`

SUSTAINABLE URBAN STORMWATER MANAGEMENT: A CASE STUDY OF ISLAMABAD

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

In

Urban and Regional Planning

By

Urooj Fatima

00000275518

Urban and Regional Planning

School of Civil and Environmental Engineering (SCEE)

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This is to certify that the thesis entitled

SUSTAINABLE URBAN STORMWATER MANAGEMENT: A CASE STUDY OF ISLAMABAD

Submitted by

Urooj Fatima

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Has been accepted towards the partial fulfilment of the requirements

For

Master of Science

In

Urban and Regional Planning

Supervisor

____

Dr. Abdul Waheed

Department of Urban & Regional Planning

School of Civil and Environmental Engineering (SCEE)

National University of Sciences & Technology (NUST)

THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS thesis written by Ms. Urooj Fatima (Registration No. 00000275518), of URP/SCEE (Institute/School) has been vetted by undersigned, found complete in all respects as per NUST Statutes / Regulations, is free of plagiarism, errors, and mistakes and is accepted as partial fulfillment for award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

Signature: ______________________________

Name of Supervisor: Dr. Abdul Waheed

Date: ___________________________________

Signature (HOD): ________________________

Date: ___________________________________

Signature (Dean/Principal): _______________

Date: __________________________________

DEDICATION

This project is dedicated to my brother Hassan Iftikhar and my father who encouraged me and supported me throughout my research.

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Surely, Allah is the best of planners. First and foremost, I am grateful to Allah Almighty for bestowing upon me his blessings and the intellectual ability to search for the facts surrounding this research.

Secondly, I would like to express my sincerest gratitude to my supervisor Dr. Abdul Waheed for his support and patience during my research. I will be ever grateful for the opportunity to work with him and for the much-needed guidance and encouragement. I am thankful to Dr. Irfan Ahmad Rana for his valuable suggestion and help during my research. I am very grateful to the respondents for surveys and interviews for their time and cooperation.

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Grateful,
Urooj Fatima

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LIST OF ABBREVIATIONS

DHA	Defense Housing Authority
CDA	Capital Development Authority
LDA	Lahore Development Authority
PCRWR	Pakistan Council of Research in Water Resources
ICT	Islamabad Capital Territory
SWM	Stormwater Management
SWMM	Stormwater Management Model
GIS	Geographical Information System
SCADA	Supervisory Control And Data Acquisition
GDP	Gross Domestic Product
IMF	International Monetary Fund
EPA	Environmental Protection Agency
SUSTAIN	Supervised and Unsupervised Stratified Adaptive Incremental Network
BMP	Best Management Practices
LID	Low Impact Development
SDG	Sustainable Development Goal
UNDP	United Nations Development
SPSS	Statistical Package for the Social Sciences Programme
EMC	Event Mean Concentration
PCA	Principal Component Analysis
KMO	Keyser-Mayer-Olkin
CBF	City Blueprint Framework
ADB	Asian Development Bank
WHO	World Health Organization
SUDS	Sustainable Urban Drainage System
WSUD	Water Sensitive Urban Design

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Contents

CHAPTER 1: INTRODUCTION

With the rapid increase in urbanization, the need for the water resource has significantly increased because of the water being the basic necessity of life. Due to the population growth and the climate change effects, the natural water balance is disturbed greatly resulting in the water scarce conditions in most of the areas. According to the UN Department of Economic and Social Affairs 2018, 68% of the global population is expected to live in the cities by 2050 as compared to the 55% in 2018. Research also explains that the increased concentration of people in the densely settled cities is likely to exacerbate the water scarcity issue Mekonnen, (2016) and make it more vulnerable to water related disasters. Urbanization not only involves the migration of people from rural to urban areas or population growth but also effects in the increased impervious surfaces, removal of natural vegetation, paved road networks etc. These effects cause imbalance in the natural hydrological and ecological processes resulting in the natural hazards such as hurricanes, land sliding, flash flooding etc.

