High
Islam Pura, UC 82	Very High
Ganj Kalan, UC 70	Very High
Sanda Khurd, UC 86	Very High
Muhammad, UC 37	Very High
Makhanpura, UC21	Very High
Wassanpura, UC 5	Very High
Faiz Bagh, UC 25	Very High
Farooq Ganj, UC 26	Very High
Qila Lachhman Singh, UC 9	Very High
Androon Texali Gate, UC 30	Very High
Androon Bhatti Gate, UC 29	Very High
Rang Mahal, UC 28	Very High
Aandroon Dehli Gate, UC 27	Very High
Bibi Pak Daman, UC 75	Very High
Riwaz Garden, UC 81	Very High
Jinnah Hall, UC 80	Very High
Anarkali, UC 72	Very High
Mozang, UC 79	Very High
Qila Gujjar Singh, UC 77	Very High
Sare Sultan, UC 74	Very High
Gawalmandi, UC 73	Very High
Bilal Gunj, UC 71	Very High
Ameen Pura, UC 68	Very High
Sodiwal, UC 92	Very High
Gulgasht Colony, UC 88	Very High
Gulshan-e-Ravi, UC 89	Very High
Nawan Kot, UC 105	Very High
Saidpur, UC 111	Very High
Raiwind, UC 113	Very High
Pakki Thatti, UC 103	Very High
Kashmir Block, UC 104	Very High
Gulshan-e-Iqbal, UC 108	Very High
Bhaseen, UC 52	Very High
Bilal Park, UC 20	Very High
Kot Khawaja Saeed, UC 22	Very High
Railway Colony, UC 31	Very High
Salamat Pura, UC 40	Very High
Tajpura, UC 58	Very High
Guldasht Colony, UC 60	Very High
Taj Bagh, UC 57	Very High
Harbanspura, UC 41	Very High
Fateh Garh, UC 44	Very High

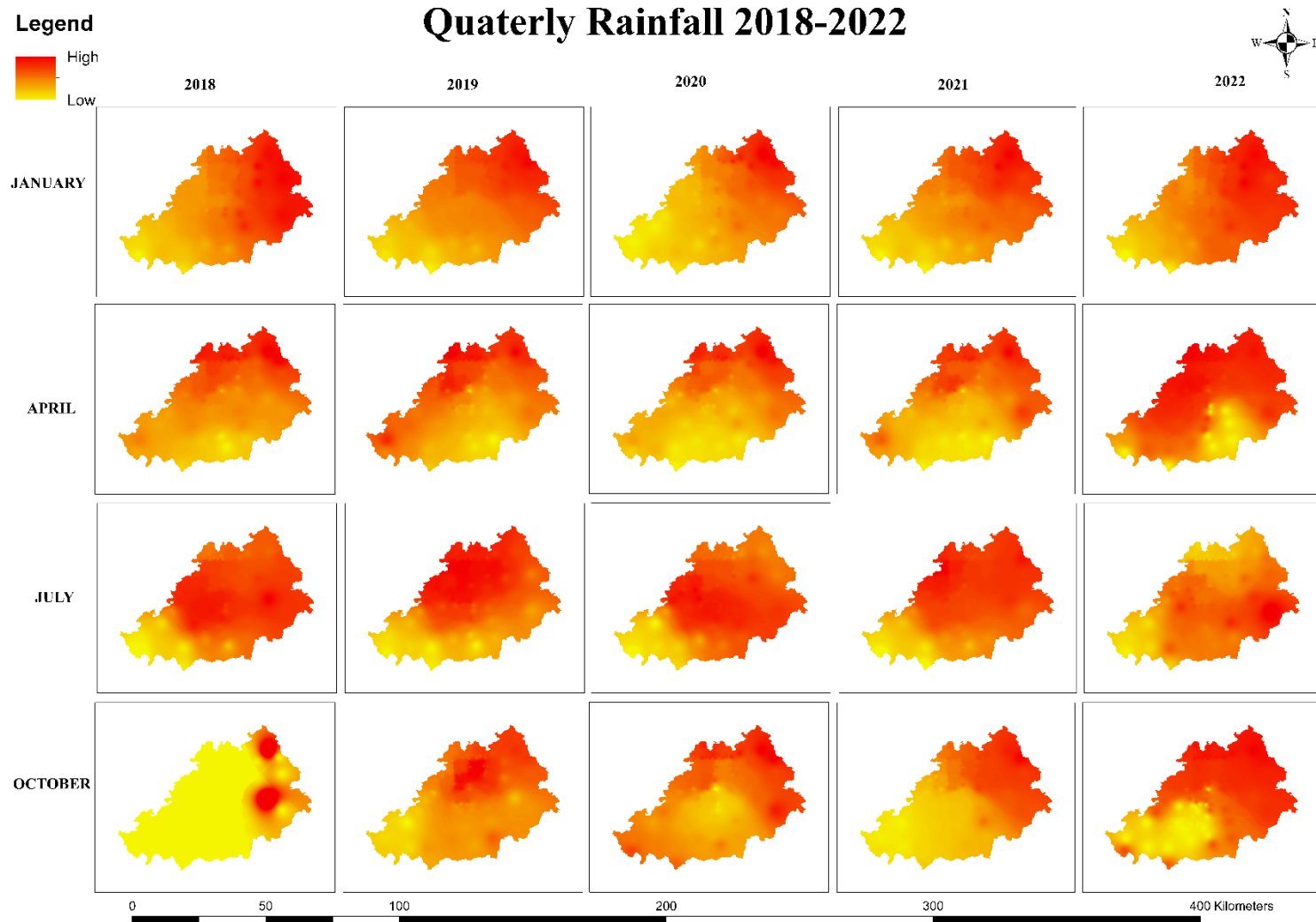
Rashidpura, UC 43	Very High
Muslim Town, UC 115	Very High
Al-Hamra, UC 95	Very High
Ghaziabad, UC 56	Very High
Sultan Mehmood, UC 38	Very High
Darogha Wala, UC 42	Very High
Mujahidabad, UC 47	Very High
Angori Bagh, UC 46	Very High
Baghbanpura, UC 36	Very High
Crown Park, UC 33	Very High
Madhu Lal Hussain, UC 34	Very High
Begum Pura, UC 18	Very High
Rehmatpura, UC 17	Very High
Chah Miran, UC 19	Very High
Zaman Park, UC 96	Very High
Daras Barey Mian, UC 32	Very High
Garrhi Shahu, UC 76	Very High
Mustafa Abad, UC 55	Very High
Mian Meer, UC 54	Very High
Fateh Garh, UC 44	Very High
Nabipura, UC 45	Very High
Mughalpura, UC 48	Very High
Rehman Pura, UC 107	Very High
Ichhra, UC 100	Very High
Samanabad, UC 106	Very High
Shah Kamal, UC 102	Very High
New Samanabad, UC 101	Very High
Bahawalpur House, UC 93	Very High
Shadman, UC 94	Very High
Race Course, UC 78	Very High
Cantonment, UC 152	Very High
Al-Faisal Town, UC 59	Very High
Bhangali, UC 61	Very High

*Table 6. Flood Affected UC's of Lahore*

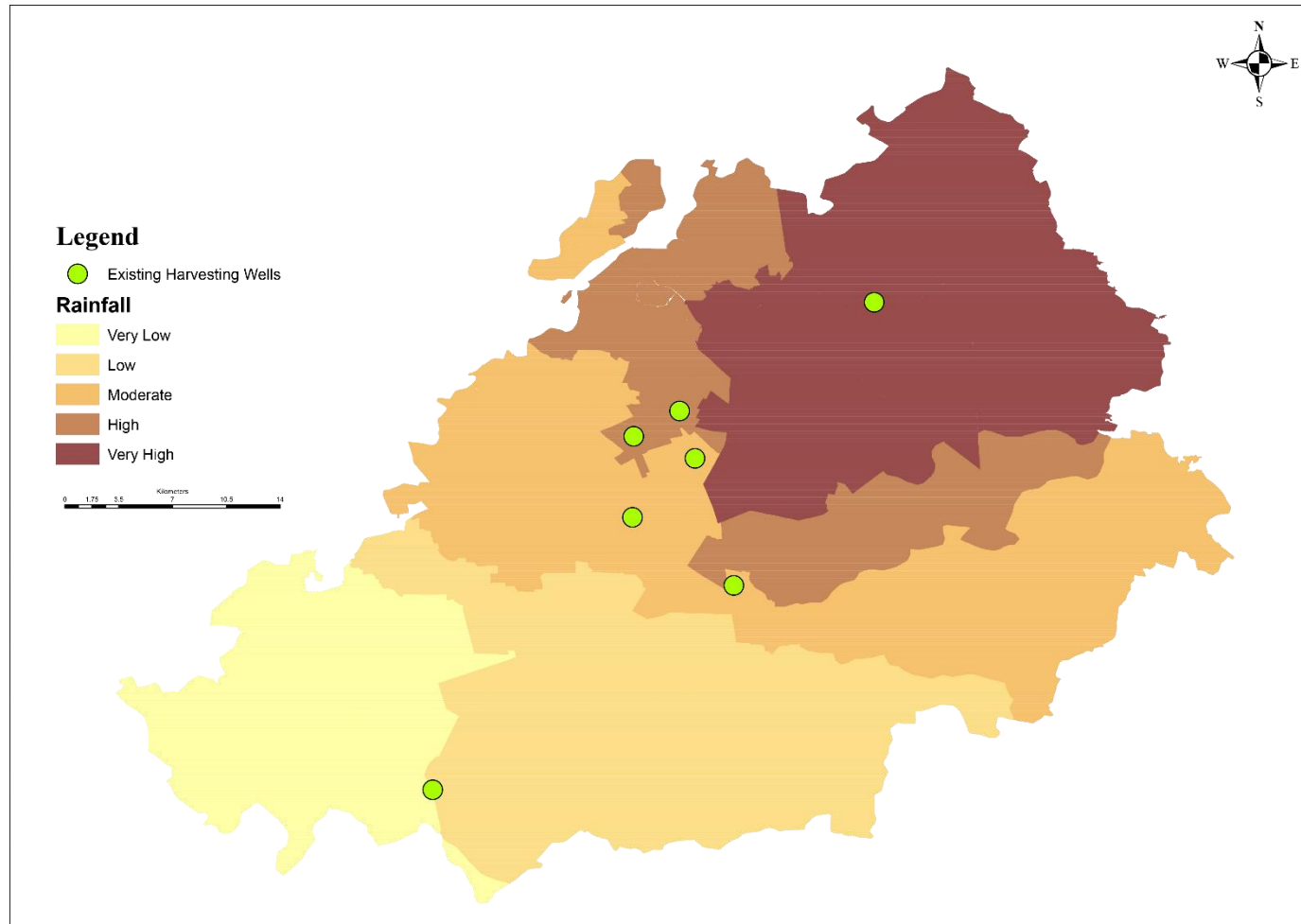
# Yearly Rainfall Comparison with Rainy Season



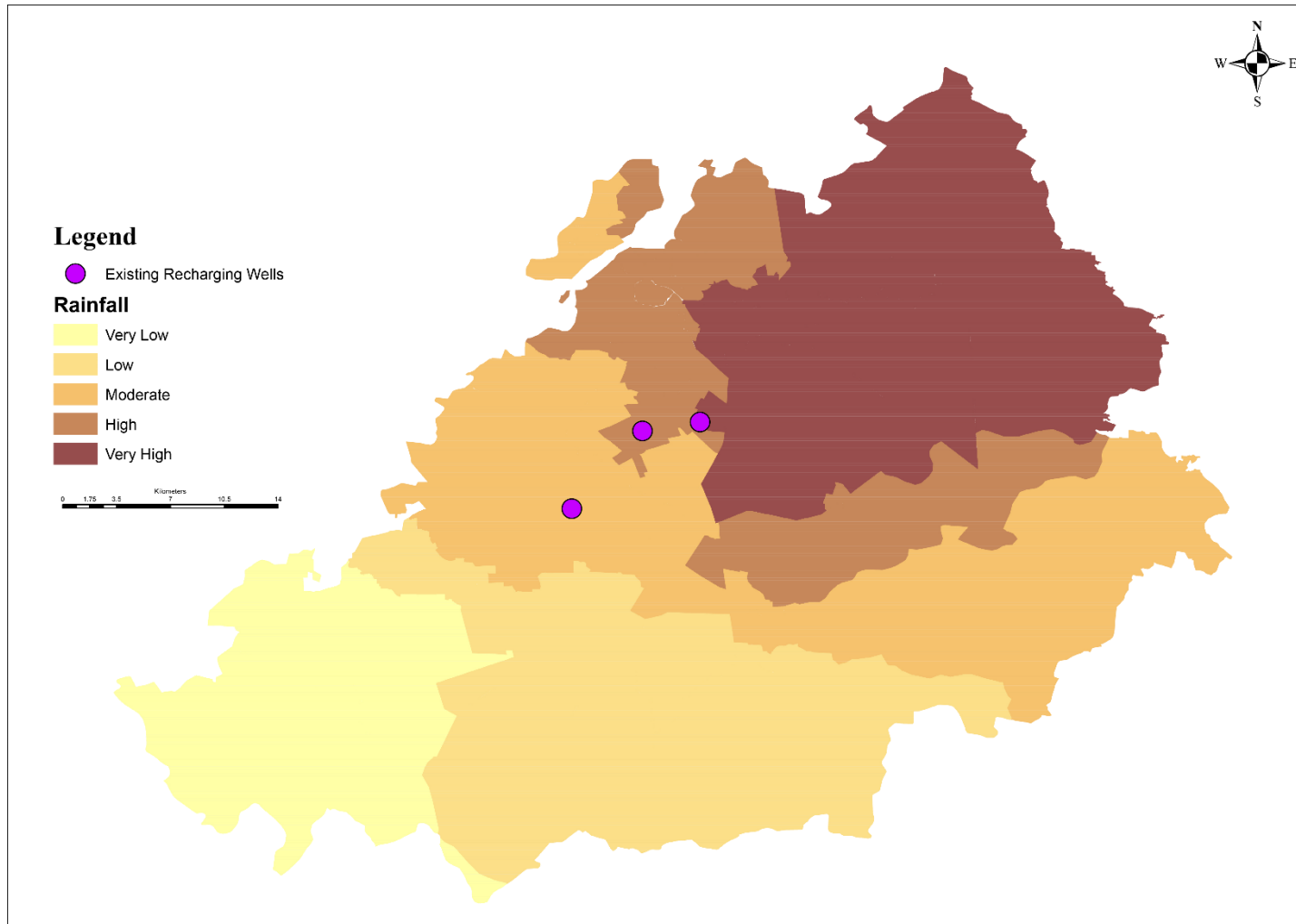
Using the Inverse Distance Weighting (IDW) method of GIS, this map provides a comprehensive comparison of annual rainfall from 2018 to 2022 with related monsoon seasons. This chart shows that the northern side of Lahore receives more rainfall than the inner side.