Few studies of stormwater management acknowledge the importance and impact of both urbanization and climate change for water management. Wang, (2017) reported that urbanization and climate change are the main drivers in simulations of the future water flow/quantity and quality in urban settlements. With the increasing urbanization and extreme temperature events as resulted from climate change, water scarcity is becoming the major issue for the cities. It results in the ground water shortage and unable access to safe drinking water. Urban densification requires more resources to manage such large population in the small area. Hence, it requires the basic utilities for life for its normal functioning and development. Basic utilities include the facilities like water, electricity, gas connection for each household. Water utilities has major role in functioning of the society. Daily routine chores require water demand to meet the daily needs. The water supply, water sewage connections are the major drivers to attract the people to cities. Water is needed for in different sector like industry, domestic, public use (railway subways, bus stands, airport, hospitals) and agriculture.

The major source to meet this huge demand is the underground water flowing and used by the water extracting pumps, well. This underground water is the restored from the surface water and seasonal rainfall such as monsoon etc., through natural process like infiltration and adsorption in soil. This underground water is purified by the natural process by passing through the series of sieve-like layers of different measurements of soil particles. This filtered water contains the minerals and salt form the naturally built surface soil layers and have the maintained pH level. This water cycle includes the evaporation and evapotranspiration process to balance the natural ecosystem.

Evaporation is occurred due to the high temperatures in the areas having water bodies. Evapotranspiration is the evaporation of water and moisture from the tree canopy cover that is ultimately led in the cloud formation and rainfall over the dry temperate zones. This water balance is thus disturbed by the excessive development and urbanization which causes the removal of forest and tree canopy and also replace the pervious surface such as grassland, heathlands by the concrete area and impervious surface such as parking lots, building parcels, concrete grounds and surface. The excessive development minimizes the transpiration and infiltration process in the large-scale area but leads towards higher urban runoff and the climate change in context to the small-scale areas. The growing cities need the increased water demand to facilitate its inhabitants. The developed cities help in increases the green-house gases, ozone emission and ultimately leads towards the extreme temperatures and rainfalls to overcome the challenges caused by this development.

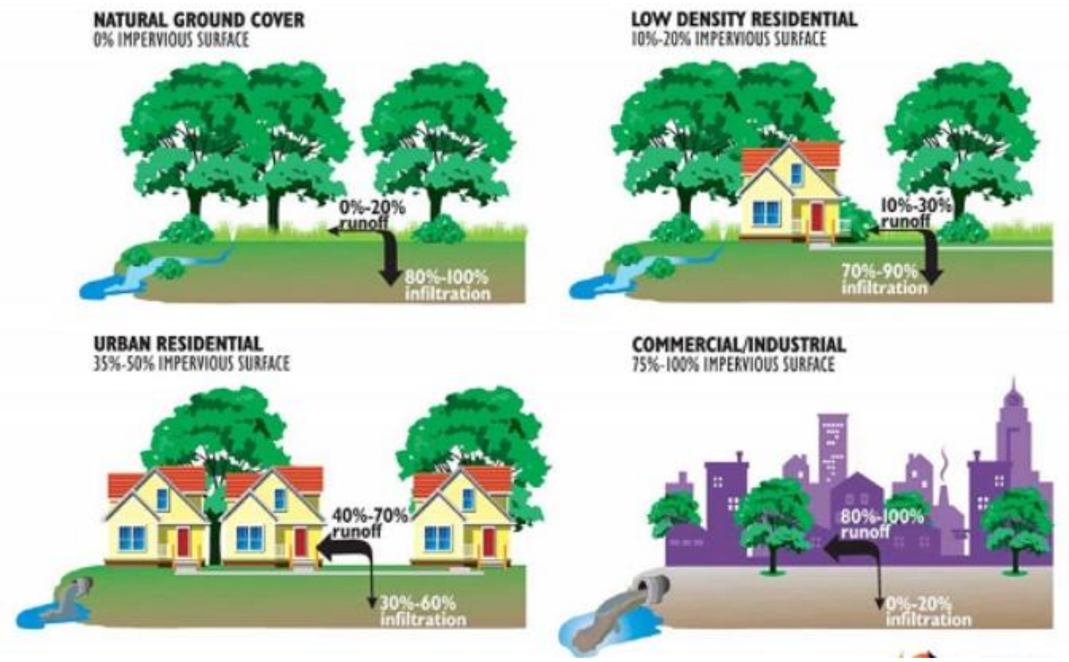

Figure 1: Increase in SW runoff with increased urbanization

Source: Archived from (Critical Concrete - Minimizing impact of water system)