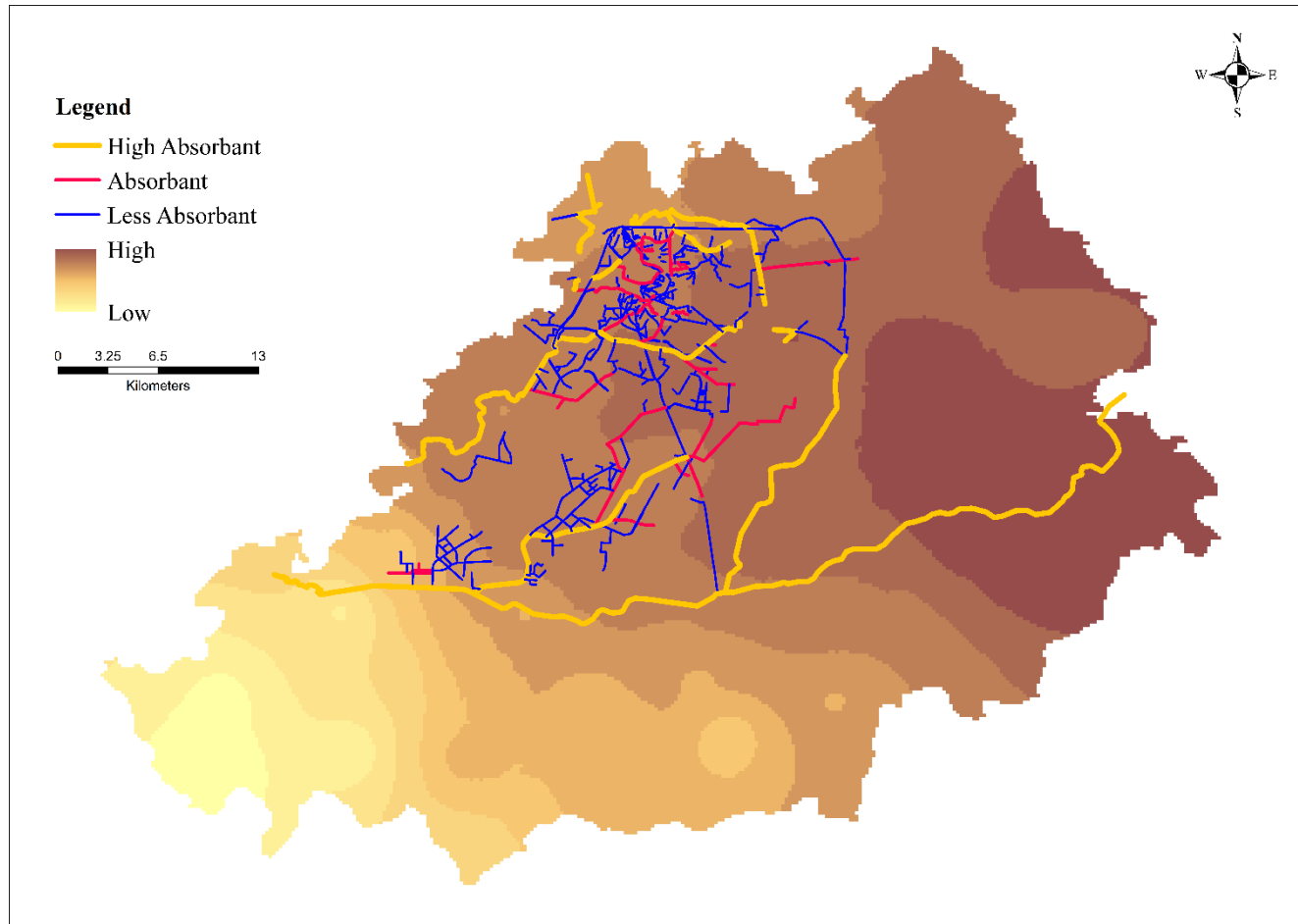
Using the Inverse Distance Weighting (IDW) analysis technique, the map shows the spatial distribution of precipitation ratios. Areas with a higher proportion of precipitation and places with a lot of precipitation in the marked quarters are marked with dark colors on the map. Lighter shades, on the other hand, indicate less precipitation and areas that were somewhat dry.



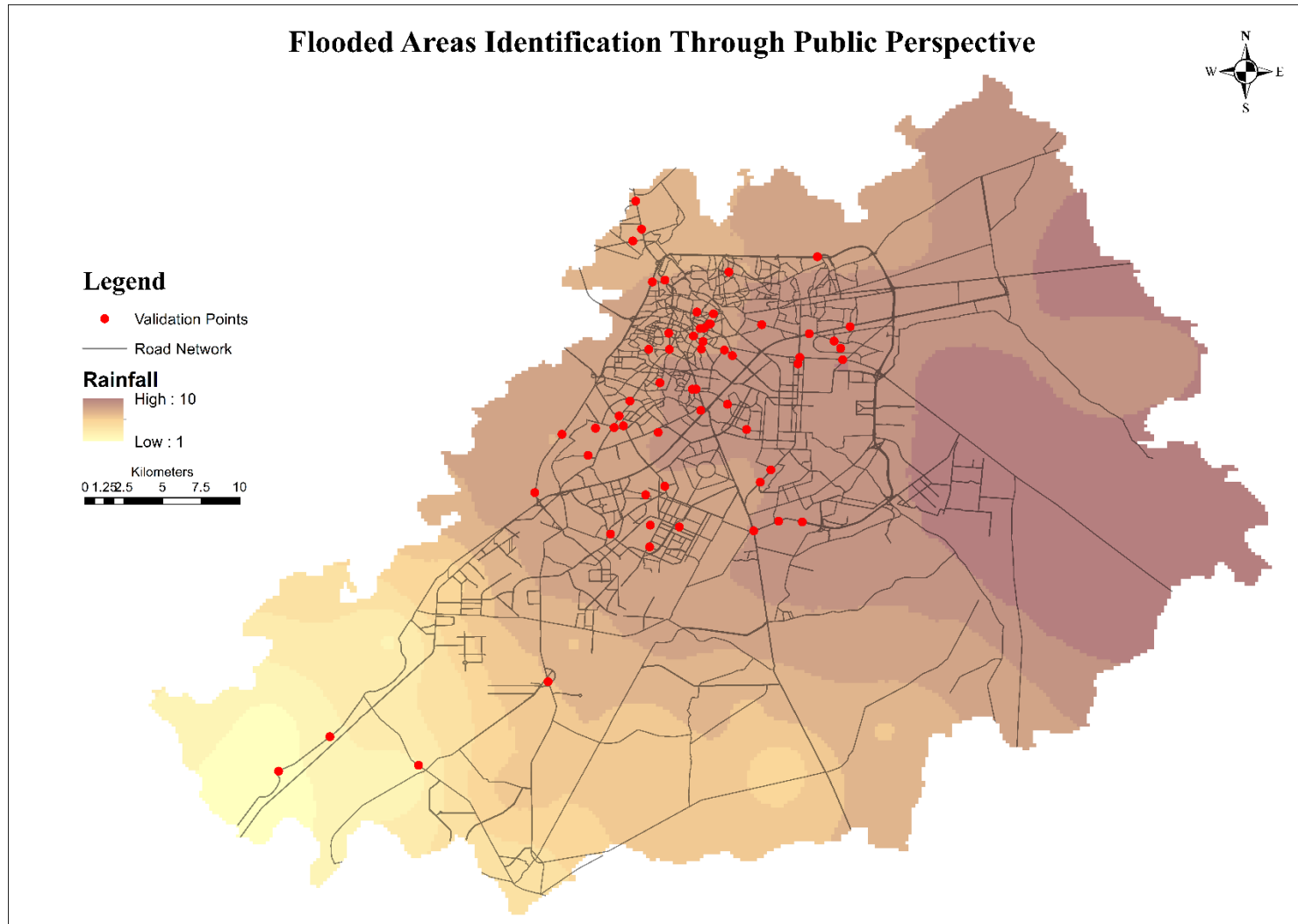
Location of rainwater harvesting wells are shown on this GIS generated map of Lahore City provided by WWF. The locations of the wells include Qaddafi Stadium, Yuhannabad, Nawabpura, Ali Institute of Education, PU Mosque, Bhaikot Village and Govt. City College for Girls. The highest to lowest rainfall distribution in Lahore is shown in the background of the map. Areas with higher precipitation are represented by darker colored areas, while areas with less precipitation are represented by lighter shades. (WWF-Pakistan Organizes Field Visit to Groundwater Replenishment Site for Stakeholders, 2020)



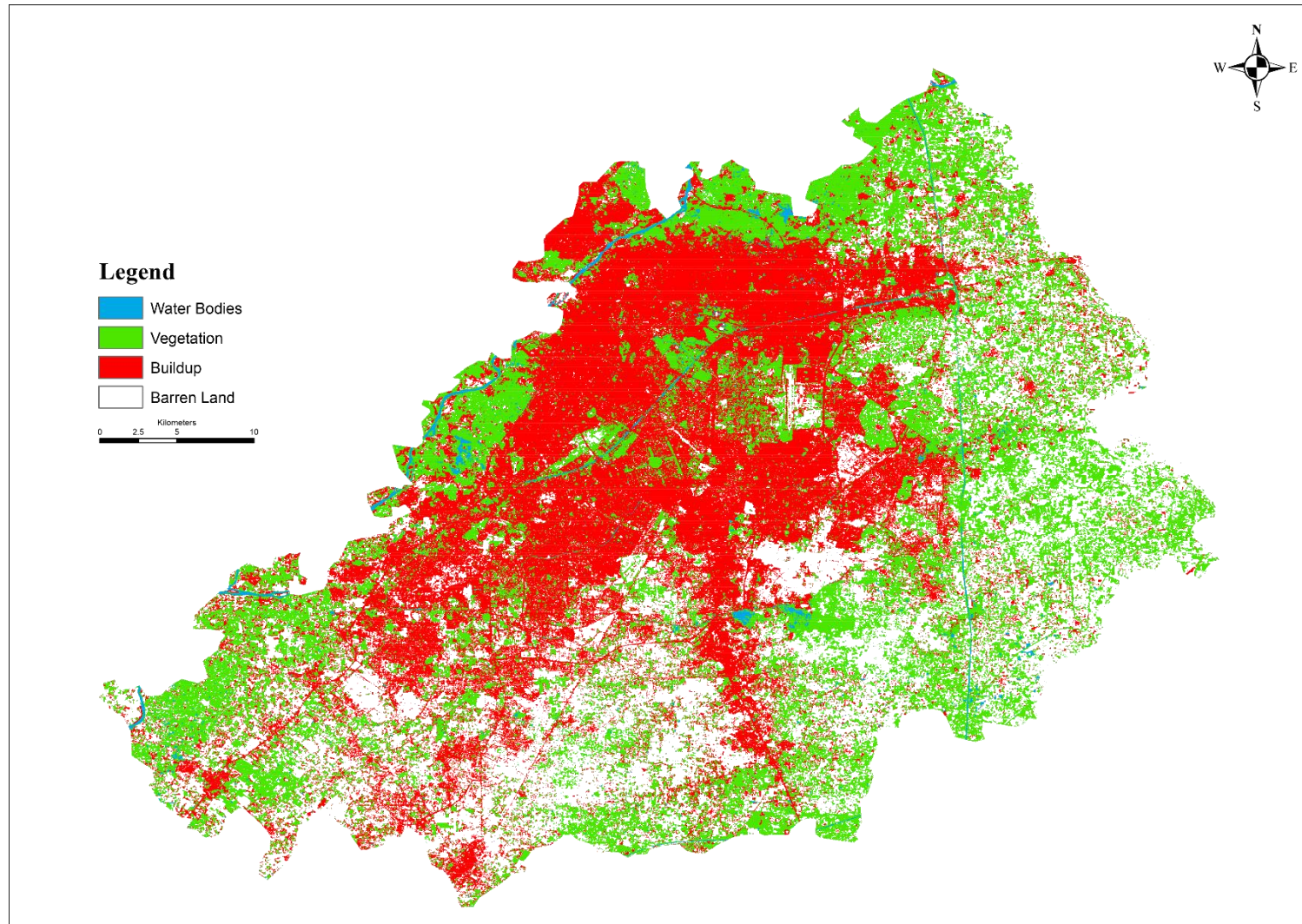
This GIS-generated map of the city of Lahore shows the locations of storm water recharge wells obtained by WWF. University of Punjab, Gulberg Governorate. The Women's College and the Abdalian Society are well located institutions. Lahore's rainfall classification from highest to lowest is shown in the background of the map. Areas with more rainfall are represented by darker colored areas, while areas with less rainfall are represented by lighter shades. (WWF-Pakistan Organizes Field Visit to Groundwater Replenishment Site for Stakeholders, 2020)



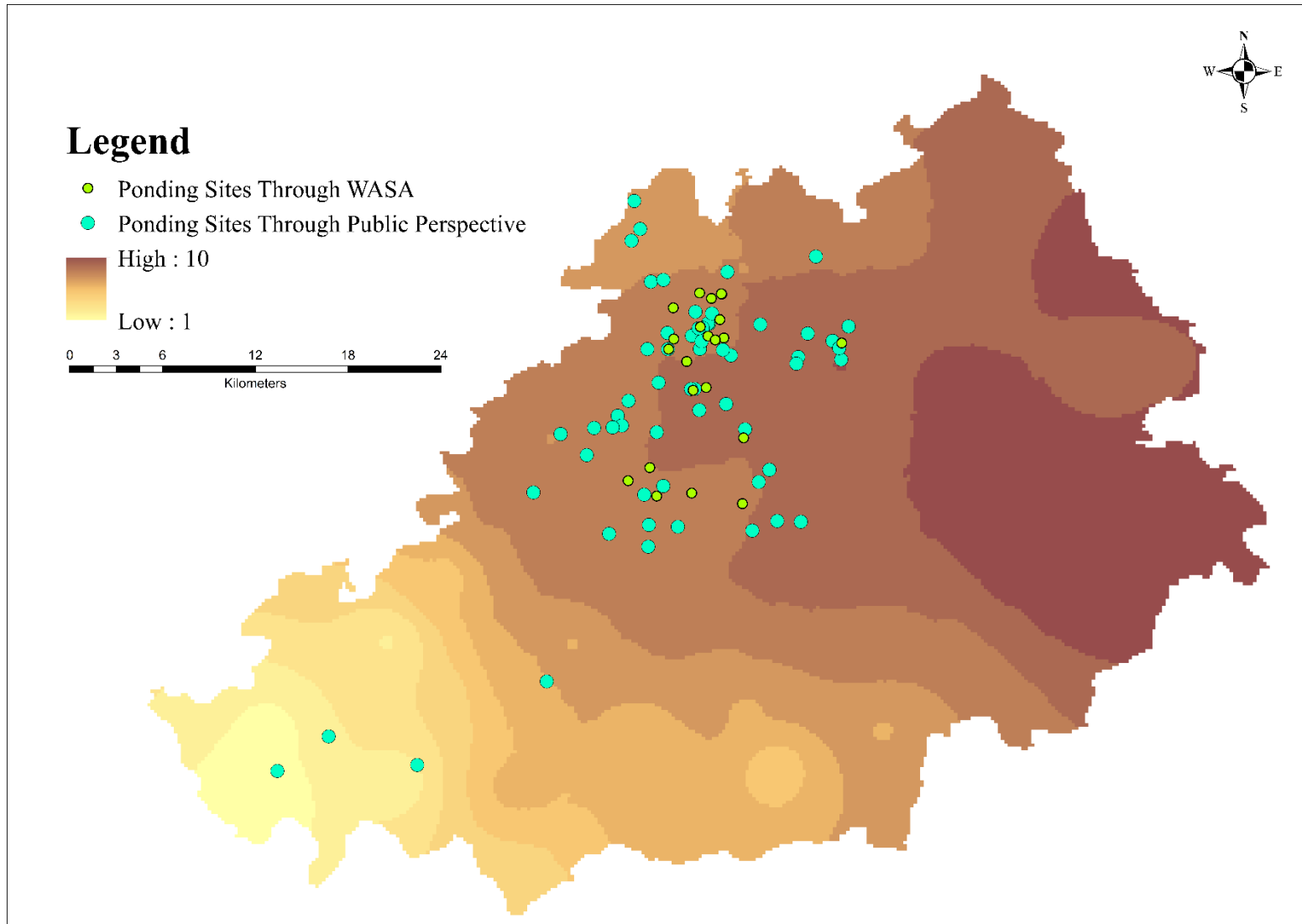
The drainage pattern of Lahore is shown in a GIS-generated map which also highlights the rain-harvesting capacity of various areas of the Union Council. The absorption properties of the drainage network are shown on the map using a color-coded categorization system. The yellow drainage network indicates areas with a strong absorption capacity of rain, indicating efficiency in managing rain runoff. While the red drainage network indicates areas with a significantly lower rain absorption capacity, the blue drainage network indicates places with an average precipitation absorption capacity. This categorization helps to identify and prepare suitable storm water management methods by revealing the different level of rain absorption potential of different Union Councils of Lahore.



This GIS-generated map of Lahore shows how the flooded areas are located based on public perception. The public has identified several areas on the map that are more vulnerable to flooding after heavy rainfall. The map provides a comprehensive view of urban flood prone areas from community perspectives, combining data from surveys and public input.