Physical water scarcity involves the inadequacy of the water resources to meet the demand of the people in the region whereas economic water scarcity is the result of poor management practices, not implementing the sustainable modern practices and careless human behavior. According to the United Nations Development Programme, economic scarcity is found more often to be the cause of water scarcity in the countries these days. Cape town 'Day Zero' is the largest drought induced municipal water failure in modern history. Cities are now globally facing the increased risk of extreme environmental events due to poor management practices such as extreme rainfall, flooding and droughts etc.

Rainwater being the natural resource is available abundantly, if properly planned and managed it can be used to meet the future water demands of the city. In Pakistan, cities have the rainwater capacities but it is not implemented and utilized properly. Cities are now made of concrete and the natural soil cover is replaced by the concrete walls, impermeable roads and floor surfaces which are causing imbalance to the natural water system by creating the maximum runoff without letting it seep down to the soil for underground water channel. Metropolitan/developmental practices needs to be ensured through policy implementation and practical facilitation thus, there is a dire need to develop the stormwater management system to overcome the water scarcity.

Figure 2: Urban areas having impermeable and permeable surfaces

Source: Archived from (EPA SWMM – Stormwater Management Model)

Stormwater management is integrated to the urban land use and landscape and thus plays an important role in the urban planning. Stormwater management is the effort to reduce the surface runoff of rainwater, prevent soil erosion and maximize the infiltration process for the recharge of the ground water in the urban areas. Water runs rapidly over the impervious surface into the drainage and sewer system that can cause the urban flash flooding, erosion etc. This urban storm water management can lead to the sustainable development of the urban areas and aims to rebuild the natural water cycle. Stormwater management practices can lead to the possibility to recharge the ground water by storing the surface runoff in retention basins and to reuse precipitated water. Good management practices can also avoid damage to the infrastructure. It also helps in improvement of the water quality and consumption efficiency. It can also be helpful in establishing and implementation of good management practices. It also includes the support to the capacity development of the institutions engaged in the water management.

The GIS literature in context with the integrated stormwater management is broad, utilizing the geographical data in diverse application to derive the desired results in the field of surface and groundwater hydrology. GIS application with the water resources is full of literature and models including the natural hydrological models, river hydrology, ground water predictive modeling, natural hazard identification based on geographical simulations. GIS modeling in SWM is limited somehow due to the large, expensive spatial and temporal databases, computer tools and software's for its accurate processing. Urban stormwater models use the GIS as the spatial database, pre-processor and also post-processing for its working operation. GIS software now integrated with the urban water models to extract the desired results. The GIS parameters hold the geographical information and hydrological models have the input parameters information that is processed in the integrated environment. This integrated modeling is termed as the "hydro-informatics" in the European literature. Hydro-informatic approach uses the different GIS models are used for the urban water system modelling such as SWMM, SCADA. Each model integrates the geographical data of digital elevation, slope, aspect with the hydraulic parameters such as drain discharge, rainfall capacity, recharge capacity. Every model has its own application and input parameters for the processing of water and geographical data to deduce the simulation and model results according to the desired application.

Cities often depend on the administrative jurisdictions for access to the water resources to meet their demands. The stormwater management system needs to in strong coordination with the other institutions to actively manage the resource for future need. The temperature and precipitation patterns vary over the space and time which shows that the drainage network should have the capacity to actively manage and perform well for varying concentration of precipitations over the region. Sustainability is currently a driving force in the evolution of water policy in developed countries. It involves restoring the balance of the natural earth's ecosystem with minimizing the effects of anthropogenic activities. This approach recognizes the natural and built environment and manages them as integrated component to minimize the negative impacts of development on earth's environment and to conserve the natural resources for future generations.