This GIS-generated map shows the Land Use and Land Cover (LULC) Survey of Lahore in 2023. The city is divided into four different groups on the map: built-up areas, vegetated areas, water bodies, and barren land. A complete visual picture of the mix of urban farming is given by the clear boundaries of each class.

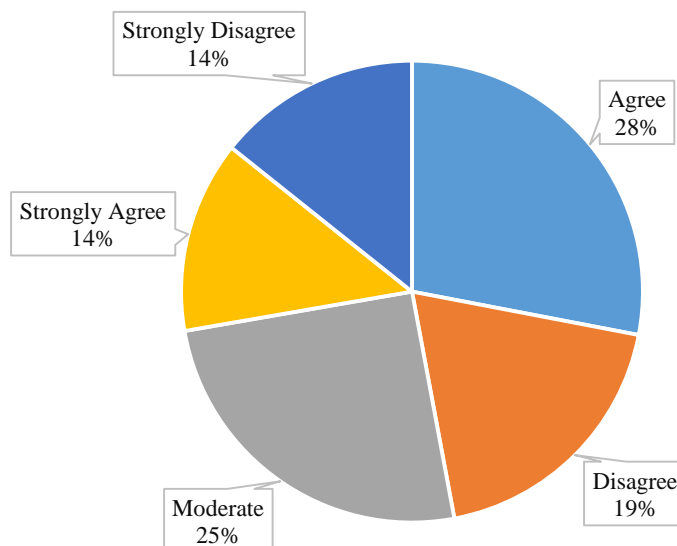


This GIS generated map assesses the flood risk in the city of Lahore and rates the probability of flooding in the city from high to low. The image clearly shows the parts of Lahore most vulnerable to flooding, with darker areas indicating high-risk areas relative to the city's outskirts.

## Descriptive Data

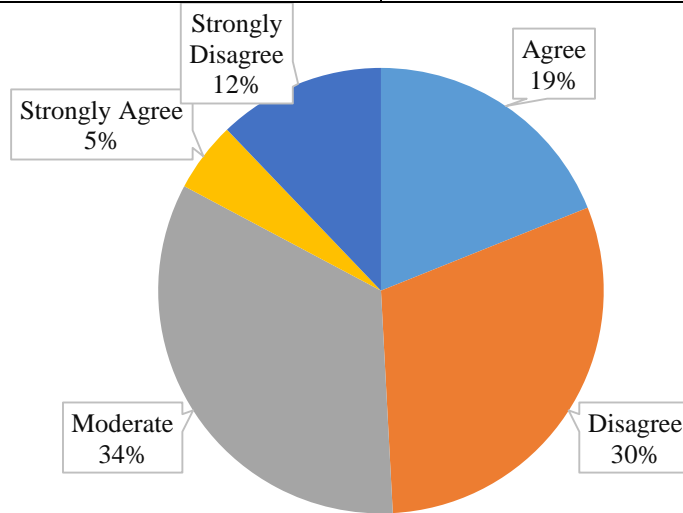
To investigate how people perceive the relationship between rainfall and urban flooding. The results were presented using graphs and tables prepared in MS Excel. The thoughts and impressions of the participants are clearly depicted in the graphs, giving us important insights into how they see the city's flood and storm water problems.

Have you ever face damages from urban floods?	
Agree	28.01%
Disagree	19.05%
Moderate	25.21%
Strongly Agree	13.45%
Strongly Disagree	14.29%
<b>Grand Total</b>	<b>100.00%</b>



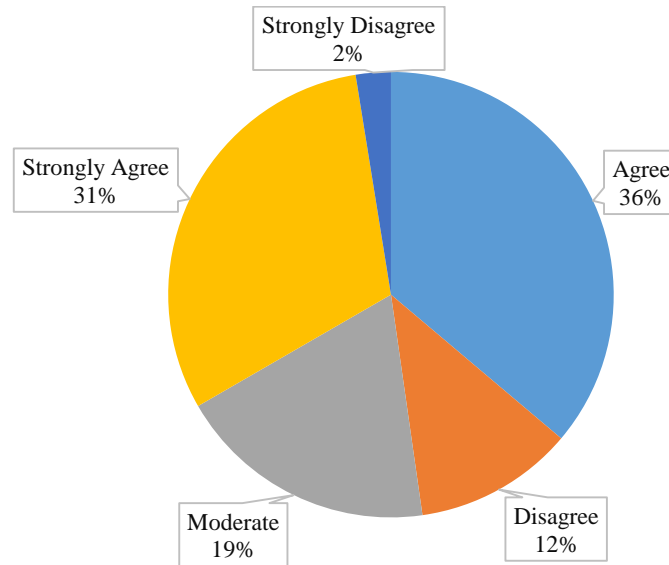
The graph shows the distribution of responses to a survey on the damage from urban flooding. The largest number, 28.01%, admitted to being injured, indicating that a significant proportion were affected. 25.21% of responses were moderate, indicating some impairment. Strong agreement earned 13.45%, disagreement 19.05% and strong disagreement 14.29%

Is the damage from flooding is on a lesser than the earlier?	
Agree	18.93%
Disagree	30.23%
Moderate	33.62%
Strongly Agree	5.08%
Strongly Disagree	12.15%
<b>Grand Total</b>	<b>100.00%</b>



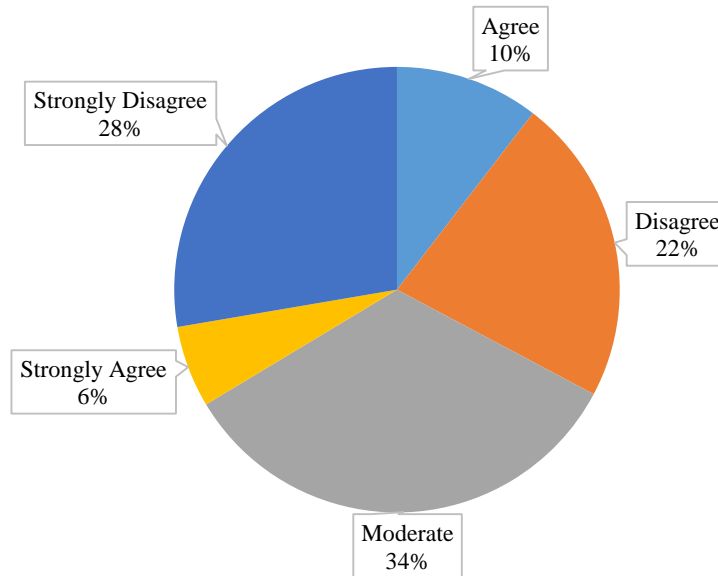
The graph shows people's views on whether recent floods have caused less damage than in the past. Five categories are used to categorize responses: agree, disagree, moderate, strongly agree, and strongly disagree. The majority (33.62%) indicated the ambiguity or neutrality of the topic and chose Moderate as the answer option. A high proportion of respondents (30.23%) disagreed, indicating that they do not feel that damage caused by flooding has decreased compared to the past. Strong agreement and strong disagreement scored 5.08% and 12.15%, respectively, while agreement accounted for 18.93% of the total. The graph shows the different opinions about the amount of damage caused by floods compared to previous times.

<b>Have you ever see the roads damages by urban flooding?</b>	
Agree	36.16%
Disagree	11.58%
Moderate	18.93%
Strongly Agree	30.79%
Strongly Disagree	2.54%
<b>Grand Total</b>	<b>100.00%</b>



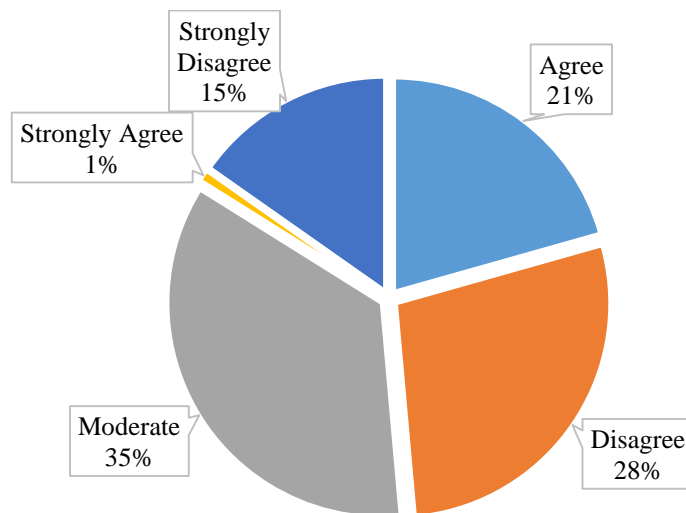
The answers to the question about the observation of road damage caused by flooding in cities are given in the graph. 36.16% of respondents said they saw road damage, which is a high percentage of people who have seen such things. A large proportion of participants strongly acknowledged the existence of road damage, as evidenced by a significant agreement rate of 30.79%. A small percentage of respondents (11.58%) indicated that they did not agree with the statement. 18.93% of responses were moderate, indicating ambiguity or neutrality. Only 2.54% of respondents disagreed with seeing road damage.

<b>Do you feel that in this time of flood, the support of Govt. was good?</b>	
Agree	10.45%
Disagree	22.32%
Moderate	33.62%
Strongly Agree	5.93%
Strongly Disagree	27.68%
<b>Grand Total</b>	<b>100.00%</b>



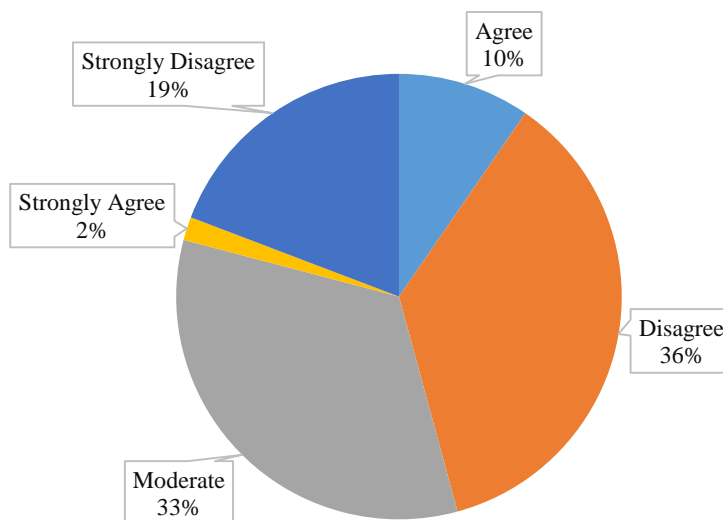
Views on government support for floods are in the chart. Agree, disagree, moderate, strongly agree and disagree for group responses. 10.45% of the respondents, who are a minority, agree with government support. More people, 27.68%, disagreed with the government's support. The moderate answer choice was chosen by 33.62% of the respondents, indicating ambiguity or neutrality. 22.32% of respondents disagreed, indicating that a large proportion of them were not satisfied with government assistance. 5.93% of respondents strongly agreed with the government's position. The image illustrates different perspectives on how the government helped during the floods.

<b>Is the cleaning of the area (sewer cleaning before monsoon) was better than the earlier?</b>	
Agree	20.62%
Disagree	27.97%
Moderate	35.31%
Strongly Agree	0.85%
Strongly Disagree	15.25%
<b>Grand Total</b>	<b>100.00%</b>



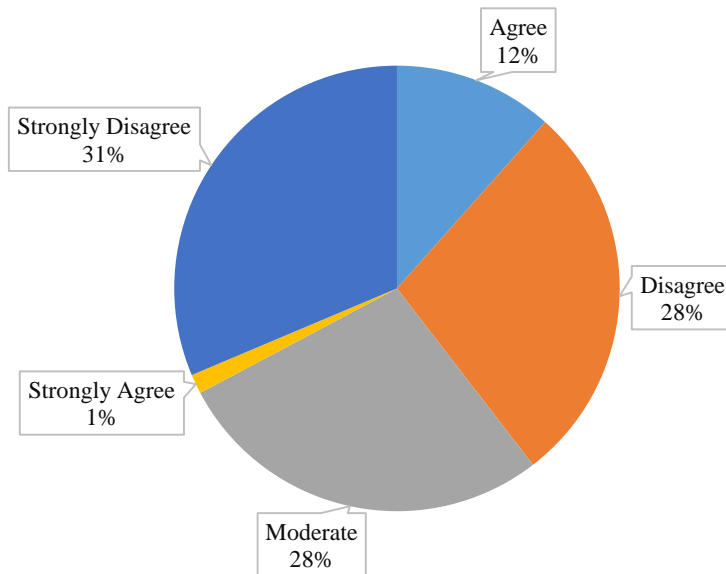
The graph shows whether the cleanliness of the neighborhood, especially the pre-monsoon sanitation, has improved compared to the past. The majority (35.31%) of the respondents stated that they are ambivalent or neutral on this question, choosing the answer option Moderate. A significant number of respondents (27.97%) who disagreed said that there has been no improvement in the cleanliness of the area. significant agreement and significant disagreement accounted for 0.85% and 15.25%, respectively, while agreement accounted for 20.62% of the total. The chart shows a range of opinions on how successful pre-monsoon sewage treatment is, with a significant proportion expressing ambivalence or neutrality.

<b>Were the government support easily accessible to you during flooding?</b>	
Agree	9.60%
Disagree	36.16%
Moderate	33.33%
Strongly Agree	1.69%
Strongly Disagree	19.21%
<b>Grand Total</b>	<b>100.00%</b>



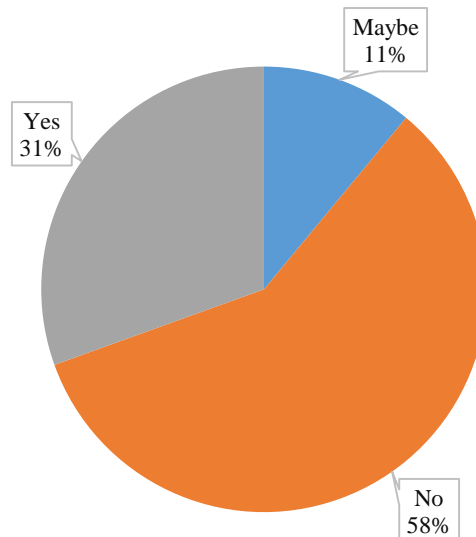
The graph shows how people reacted to government support during the flood. 36.16% of respondents, the majority, disagreed with the statement that government support was not available for free. 33.33% of the responses were moderate, indicating some ambivalence or neutrality. Only 9.60% of respondents thought it was easy to get government support. 19.21% strongly disagreed, while 1.69% strongly agreed. All in all, the graph shows that a significant percentage of the respondents indicate that it is difficult to get help from the government after the floods.

<b>Have you ever been relocated from your residence by the government in case of flooding damage?</b>	
Agree	11.58%
Disagree	27.97%
Moderate	27.68%
Strongly Agree	1.41%
Strongly Disagree	31.36%
<b>Grand Total</b>	<b>100.00%</b>



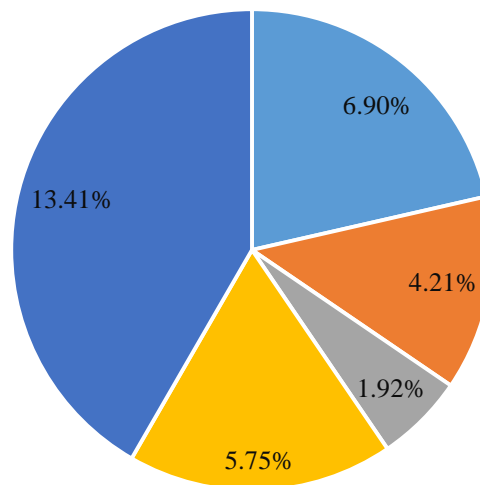
The graph shows responses to the question of whether the government evicted people from their homes due to flood damage. They have not moved, as confirmed by the majority of 31.36% who disagree with the statement. As 27.97% of respondents disagreed, the government may not relocate many respondents. 27.68% of the respondents gave moderate answers indicating uncertainty or neutrality. Consensus was 11.58% and strong consensus was 1.41% of that. Overall, the chart shows that a small percentage of respondents were covered by the government for water damage.

<b>Do you have any idea about rainwater harvesting tank in your house?</b>	
Maybe	11.02%
No	58.47%
Yes	30.51%
<b>Grand Total</b>	<b>100.00%</b>



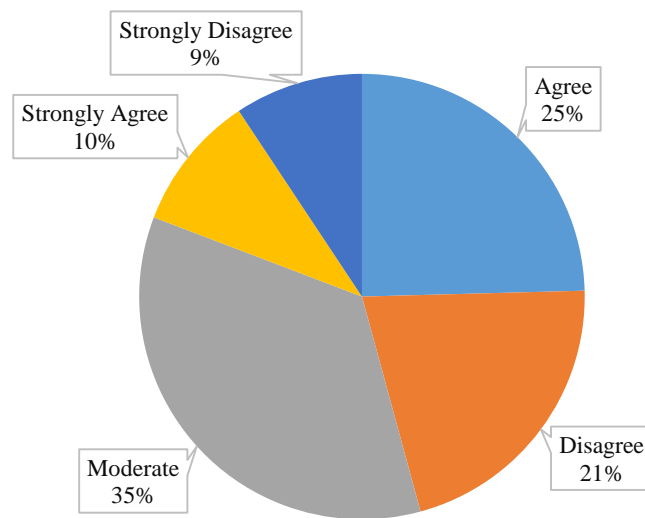
The answers to whether or not respondents' homes had rainwater harvesting tanks are shown in the chart. Most respondents (58.47%) said they do not have rainwater harvesting tanks in their homes. However, 30.51% of respondents said they have rainwater harvesting tanks. The corresponding option "Maybe" received 11.02% of the vote, indicating doubt or ignorance about the existence of such tanks. Overall, the data shows that while a large majority of respondents claimed to have rainwater harvesting tanks, a large minority did not. This shows that the people interviewed have adopted different levels of rainwater harvesting practices.

What is your plan in future for giving a rainwater tank in your house?						
Row Labels	Agree	Disagree	Moderate	Strongly Agree	Strongly Disagree	Grand Total
10000-20000	6.90%	0.00%	5.75%	4.21%	2.30%	19.16%
20000-30000	4.21%	0.77%	0.00%	1.15%	0.77%	6.90%
30000-40000	1.92%	0.00%	1.15%	2.30%	0.00%	5.36%
5000-10000	5.75%	1.15%	11.11%	5.36%	0.00%	23.37%
Less than 5000	13.41%	7.66%	15.33%	5.75%	3.07%	45.21%



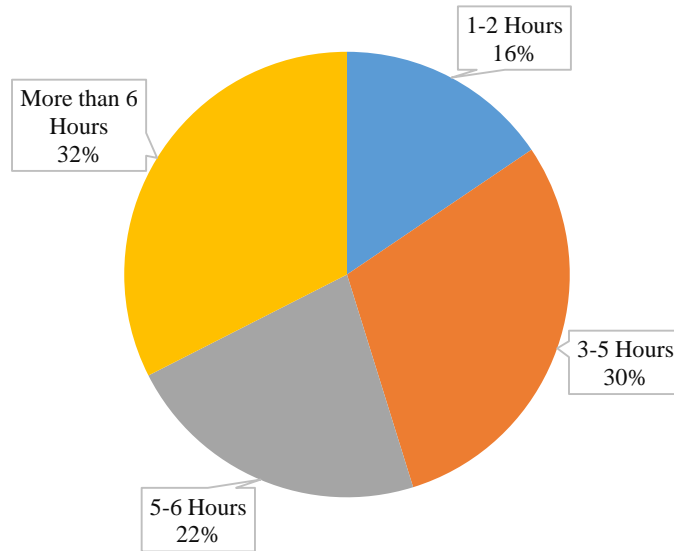
The graph shows the number of respondents who want to build a rainwater tank in their home in liters. Between 10,000 and 20,000 liters, 6.90% of the respondents were in favor of building a rainwater tank and nobody was against it. Of the 20,000-30,000 liter respondents, 4.21% agreed, not 0.7%. 1.92% agreed with those between 30,000 and 40,000 liters and no one objected. 5.75% of respondents agreed and 1.15% disagreed between 5000 and 10000 liters. 13.41% of the respondents, whose house has a water tank of less than 5,000 liters, indicated that they would build a rainwater tank. In general, the chart shows that there are differences between the different bed groups, with the majority of respondents in the lower bed segment indicating that they plan to build a rainwater tank in their home.

<b>Do you clean your water tank regularly?</b>	
Agree	24.58%
Disagree	21.19%
Moderate	35.03%
Strongly Agree	9.89%
Strongly Disagree	9.32%
<b>Grand Total</b>	<b>100.00%</b>



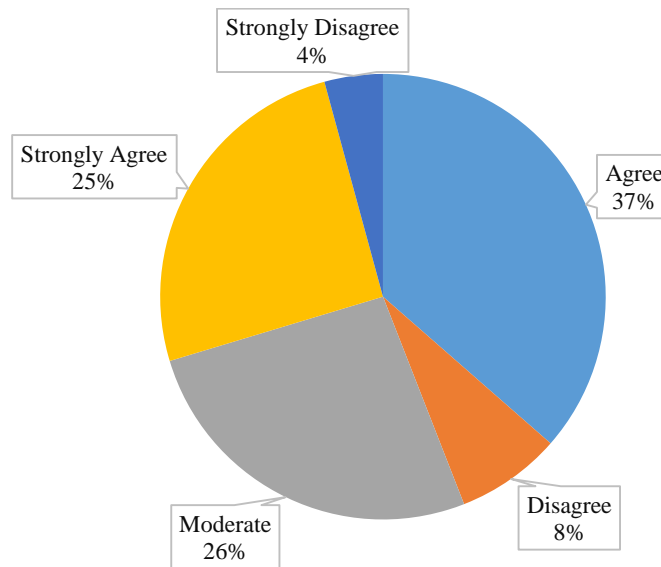
The graph shows the answers to the question how often the respondents clean their water tanks. Most (35.03%) respondents indicated uncertainty or a neutral opinion about the topic and chose Moderate as the answer option. 21.19% of respondents disagreed, indicating that many do not regularly clean their water tanks. significant agreement and significant disagreement scored 9.89% and 9.32%, respectively, while agreement scored 24.58%.

<b>How many hours do you observed water remains stagnant on the road?</b>	
1-2 Hours	15.54%
3-5 Hours	29.66%
5-6 Hours	22.32%
More than 6 Hours	32.49%
<b>Grand Total</b>	<b>100.00%</b>



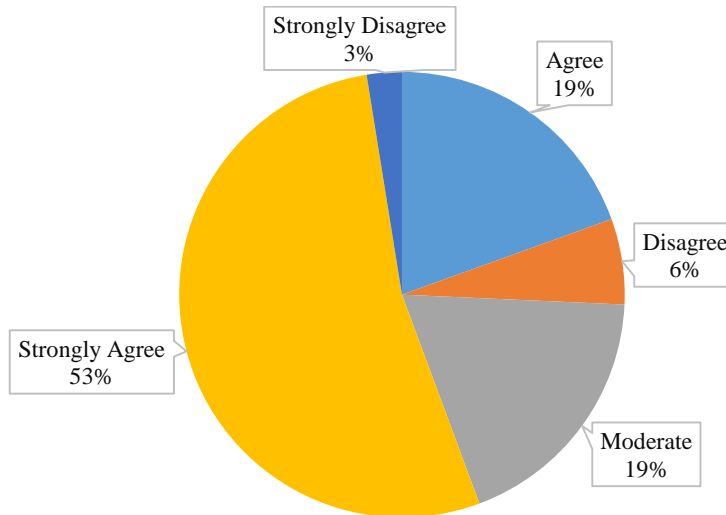
The graph shows how often respondents said they see standing water on roads. The majority (32.49%) reported seeing stagnant water for more than six hours. A significant percentage of respondents saw standing water during this period, with the 3-5 hour group accounting for 29.66% of all responses. 22.32% of the respondents reported standing in the water for 5-6 hours. 15.54% of respondents indicated 1-2 hours as the shortest possible time frame.

Water in a rainwater catchment system should be tested regularly?	
Agree	36.44%
Disagree	7.63%
Moderate	26.27%
Strongly Agree	25.42%
Strongly Disagree	4.24%
<b>Grand Total</b>	<b>100.00%</b>



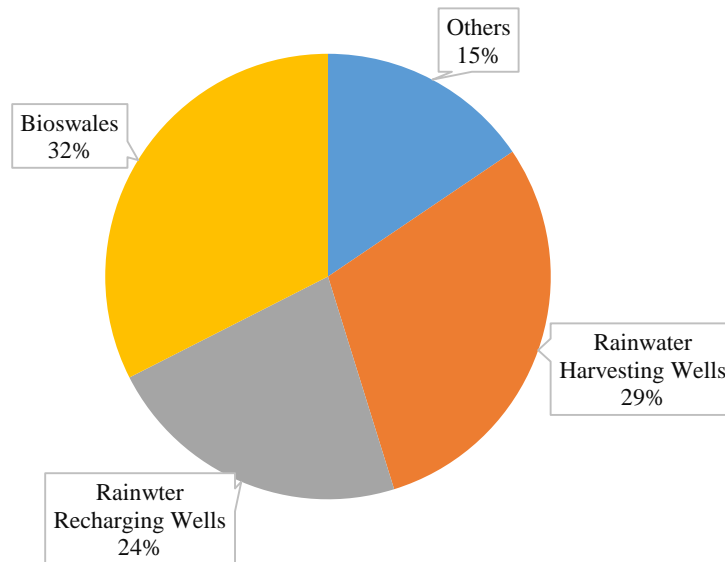
The graph shows the responses to the recommendation to regularly test the water in rainwater harvesting systems. The majority of respondents, 36.44%, agreed with the statement, citing the value of routine testing. Strong agreement was 25.42%, further highlighting the value of routine water testing. A minority of respondents, 7.63%, disagreed with the statement, which is relatively few. Moderate received 26.27% of the vote, indicating significant ambivalence or neutrality. A small percentage of respondents (4.24%) strongly opposed routine water testing in rainwater harvesting systems, which was significant.

Proper drainage pattern should be provided in the city?	
Agree	19.49%
Disagree	6.21%
Moderate	18.64%
Strongly Agree	53.11%
Strongly Disagree	2.54%
<b>Grand Total</b>	<b>100.00%</b>



Responses to the recommendation that the city implement an appropriate drainage pattern are shown in the table. The majority, 53.11%, strongly agreed with the statement that good drainage is essential. 19.49% of respondents agreed, indicating that many people felt that a proper drainage project was necessary. A small percentage of respondents, namely 6.21%, disagreed. The moderate answer option was chosen by 18.64% of the respondents, which indicates some ambiguity or neutrality. Strong opposition, represented by a small percentage of people strongly opposed to providing an adequate drainage system for the city, was 2.54%.

What should be the possible solution to handle urban flooding?	
Bioswales	32%
Rainwater Harvesting Wells	29%
Rainwater Recharging Wells	24%
Others	15%
<b>Grand Total</b>	<b>100.00%</b>



The graph offers possible answers to the problem of urban flooding. The majority (32%) require the use of Bioswales as a resource. Rainwater harvesting wells scored 29%, demonstrating the city's potential for flood management. Rainwater recharging wells accounted for 24%, indicating their function in flood risk reduction. 15% of the total was assigned to the "Other" category, which respondents offered as additional or different options.

## Field Survey of Affected Roads



Figure 3. Abdul Aziz Road F2-Block Johar Town



Figure 4. Abdul Haque Road G-1 Block Johar Town



Figure 5. Canal Road Near Westwood Colony



Figure 6. E-Block Phase 1 Johar Town



Figure 7. Ghazan Road Johar Town

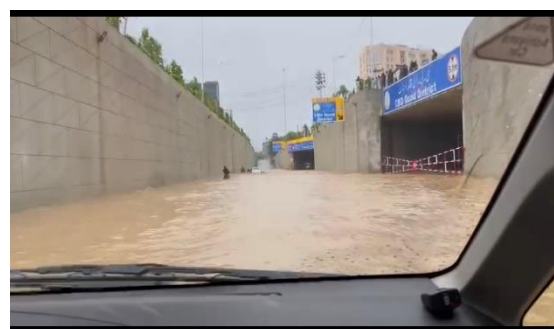


Figure 8. Kalma Underpass



Figure 9. Katar Bund Road, Industrial Estate, Thokar



Figure 12. Main Thokar Chowk



Figure 10. Khayaban-e-Firdousi Road Allah Hoo Roundabout



Figure 13. Nazaria-e-Pakistan Avenue Near Expo Center Phase 2 Johar Town



Figure 11. Khayaban e Iqbal Road DHA Phase 3



Figure 14. Park View City Main Road

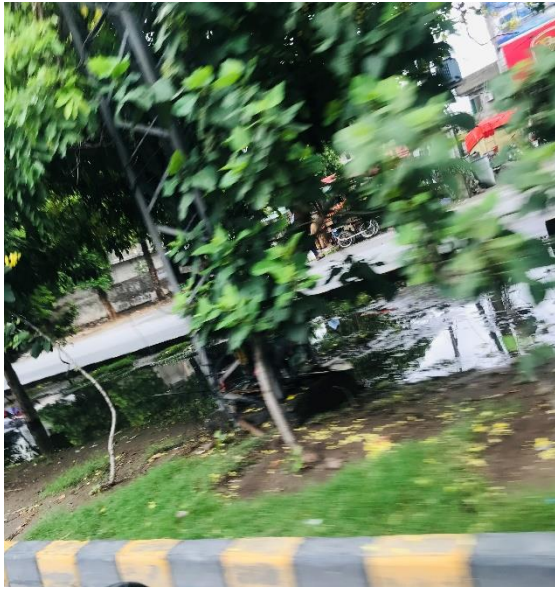


*Figure 15. Shawala Road Johat Town E1-Block*



*Figure 16. UMT Road*

## Active Bioswales in Lahore



*Figure 17. Abdul Haque Road G-1 Block Johar Town*



*Figure 18. Abdul Haque Road G-1 Block Johar Town*



*Figure 19. Abdul Haque Road G-1 Block Johar Town*



*Figure 20. Canal Road*



*Figure 21. Canal Road*



*Figure 23. Canal Road*



*Figure 22. Canal Road*



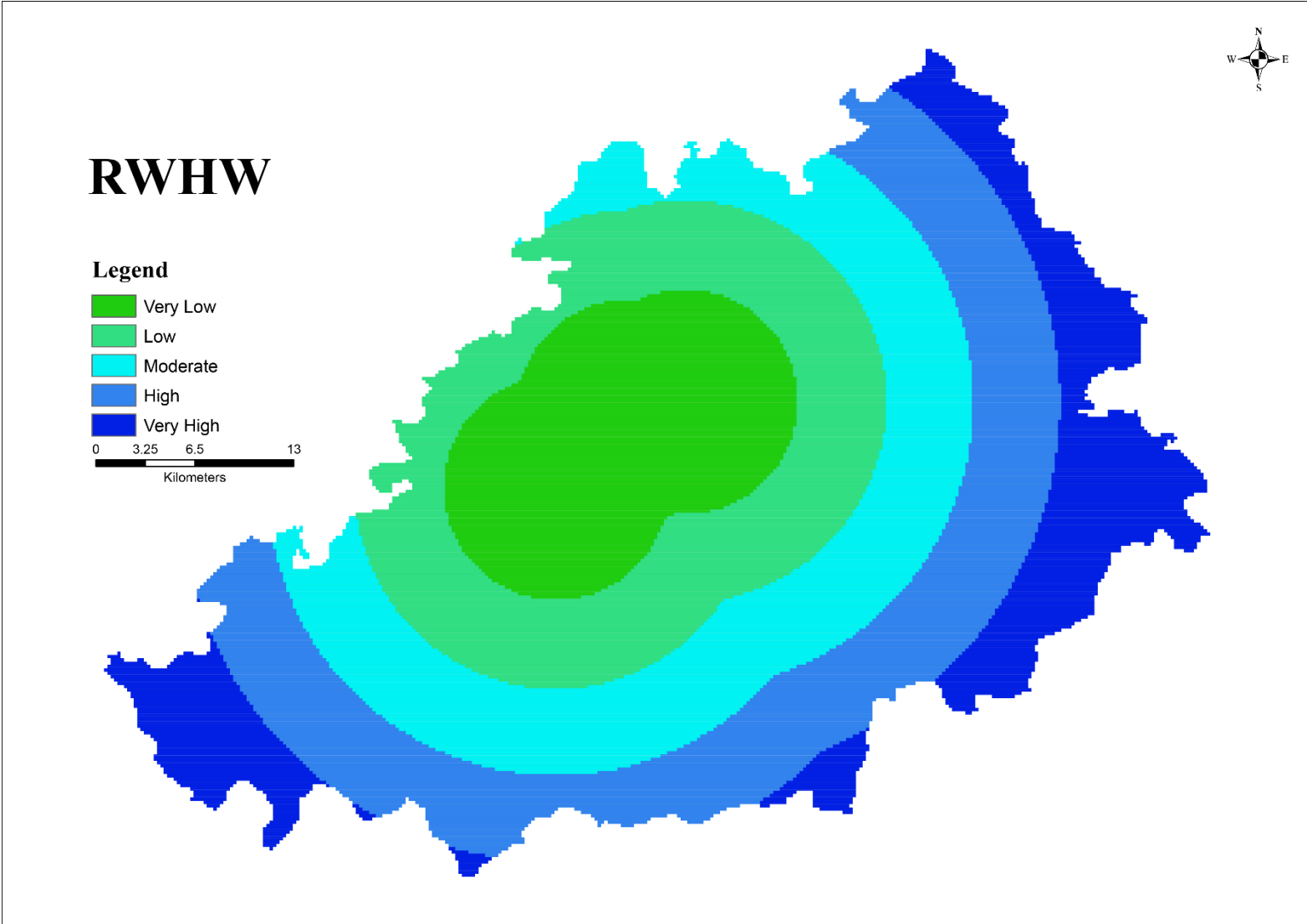
*Figure 24. Near Doctor Hospital Canal Road*