Cities have become complex entities because of its interlinked systems. The integrated planning approach is needed to overcome the stormwater management issue. The new integrated urban SW design requires the collaborative practices from the past to mitigate the harmful impacts on the infrastructure and to make the cities more sustainable and resilient to overcome the negative effects of industrialization and urbanization. The pipe-based system has changed from the traditional design to more informative and effective water system for supply, sewer and rainfall drainage. Treatment plants have been installed for more effective processing and reuse of rainfall water drainage which can be utilized for horticulture, car wash and domestic use other than drinking purpose.

Retention wells, pot holes, infiltration ponds need to be incorporated to the system for enhanced infiltration and soil seepage to keep the balance. All these practices of needs to be well integrated to work properly for the maximized use of the natural ecosystem and for sustainable city development to cope with the growing needs and risks of development. The concept of integrated management system is used to describe a comprehensive, ecosystem-based approach. This system integrates the human intelligence and expertise with the scientific technical advancements to make use the best of it to benefit the world in the whole manner which needs to be ready for the unforeseeable future. It involves every aspect of ecosystem, ecological, social, economic infrastructure for its proper functioning.

Figure 3: Integrated Stormwater management support system

The integrated stormwater approach utilizes the supply system, drainage system, natural topography integrated with the natural blue and green infrastructure along with the underground reservoirs and channels to provide the maximum use of water resource and to converse the water for future use when demand is high. This integrated approach also includes the coordination of different working institutions along with the relevant stakeholders. This approach not only utilizes the water management in the best possible manner but also response in terms of climate change action because of its huge impact on the regional level planning. This integrated method not only uses the technological improvements but also focus on the environmental issues raised from its impact and hence, also manages the social awareness programs for social strengthening. Integrated system requires a close collaboration of variety of stakeholders which is critical to enable the development of holistic approach for large scale management.

Sustainable approach is the shift towards the modern world solution to the modern problems. The formal institutions such as organizations, authorities, policies & regulations and informal institutions such as conventions, norms and traditions influence the action plans and procedures for the collaborative and cross-sectional support for management.

Sustainability is defined as the equity over time. It is the self-reliance and self-perpetuating limits for all the needs on the available resources and to make use of it to meet the current needs. It is concerned to maintain the natural balance of earth to make room for the future needs and availability of resources. It negates the concept of resource exhaustion and move towards the natural processes that benefit the current inhabitants and support the future generations. It includes all the sectors needed for the growth such as economic support, environmental neutrality, ecosystem management When we get down to the sustainability concept, it is the study of interconnectedness of all the things and make them efficient. Following figures explain some of the sustainable solutions for the integrated stormwater management. It basically involves the minimized maintenance burdens for the institutions, which uses the natural process to manage the excess water by using sensitive areas. These solutions include the enhancement of the bio diversities and to focus on the near source technique at the regional level planning.