## **Euclidean Distance**

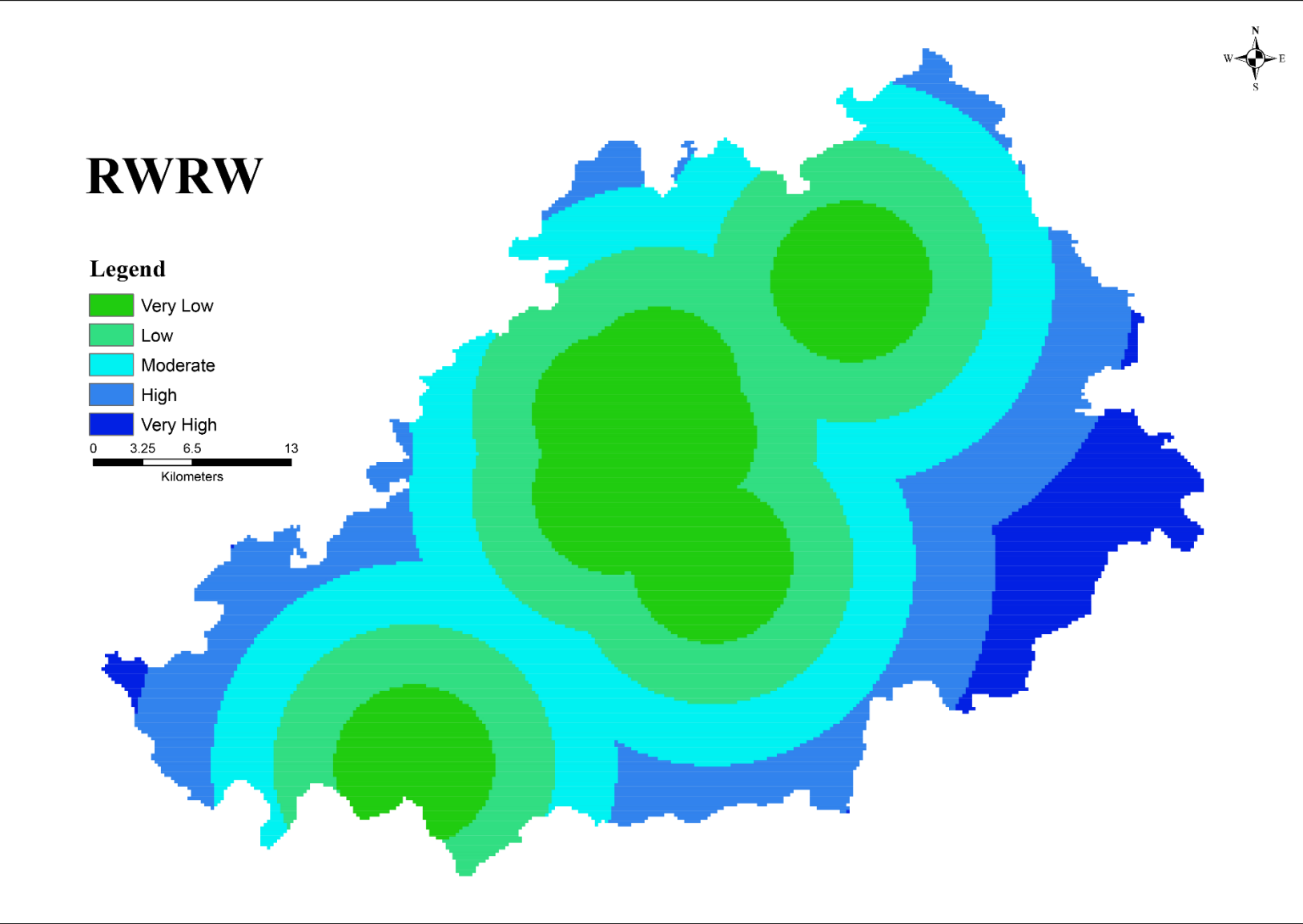
Nine variables Euclidean distance analysis are displayed, including rainwater harvesting wells (RHHW), rainwater recharge wells (RWRW), slope, digital elevation model (DEM), precipitation, road network, drainage pattern, watershed area, and ponds. On a GIS-generated map. The distance values show the geographic interaction and variation of each variable and provide comprehensive information about their relative distribution across the study area. This comprehensive study helps to understand the geographical distribution of these components and lays the foundation for smart decision-making and effective flood risk assessment and management techniques.

These are the given maps which are generated through Euclidean Method;