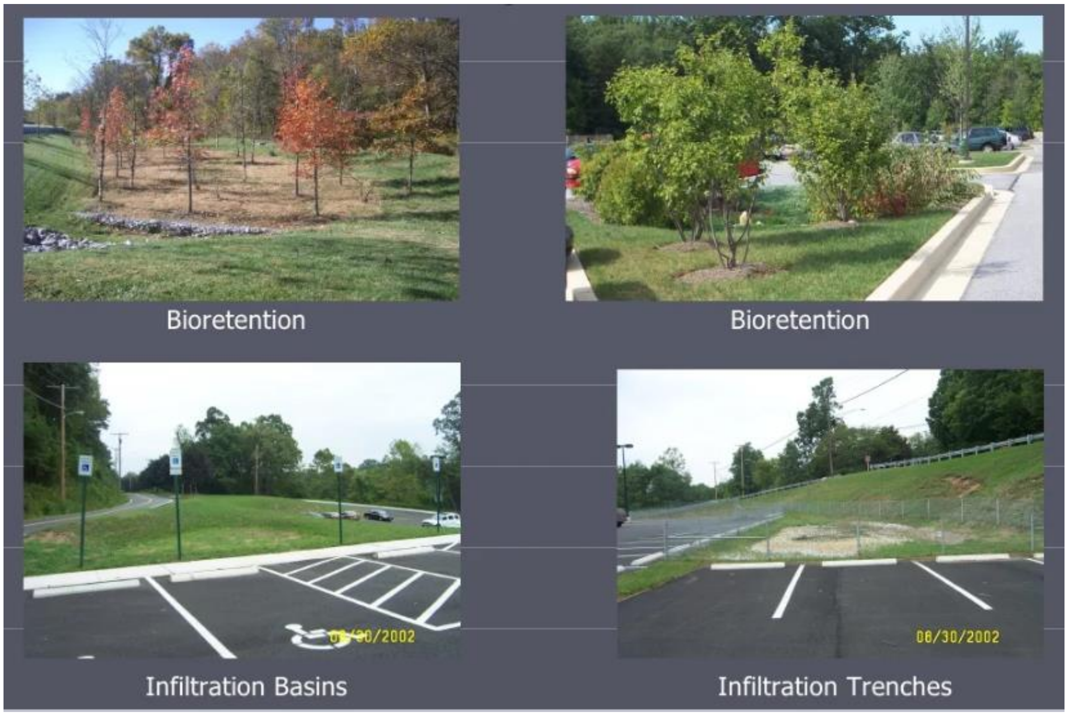

Figure 4: Strategic approach towards integrated water management

Source: Archived from (integratedstormwater.eu)

Figure 5: Strategic approach towards integrated water management

Source: Archived from (integratedstormwater.eu)

Sustainable stormwater management uses both structural approach such as rain gardens, green building concept, permeable road surfaces, retention ponds and non-structural approach such as infiltration basins etc. The sustainable approach is cost effective and attractive. It also addresses soil erosion, water pollution, sewer overflows and other water related problems. Willuweit, (2013) explains that the decentralized practices have a critical role in sustainable urban stormwater management. The approach used according to the site-specific characteristic such as slope, watershed basin area, land use/ landcover information, building codes etc. to reduce the impacts of development on water management. Sustainable management is focused towards controlled engineering, planning and prediction rather than the system thinking rational approach towards the unpredicted scenarios that involve the complexity and resource exhaustion.

1.1 Problem Statement

A study Mekonnen, (2016) imply that four billion which are more than half the world's population may currently face water insecurity driven by resource scarcity. Water security was first articulated as a policy challenge at the World Water Forum in 2000 in the United Nations Ministerial Declaration of The Hague on Water Security in the Twenty-first Century and it has remained on the agenda of international organizations since then United Nations, (2000); UN Water, (2013); ADB, (2013). According to the report by Maqbool, (2022) Pakistan is facing a serious threat of acute water crisis. This will not only affect the agriculture industry which comprises of almost 23% of Pakistan's GDP but also an existential threat to energy production and food security. It is also mentioned that Pakistan ranks 14 out of 17 countries that are at extreme water risk as the country waste almost one third of its available water resource. Report highlights that almost 80% of the population faces sever water scarcity and the statistics shown that the figures in 1962 were 5229 cubic per person and has fallen down to 1187 cubic meters per person in 2022. This shortfall is explained by the higher water withdrawal rate from the ground, only 1% treatment of waste water, lowest rate around the globe. Around 40% of water is lost due to the infrastructure inadequacy and insufficiency.

These issues give rise to the other related problems such as water scarcity, sanitation problems, public health, food insecurity, infrastructure damage, economic and biodiversity loss. Most of these consequences are getting worse with time so there is a dire need to develop the urban management system for stormwater-a natural resource to overcome these problems and ensure sustainable urban water availability.

1.2 Advantages of Study

Water demand is highly influenced by countries' population growth rate. Conner, (2015) estimates that Pakistan's total population could reach 245 million in 2030 and up to 309 million in 2050. As total renewable water availability in the country is relatively stagnant i.e., 246 cubic kilometers, with the increase in population there will be decline in per capita water availability, classifying the country as water scarce.

According to a report by International Monetary Fund (IMF), Pakistan ranks third in the world among countries facing acute shortage of water. This water scarcity is not deniable; the cities of Pakistan are developing day by day and water is the resource which needs to be immediately managed for the future. This study aims to facilitate the planning and practical implementation of Stormwater management in urban planning.