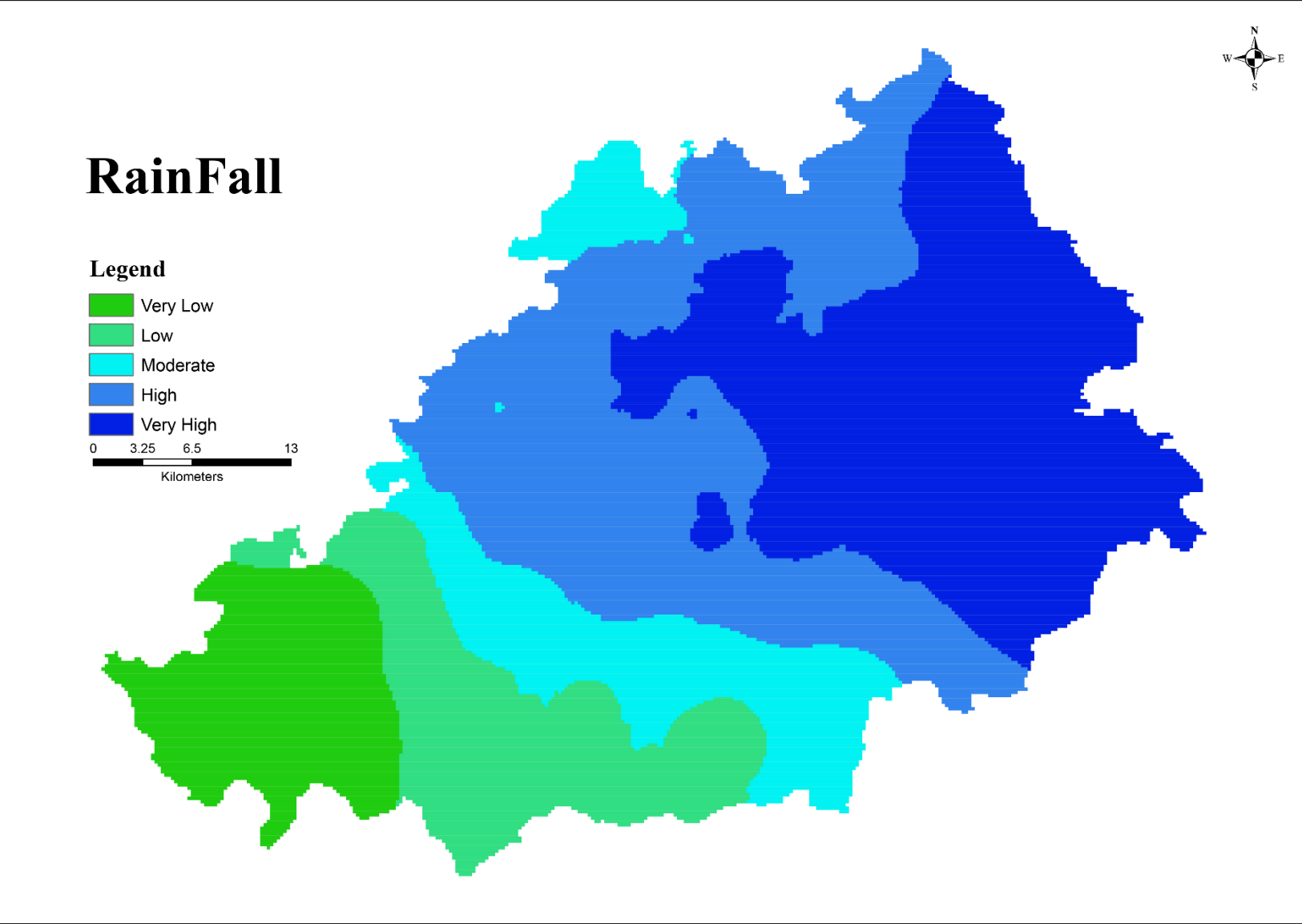
# Rainwater Harvesting Wells



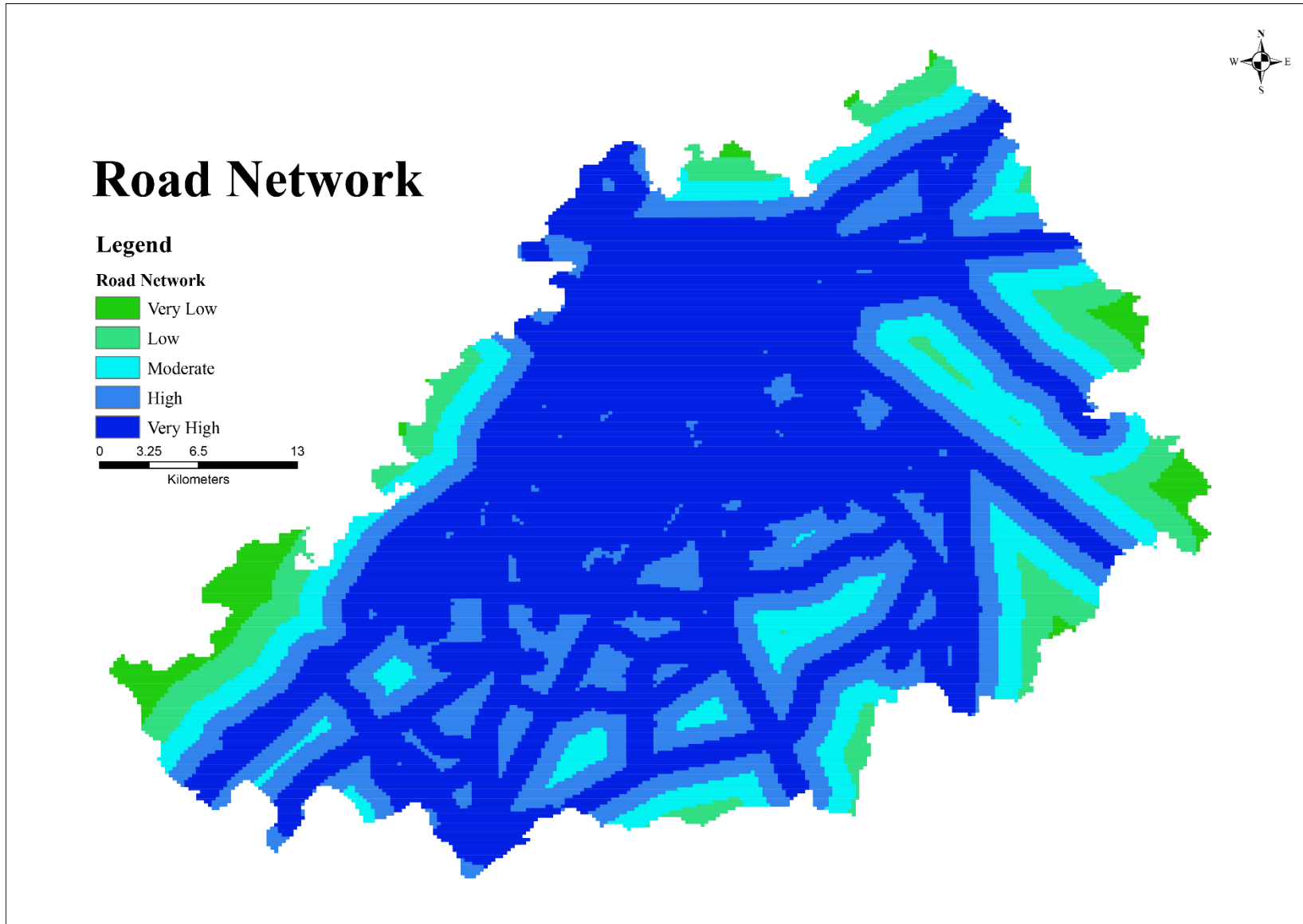
Rainwater Water Recharging Wells



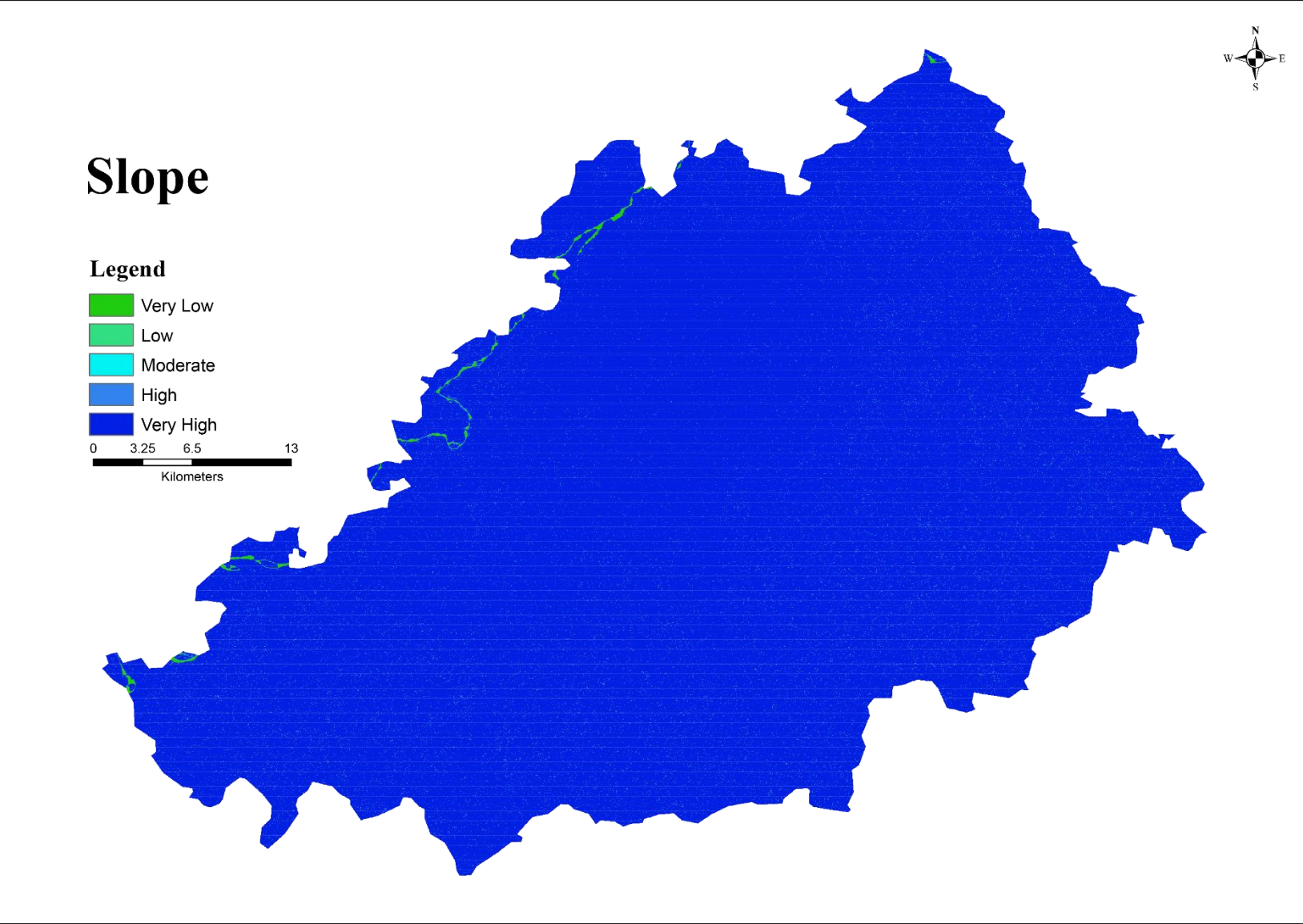
Rainfall



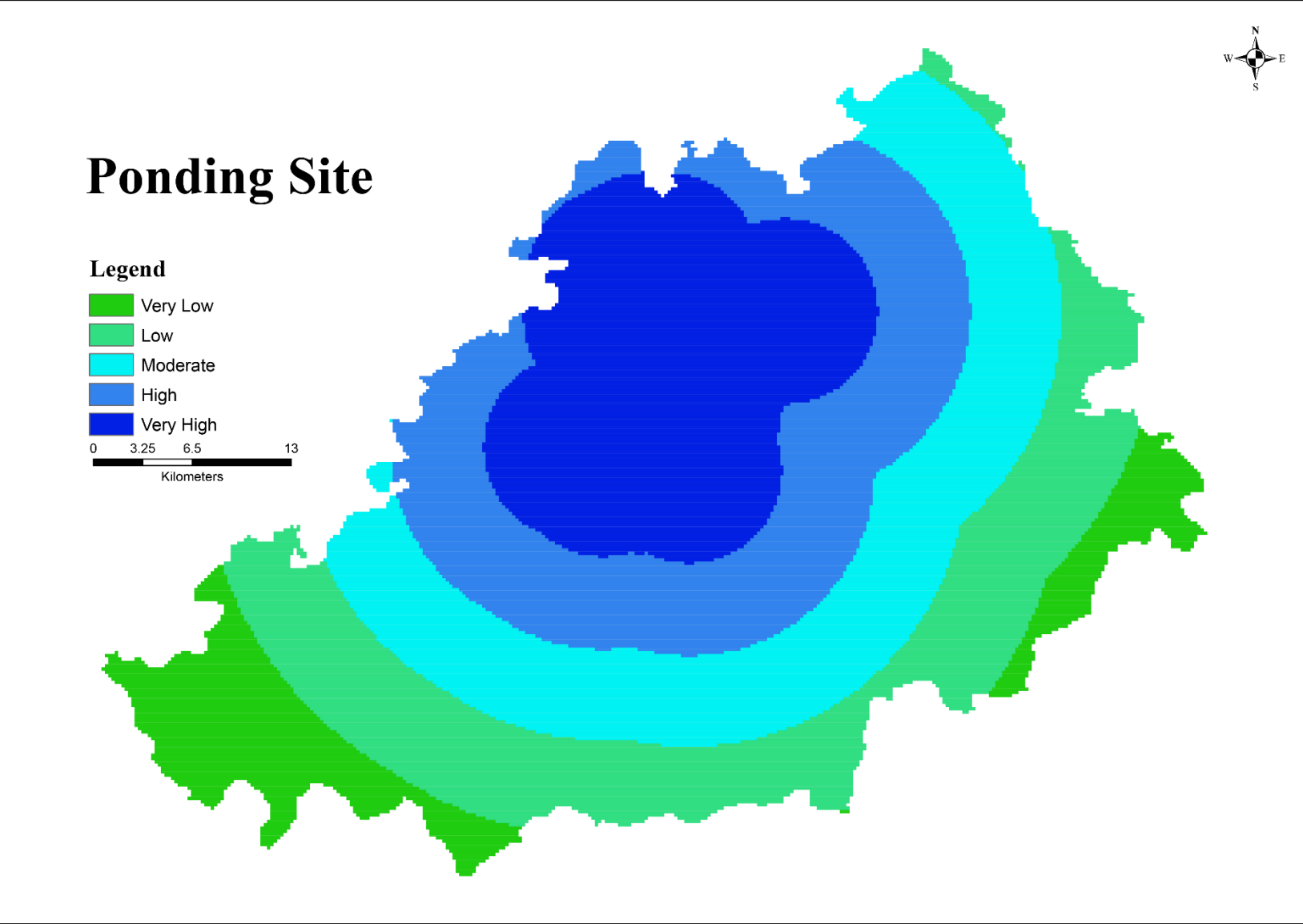
## Road Network



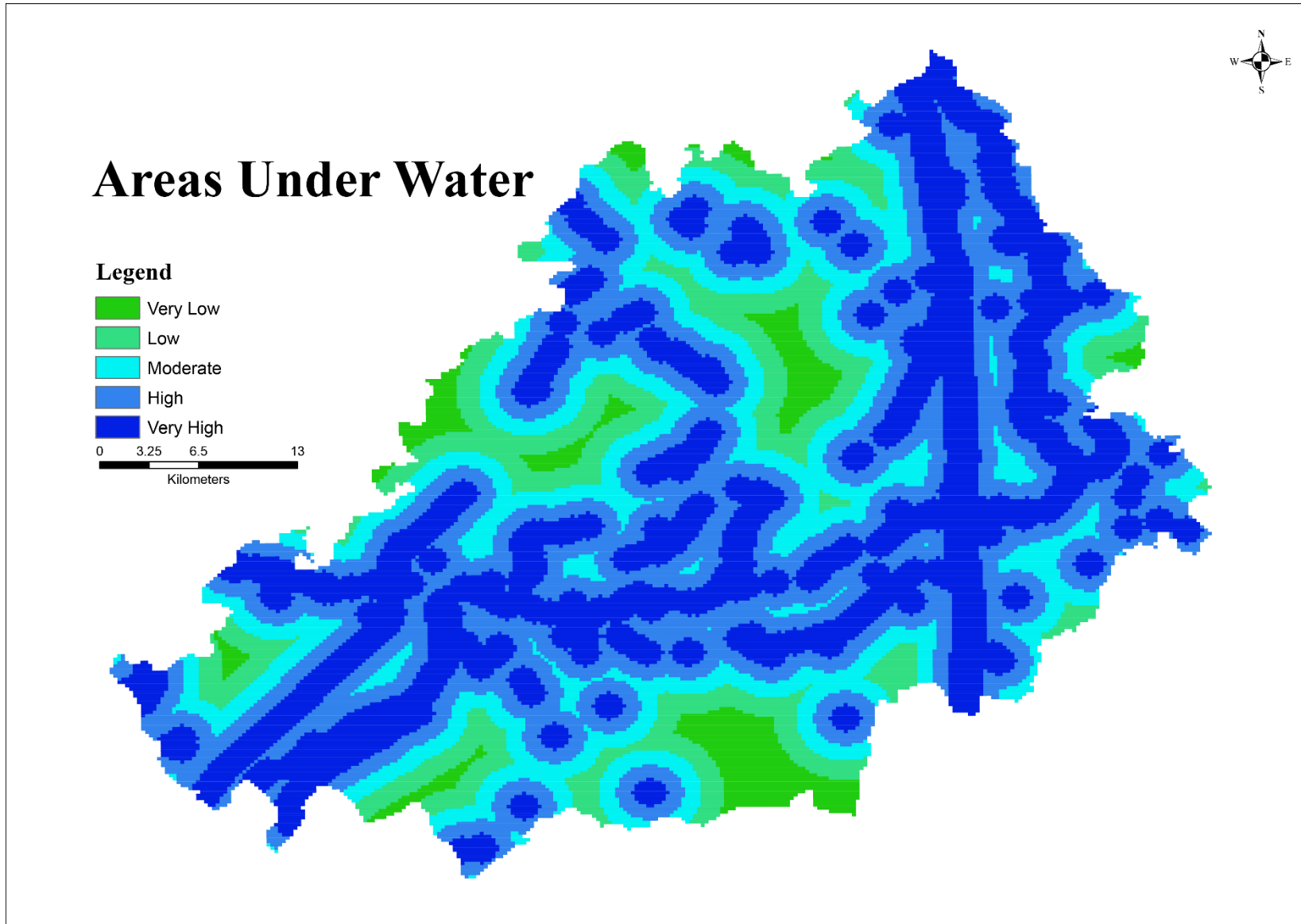
Slope



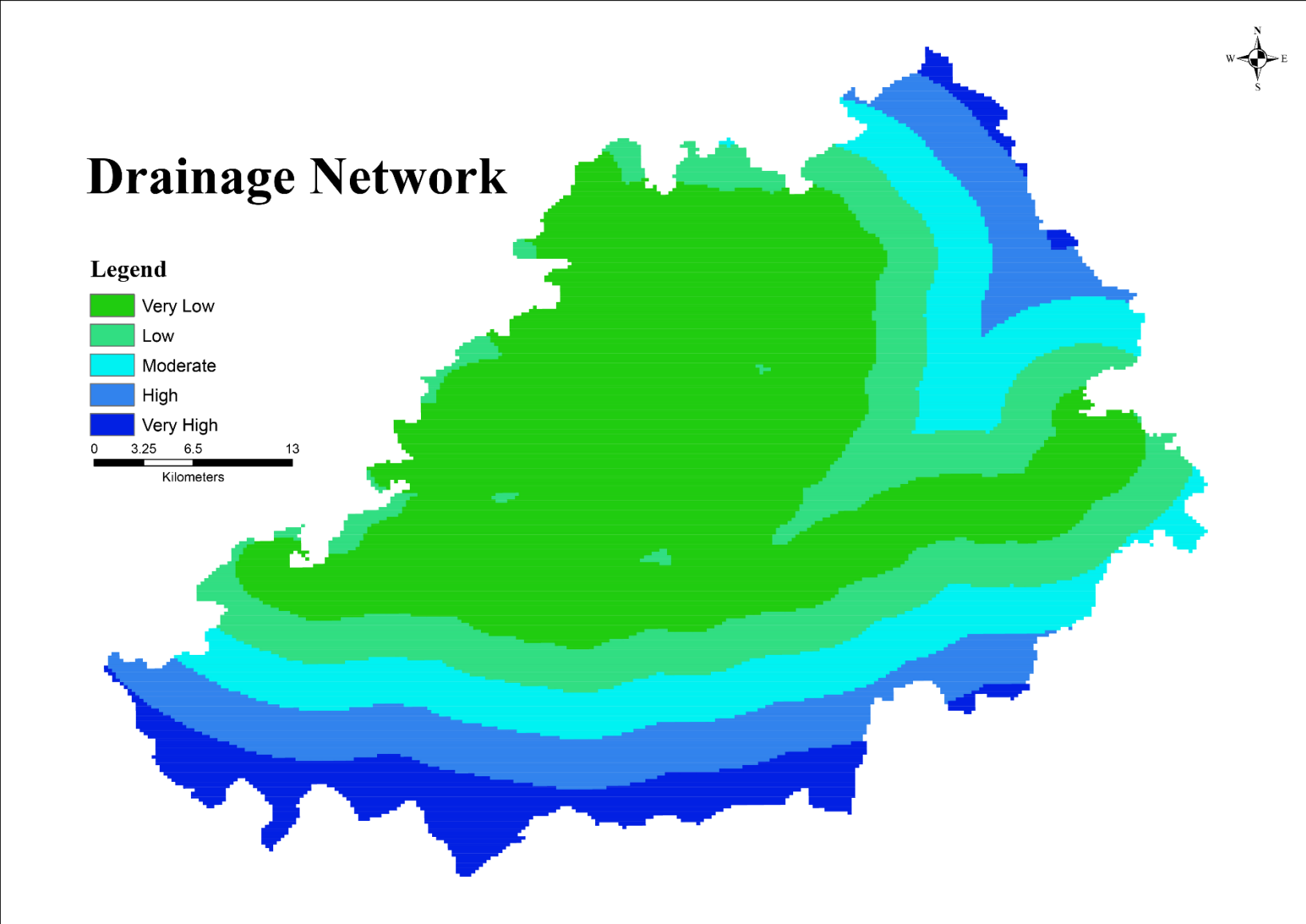
Ponding Sites



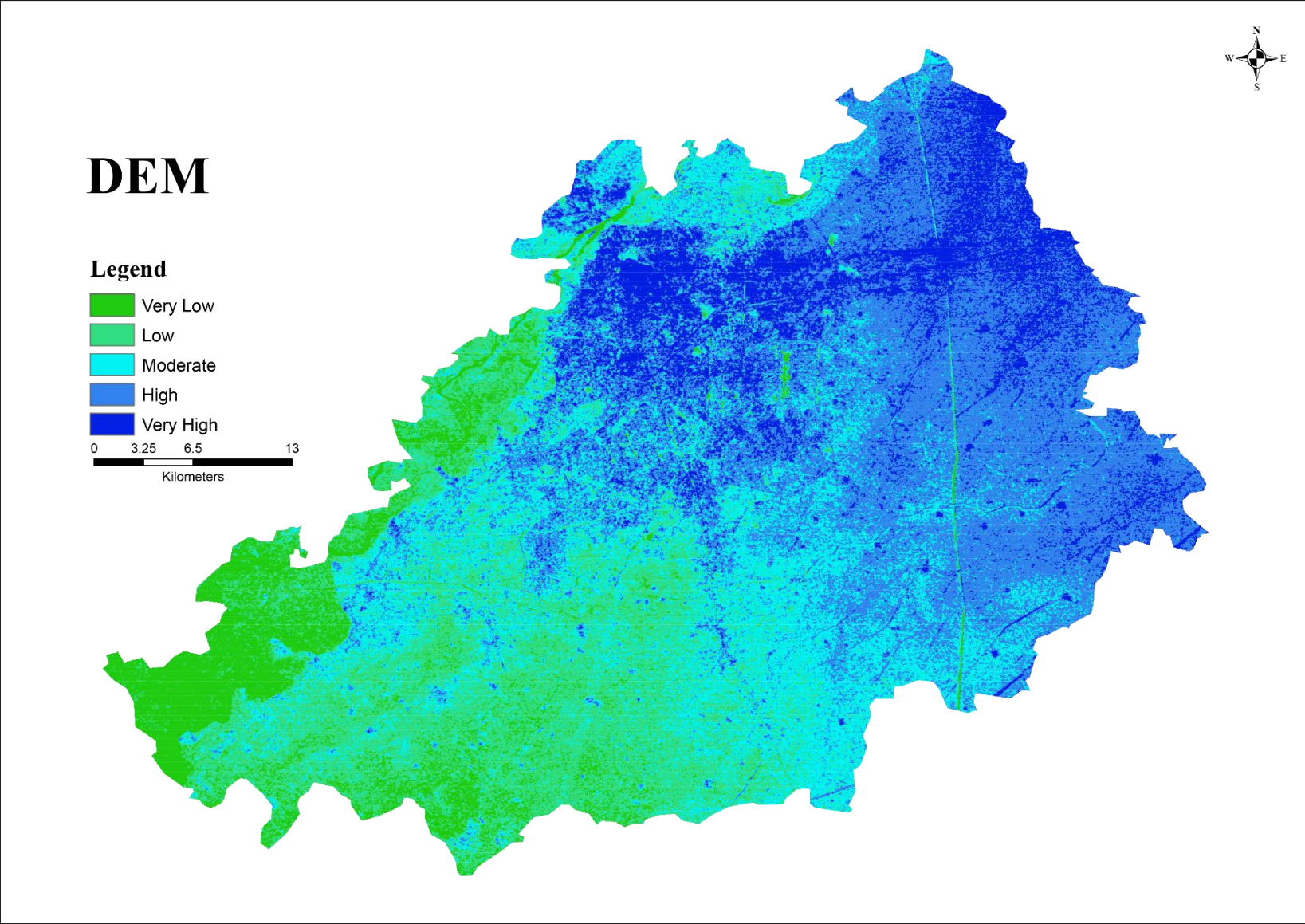
## Areas Under Water



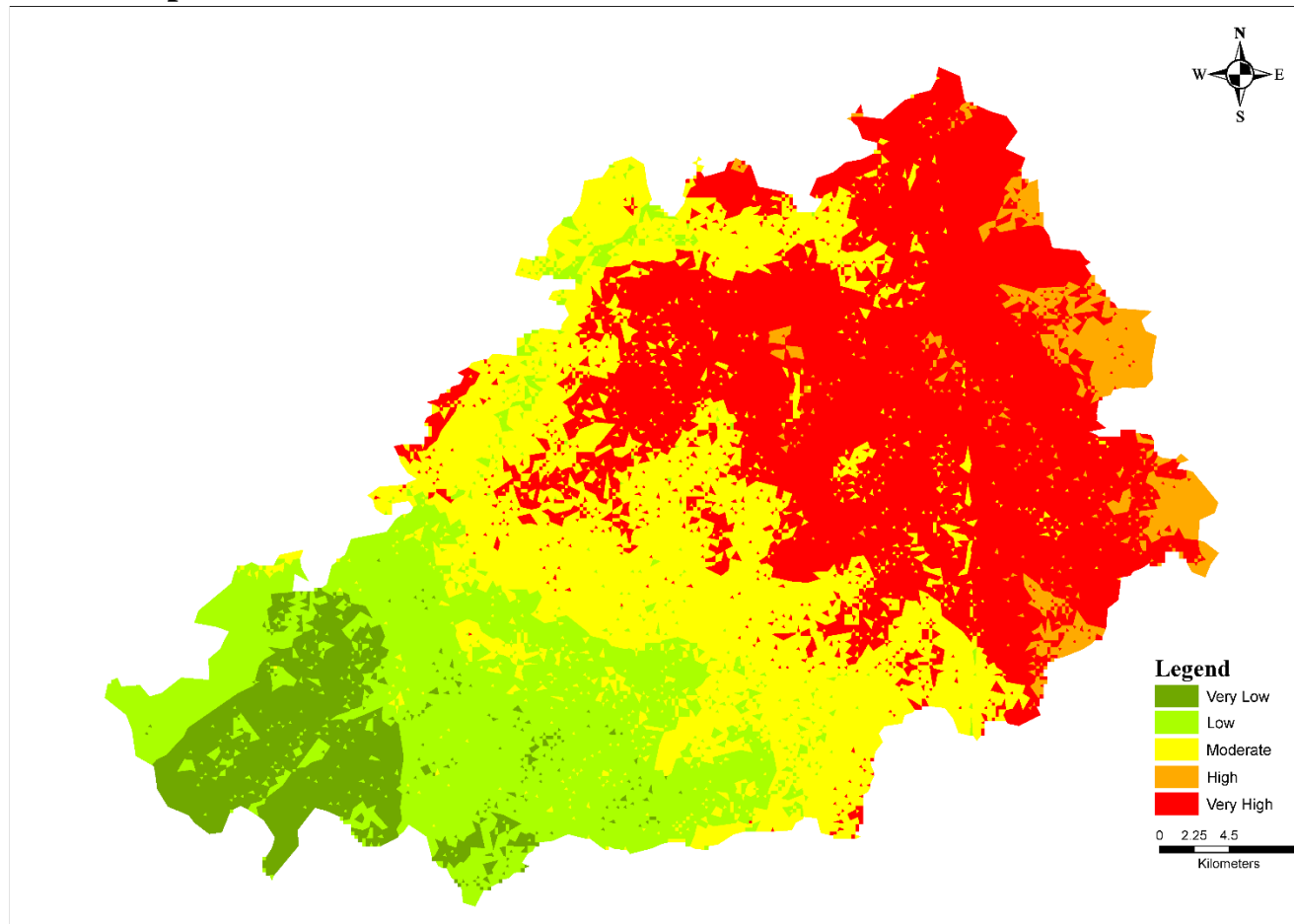
Drainage Network



DEM

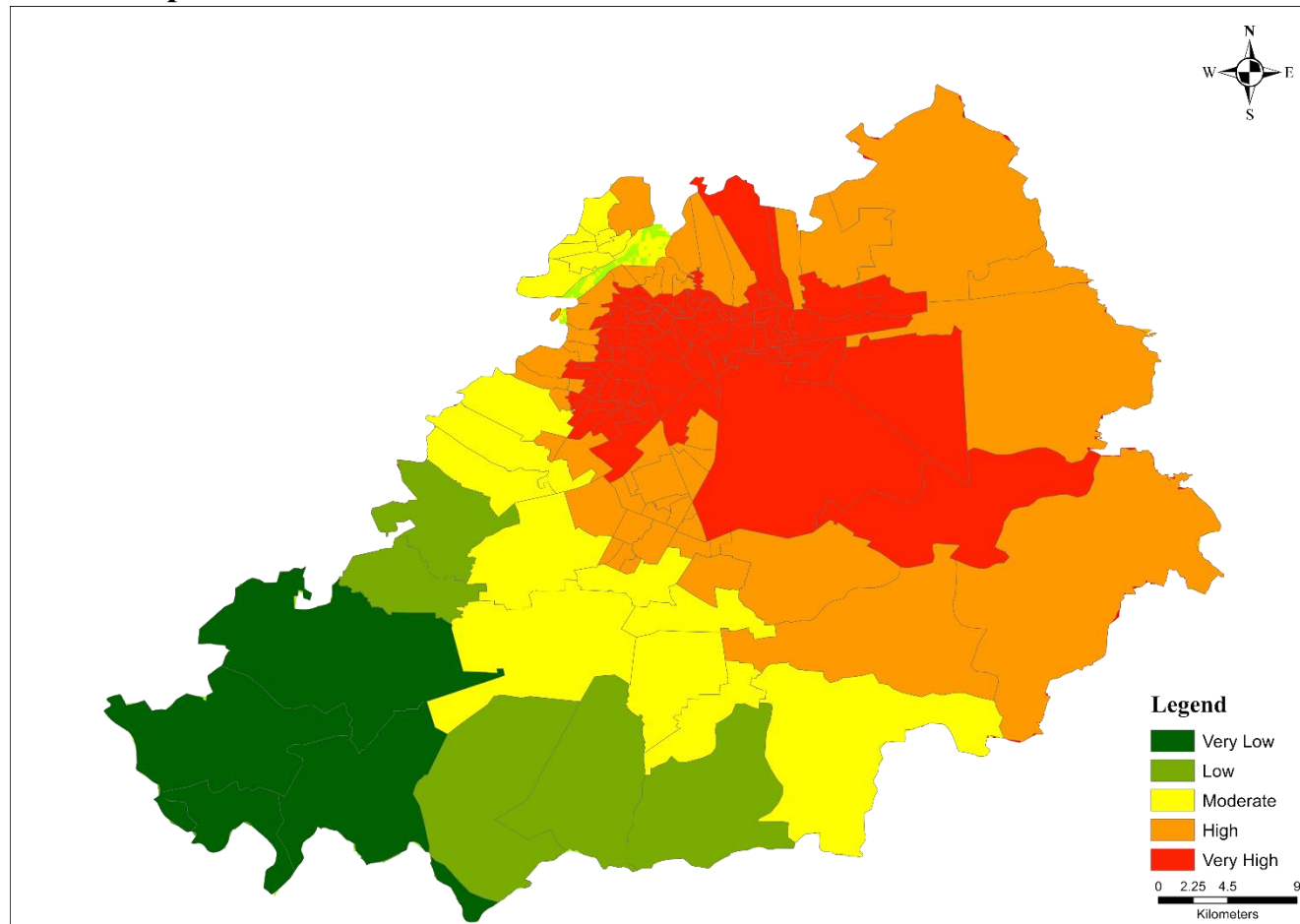


## Flood Risk Assessment Map



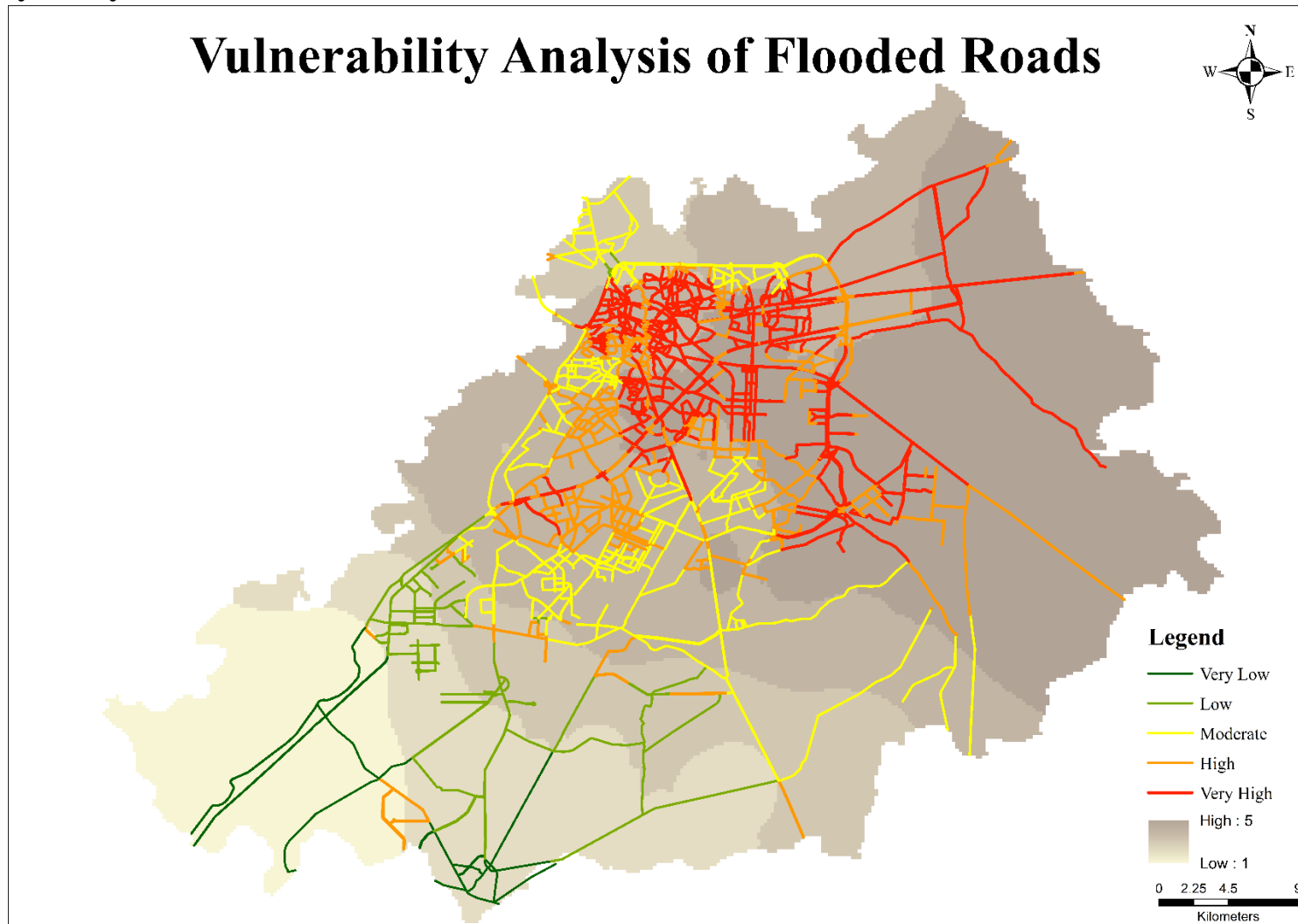
An Analytic Hierarchy Process (AHP) approach was used to compile a GIS-generated flood risk assessment map showing the geographic distribution of flood risk levels across the Lahore. To prioritize sites based on their vulnerability to flooding, the AHP analysis includes several characteristics, including ponding sites, LULC, rainfall patterns, drainage network, and other relevant variables. The resulting map divides areas into risk categories, from very high to very low, and provides useful information to support flood preparedness and flood mitigation initiatives.

## Flood Risk Assessment Map UC's Wise



The Analytic Hierarchy Process (AHP) approach was used to analyze the GIS-generated flood risk assessment map of Lahore and clarify the levels of flood risk at the Union Council (UC) level. This comprehensive map shows the different levels of flood vulnerability of UCs in Lahore, taking into account the development of regional flood control plans. AHP analysis provides comprehensive knowledge of flood risk at the community level, covering several elements such as landscape, land use, rainfall and drainage network.

## Vulnerability Analysis of Flooded Roads of Lahore



The GIS-generated map shows vulnerability analysis of flooded roads in Lahore and groups roads according to how vulnerable they are to flooding. Red indicates a high level of sensitivity, while orange, yellow, parrot (a shade of green) and green indicate a low level of risk.

## **CHAPTER 05: CONCLUSION**

# Proposal

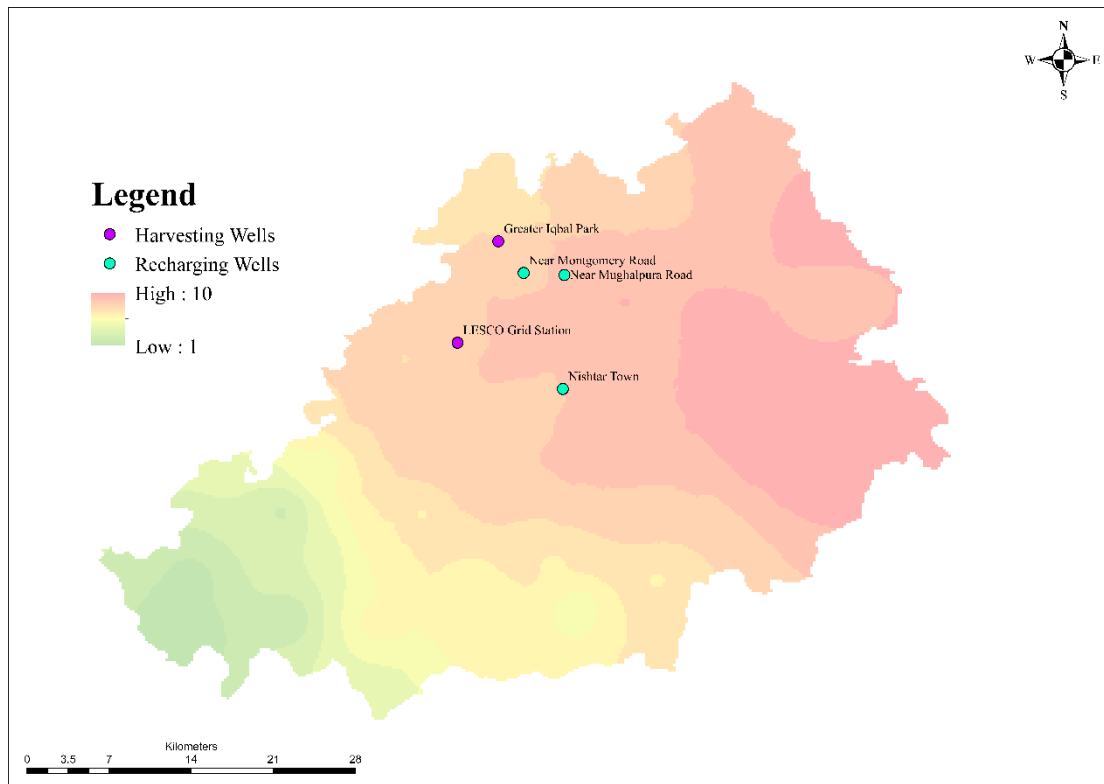


Figure 25. Proposal of RWHW

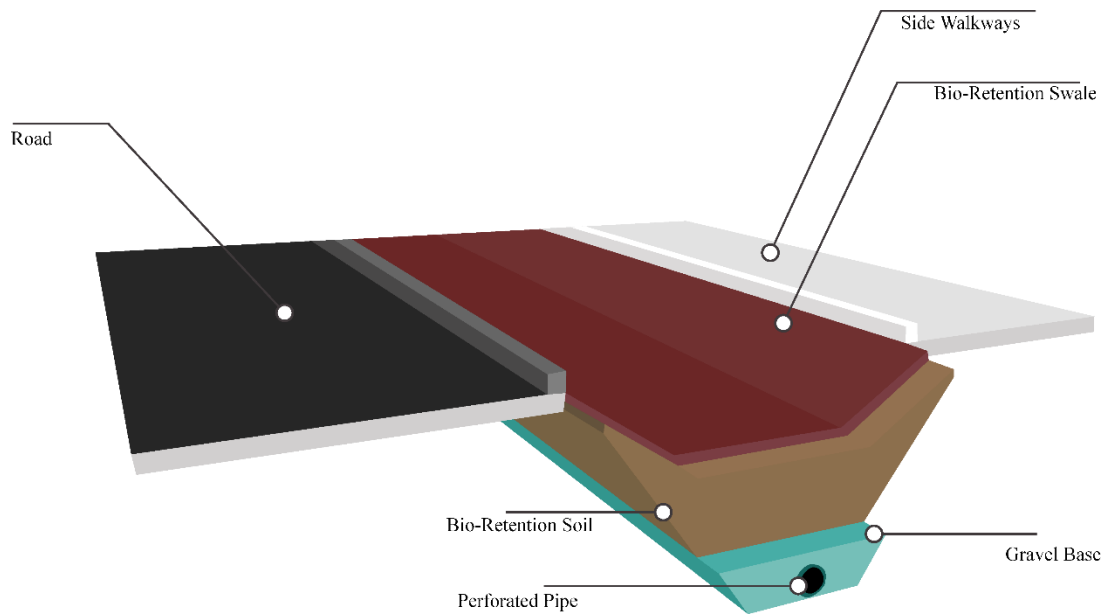


Figure 26. Proposal of Bioswales

## Conclusion

In conclusion this thesis aimed to assess potential of rainwater harvesting using GIS and remote sensing techniques as a possible way to prevent urban flooding in Lahore, Pakistan. Through an extensive literature review, we identified the importance of sustainable flood management techniques and the effectiveness of rainwater harvesting in other areas of Lahore. We have effectively analyzed rainfall patterns, flood-prone areas and potential locations of rainwater harvesting systems using GIS and remote sensing methods. According to research, rainwater harvesting and bioswales can significantly reduce the risk of urban flooding by reducing runoff and replenishing underground water resources. But successful implementation require effective stakeholders including government agencies, urban planners and local communities must work together. This study provides a framework for future sustainable flood management research by providing insightful observations and useful recommendations for the implementation of rainwater harvesting and bioswales techniques to strengthen the resilience of Lahore's urban infrastructure against flood disasters.

## Recommendations

- **Implementation of Rainwater Harvesting Wells Connected with Bioswales**  
To effectively manage urban flooding, priority should be given to the implementation of rainwater harvesting wells connected with bioswales. These two methods improves water infiltration and retention, reducing runoff and the risk of flooding. The impact of heavy rainfall can be reduced by strategically placing rainwater harvesting wells next to bioswales to increase their efficiency in collecting and storing rainwater.
- **Community Awareness and Participation**  
For successful flood management initiative, the public must be informed and the community must be actively involved. Conducting awareness campaigns and engaging locals in the planning and implementation process will foster a sense of responsibility. Community participation in protecting the urban environment resilience is encouraged by educating them on the benefits of rainwater harvesting and bioswales.
- **Continuous Monitoring and Evaluation of urban flood patterns through GIS and remote sensing**  
Regular monitoring and assessment of urban flooding patterns using GIS and remote sensing technology will provide real-time information on flood-prone areas and their dynamics. Using this data makes it easier to identify trends, evaluate the implemented measures and adapting strategies accordingly. Timely data-driven decisions improves city's ability to respond to floods.
- **Collaboration with Local Authorities**  
Local authorities and relevant organizations must work together to manage floods effectively. Partnerships with organizations such as Water and Sanitation Agency (WASA), Lahore Waste Management Company (LWMC), Pakistan Council for Water Resources Research (PCRWR), World Wildlife Fund (WWF) and Pakistan Meteorological Department (PMD) will facilitate access to resources, expertise and data. Promoting such partnerships will allow for a comprehensive approach toward urban flood risk reduction, resulting in resilient and sustainable solutions for Lahore.

## Annexure

### Questionnaire

#### **Title: Assessing the Potential of Rainwater Harvesting through GIS and Remote Sensing Techniques in combating Urban Flooding in Lahore, Pakistan.**

**Purpose:** This questionnaire aims to gather data on the feasibility of using rainwater harvesting as a sustainable solution for managing urban flooding in Lahore. It will help identify the current level of awareness, perception, and willingness of citizens to adopt rainwater harvesting, and the potential barriers and benefits associated with its implementation. The results will provide valuable insights into the feasibility and effectiveness of rainwater harvesting as a tool for urban flood management in Lahore.

1. Name (Optional): \_\_\_\_\_
2. Gender:
  - a. Male
  - b. Female
3. What is your education qualification
  - a. \_\_\_\_\_
4. From which area you belong?
  - a. \_\_\_\_\_
5. How long have you live in that area?
  - a. Less Than 5 Years
  - b. 5-10 Years
  - c. 10-20 Years
  - d. More Than 20 years
6. In your perspective, who is responsible for urban flooding in your community? (Rainey et al., 2021)
  - a. Storm Water Management Authority
  - b. Elected Officials
  - c. Community Itself
  - d. Not a Significant Problem
7. Do you feel that in this time of flood, the support of Govt. was good? (Gandhi & Agnihotri, 2022)
  - a. Strongly Disagree
  - b. Disagree
  - c. Moderate
  - d. Agree
  - e. Strongly Agree

8. Is the cleaning of the area (sewer cleaning before monsoon) was better than the earlier? (Gandhi & Agnihotri, 2022)
  - a. Strongly Disagree
  - b. Disagree
  - c. Moderate
  - d. Agree
  - e. Strongly Agree
  
9. Have you ever face damages from urban floods? (Gandhi & Agnihotri, 2022)
  - a. Strongly Disagree
  - b. Disagree
  - c. Moderate
  - d. Agree
  - e. Strongly Agree
  
10. Is the damage from flooding is on a lesser than the earlier? (Gandhi & Agnihotri, 2022)
  - a. Strongly Disagree
  - b. Disagree
  - c. Moderate
  - d. Agree
  - e. Strongly Agree
  
11. Have you ever see the roads damages by urban flooding? (Gandhi & Agnihotri, 2022)
  - a. Strongly Disagree
  - b. Disagree
  - c. Moderate
  - d. Agree
  - e. Strongly Agree
  
12. Is the recovery period in post flooding has been reduced due to Self Help Groups (Self-help groups are informal groups of people who come together to address their common problems)? (Gandhi & Agnihotri, 2022)
  - a. Strongly Disagree
  - b. Disagree
  - c. Moderate
  - d. Agree
  - e. Strongly Agree

13. Do you feel that SHGs are essential for flood management activities? (Gandhi & Agnihotri, 2022)
- Strongly Disagree
  - Disagree
  - Moderate
  - Agree
  - Strongly Agree
14. Do you think that the recovery period in post flooding has been reduced due to government actions? (Gandhi & Agnihotri, 2022)
- Strongly Disagree
  - Disagree
  - Moderate
  - Agree
  - Strongly Agree
15. Do you feel that due to SHGs the damaged has been reduced?(Gandhi & Agnihotri, 2022)
- Strongly Disagree
  - Disagree
  - Moderate
  - Agree
  - Strongly Agree
16. Do you feel that due to governmental action in urban flooding the damaged has been reduced?(Gandhi & Agnihotri, 2022)
- Strongly Disagree
  - Disagree
  - Moderate
  - Agree
  - Strongly Agree
17. In your perspective, which one of the following is chief causes of Urban Flooding? (Mboma, 2021)
- Rainfall
  - Incidence of Flood
  - Improper Waste Disposal
  - Surface Runoff
  - Poor City Planning
  - Inadequate Drainage Facility
  - Deforestation

18. In your perspective, which one of the following is a major impact of Flooding on communities in the city? (Mboma, 2021)
- Loss of Property
  - Injury of Households
  - Death of Households
  - Loss of Health
  - Diseases
19. In your perspective, which one of the following is a prominent diseases spread after flooding? (Leandro et al., 2022)
- Diarrhea
  - Malaria
  - Skin Diseases
  - Water Born Diseases
  - Others \_\_\_\_\_
20. In your perspective, which one of the following is a major impact of flooding on city infrastructure? (Mboma, 2021)
- Damage to structures
  - Damage to bridges
  - Roads damaged and blocked
  - Electric cables and poles destroyed
  - Water pips damaged
21. Do you have any idea about rainwater harvesting tank in your house? (Al-Batsh et al., 2019)
- Yes
  - No
22. What is your plan in future for giving a rainwater tank in your house? (Al-Batsh et al., 2019)
- Strongly Disagree
  - Disagree
  - Moderate
  - Agree
  - Strongly Agree
23. If, Yes than what is your current Rainwater Tank Capacity (In Liters)?(Al-Batsh et al., 2019)
- 5000-10000
  - 10000-20000
  - 20000-30000
  - 30000-40000

24. Use of Rainwater? (Donohue et al., 2017)
- a. Drinking
  - b. Bathing
  - c. Household supply
  - d. Gardening
  - e. Other
25. Do you clean your water tank regularly? (Donohue et al., 2017)
- a. Strongly Disagree
  - b. Disagree
  - c. Moderate
  - d. Agree
  - e. Strongly Agree
26. Name any one road which you have observed urban flooding during monsoon season?(Gandhi & Agnihotri, 2022)
- a. \_\_\_\_\_  
\_\_\_\_\_
27. Water in a rainwater catchment system should be tested regularly? (Donohue et al., 2017)
- a. Strongly Disagree
  - b. Disagree
  - c. Moderate
  - d. Agree
  - e. Strongly Agree
28. Proper Drainage Pattern Provided in the city? (Naik et al., 2022)
- a. Strongly Disagree
  - b. Disagree
  - c. Moderate
  - d. Agree
  - e. Strongly Agree
29. Were the members of SHGs were friendly with you?(Gandhi & Agnihotri, 2022)
- a. Strongly Disagree
  - b. Disagree
  - c. Moderate
  - d. Agree
  - e. Strongly Agree

30. Were the members of SHGs were easily accessible to you?(Gandhi & Agnihotri, 2022)
- Strongly Disagree
  - Disagree
  - Moderate
  - Agree
  - Strongly Agree
31. Were the government support easily accessible to you during flooding?(Gandhi & Agnihotri, 2022)
- Strongly Disagree
  - Disagree
  - Moderate
  - Agree
  - Strongly Agree
32. Have you ever been relocated from your residence by the government in case of flooding damage?(Gandhi & Agnihotri, 2022)
- Strongly Disagree
  - Disagree
  - Moderate
  - Agree
  - Strongly Agree
33. What should be the possible solution to handle urban flooding? (Donohue et al., 2017)
- Bioswales
  - Rainwater Harvesting Wells
  - Rainwater Recharging Wells
  - Others

# Replenishment Sheet

REPELENISHMENT CALCULATION SHEET											
Sr.#	Intervention	Location	Number of unit	Capacity		Max Rain Event	Design Basis		Capacity/day Cubic.Meter	Replenishment Num/Anum	
				Liters	Cubic.Meter		Cubic.Meter	Cubic.Meter			
1	Rainwater Harvesting through Barrel System	Niallar Park Sports Complex (Qadafif Stadium)	10	2000	2	60	120	1200			
		Yuhannabad	12	2000	2	60	120	1440			
		Norwahpura	19	1000	1	60	60	1140			
		Alli Institute of Education	8	1000	1	60	60	480			
		PU Mosque	5	2000	2	60	120	600	10200		
		Government Girls College Township	3	2000	2	60	120	360			
		Bhalkot Village	3	1000	1	60	60	180			
			40	2000	2	60	120	4800			
		Sr.#	Intervention	Location	Number of unit	Area	M.Sq	Discharge Q=CJA	Replenishment Numbers Cubic.Meter	Depth of Bore Ft	Chamber Size Cubic.Meter
		1	Recharge Well	Punjab university	3	Ground	40011	15364	17165	100	37
				Road	3127	1801					
				Ground	3818	1466	4009				
				Building	4414	2542					
				Ground	11588	4450	5652	100	28		
		Abdalian Society	1	Road	2088	1203		90	28		

Table 7. Replenishment Calculation Sheet (WWF)

**Ponding Sites**

<b>Sites Name</b>	<b>8/7/2022</b>	<b>8/20/2022</b>	<b>7/29/2022</b>	<b>31/07/2022</b>	<b>7/21/2022</b>	<b>7/13/2022</b>	<b>7/14/2022</b>	<b>17/06/2022</b>	<b>1/23/2022</b>	<b>6/17/2022</b>	<b>1/7/2022</b>	<b>7/23/2022</b>
<b>Allahoo Chowk</b>	3"	0	0	0	2"	5"	4"	0	0	0	0	2"
<b>B-Block Tajpura</b>	0	0	0	0	16"	0	0	0	0	0	0	0
<b>Chowk Na-Khuda</b>	0	0	12"	0	7"	2"	8"	0	0	2"	0	0
<b>Chowk Qartaba Mazong</b>	0	4"	10"	0	20"	1"	0	5"	0	0	0	0
<b>Chuburji Chowk</b>	0	3"	7"	0	12"	0	0	2"	0	0	0	0
<b>Cooper Road</b>	0	1"	3"	0	3"	0	0	5"	0	0	0	0
<b>Davis Road</b>	0	0	0	0	0	0	0	5"	0	1"	0	0
<b>Do Moria Pul</b>	0	0	0	0	4"	0	0	0	0	0	0	0
<b>Eik Moria Pul, Ravi Town</b>	0	2"	2"	0	10"	1"	4"	0	0	0	0	0
<b>Empress Road /Haji Camp</b>	0	3"	3"	0.5"	7"	1"	0	0	0	1"	0	0
<b>Firdous Market</b>	0	0	4"	0	6"	0	0	0	0	0	0	0
<b>GPO</b>	0	3"	10"	0	12"	0	0	0	0	0	0	0
<b>Jinnah hospital U-turn</b>	5"	2"	0	0	3"	3"	4"	0	0	0	0	5"
<b>Kashmir Road</b>	0	0	0	0	0	0	0	0	0	0	0	0
<b>Lakshmi Chowk</b>	0	0	4"	0	24"	0	0	0	0	0	0	0
<b>Lytton Road</b>	0	2"	5"	2"	5"	0	0	2"	0	0	0	0

<b>Model Town Link Road</b>	0	0	0	0	0	0	0	0	0	0	1"	0	0
<b>Nabha Road</b>	0	5"	12"	0	18"	0	0	0	0	0	0	0	0
<b>O/S Bhaati Gate</b>	0	0	24"	0	18"	0	6"	0	0	0	0	0	0
<b>Qainchi stop feroz pur road</b>	0	0	0	0	6"	0	0	0	0	0	0	0	3"
<b>Shah Jamal</b>	0	0	4"	1"	2"	0	0	1"	0	0	0	3"	0
<b>Sheranwala Gate</b>	0	0	9"	0	10"	0	0	0	2"	0	0	0	0
<b>Sultan Ahmad Road Ichra</b>	0	0	12"	0	12"	1"	6"	18"	0	0	0	2"	0
<b>Tikka Chowk Johar Town</b>	24"	0	0	0	6"	6"	6"	6"	0	0	7"	0	8"

Table 8. Ponding Sites (WASA)

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