1.3 Aim of the Research

The aim of this research is to propose strategies, based on the current practices for stormwater management, which can ensure the sustainable urban stormwater management, provide improved experience of stakeholders, increased awareness level and strong recommendations and strategies for improvement in the existing system regarding stormwater management.

1.4 Research Questions

Literature review identifies the gap in the literature and which give rise to the thinking of the specific problem. The gap in literature leads to questions about the specific area of interest. This research identifies that the stormwater management is the natural resource that can be utilized to meet the water demand of the country. Following stated are the specified research questions formulated to the problem identified:

- What are the critical factors that affect the efficient stormwater management?
- How to evaluate the institutional awareness regarding storm-water management practices?
- What strategies and practices should be taken for sustainable urban stormwater management?

1.5 Research Objectives

The research objectives are the backbone of the research and derived from the corresponding research questions identified. The research objectives of this thesis are listed below:

- To investigate the factors that affect the efficient storm-water management
- To evaluate the policy framework and institutional capacity regarding storm-water management practices
- To suggest measures and recommendations for sustainable storm-water management

1.6 Areas of Application

Stormwater management is need of the modern world and it is necessary in every urban settlement. Stormwater management is integrated to the urban land-use planning and development also contribute to the city's aesthetics and landscape, so it can be useful in regional futuristic planning and decision making. Some of typical developing authorities in Pakistan are the local government, development and planning departments/ institutions such as DHA, CDA, LDA, PCRWR and water management in ICT.

1.7 Limitations

Due to the limited resource and time, the GIS data source and planning has not been included in the scope of this research. The scope of this research covers only the water management for capital city Islamabad but not cover the other big cities such as Lahore and Karachi to better understand the topographical changes for the efficient management. SWM practices vary from the region with the regional parameters geophysical state. SWM utilize the physical and built infrastructure in the integrated manner to provide the better outcome of the modern world solutions. This could help in exploring the unfamiliar trends varying with the location variation. Due to the GIS data restriction and lack of authorities for data sharing, these aspects could not be covered in this research. Lack of coordination between the organizational departments for SWM also effected the data collection process. For example, in CDA, department working on the urban planning does not include the water management of the area. Water department is also unconcerned to the SWM field. These departments working for the urban sector and water management were unclear of their authorities and boundary restrictions. This poor coordination of the departments took lot of time and the results were not that much quantity that was supposed. Only few industry interviews were conducted for this study due to the lack of interconnected departments.

1.8 Organization of Thesis

This research consists of following parts:

Chapter 1: It is the introduction of thesis. This chapter provides an idea about the research, areas which are covered in this research and a general view about all chapters and their structure. This Chapter defines the statement of problem, Research Objections and Linkage of research with Sustainable Development Principles.

Chapter 2: It is the literature review that covers the past researches which have been done on this topic nationally and internationally, this chapter link research topic with previous researches by finding research gap in literature in respect with the stormwater management.

Chapter 3: Defines the overall methodology and procedure step by step adopted for the execution of this study. The general to specific approach is adopted in order to complete the study. This chapter describes all the procedure from selection of the topic till suggestion of recommendations and compilation of the thesis document.

Chapter 4: This chapter includes the data analysis process, techniques and applied analysis tools in detail. The field data obtained from the questionnaire and industry experts knowledge opinion are analyzed critically in this chapter. This is the main processing phase of this research where indicators effectiveness was verified from the industry experts and factor analysis was performed for the identified factors.

Descriptive analysis was also done on the industry experts' interviews and key findings were analyzed using the available data.

Chapter 5: This chapter includes the crux of the study that includes the conclusion and recommendations of the analysis performed. The key points identified are the results verified from the literature studied and the data analysis process used to carry this research. This conclusion is supporting the literature review and the methodology adapted for this study.

CHAPTER 2: LITERATURE REVIEW

This chapter includes the general background of the literature in national and international standards with respect to effective stormwater management and tradition approaches used for management. This also includes the GIS component of the SWM and the factors that affect the SWM. It also discusses the SDGs that relate to the SWM, some barriers regarding it and the role of resilience in efficient management.

2.1 General Background

Climate change impacts, aging infrastructure and the population growth with rapid urban sprawl calls for the new ways of planning Bohman, (2020) and to overcome the related issues by adopting sustainable approach for urban stormwater management. Brown, (2013) explained the urban stormwater drainage network has the primarily focus on providing the engineered system to enhance the hydraulic efficiency by increasing the conveyance capacity of the rivers and water systems to minimize the negative impacts on the natural ecosystem.

Most studies about the stormwater management focusses on the climate change and the rapidly increasing urbanization as the main driver for increased stormwater flow quantity due to increased imperviousness on the land surface and disturbing the natural water balance. Both factors are significantly important for stormwater management in view of higher rainfall intensity, extreme temperatures and increased frequency of natural hazards. Wang, (2017) has examined the flow quality and quantity with the two highly developed urban areas using the US Environmental Protection Agency's Storm Water Management Model to test the sensitivity to the development or climatic conditions. It found out that the stormwater flow quantity and quality is more sensitive towards the urbanization, urban sprawl trend rather than the climatic or land use changes.

The traditional water management process includes the traditional drainage system approach for planning and development, according to the new research and technical advancement in the SW field includes the more integrated system that includes the interdisciplinary method to overcome the modern-day problems. The reactive problem-solving method is replaced by the proactive approach that is more focused to prevent the problems itself. The solutions that were more engineered are considered rational solution whereas the interdisciplinary and team-driven approach with use of modern techniques is now the solution of the hour. The sustainable solution to the SWM is the integrated system that utilizes the existing infrastructure to its best and results in the monitoring and evaluation of the system and improvements with the regular update of the infrastructure with modern technology. Sustainability involves the coordination of institutions for effective working and keeping the public well informed to improve the resilience against any harmful impacts. The extensive consultation and partnerships are encouraged to provide the more focused solutions that gives the more reliable and long-term solution obviously with the regular updating and evaluation.

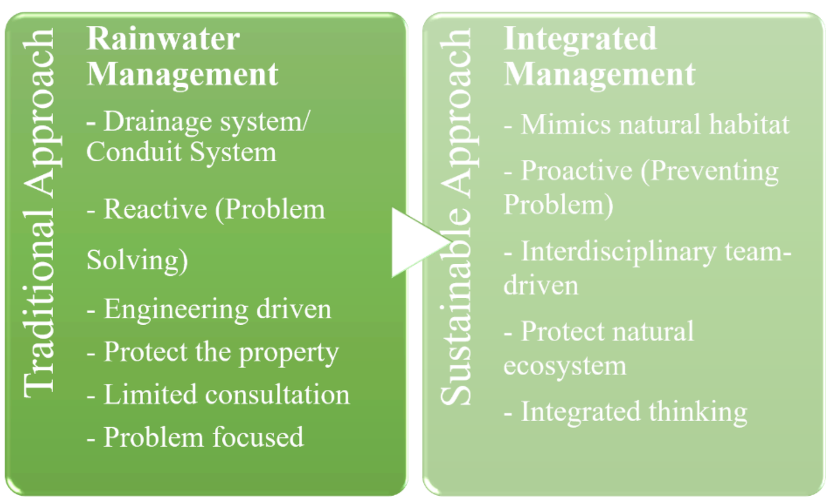

Figure 6: Traditional Vs Integrated Approach towards SWM
Source: Archived from (waterbucket.ca)

The above figure explains the difference between the traditional and integrated more of modern approach used for management of Stormwater. The modern world uses a comprehensive evaluation framework for the sustainable management of urban runoff. Effective stormwater management is the challenge faced by many developed countries around the globe and it is getting more complex with the increasing urban population Grimm, (2008) Stormwater management require the integrated approach as it involves different institutions to work together to achieve the common goal. This management has the complex climatic effect, with different socio-economics factors underlying that play an important role in its management. The figure below explains the British Columbia approach for integrated rainwater management that is being implemented from 2002 and also upgrading with the modern techniques and check parameters. This planning approach was also integrated with the community design and helped in the public to participate in the process.

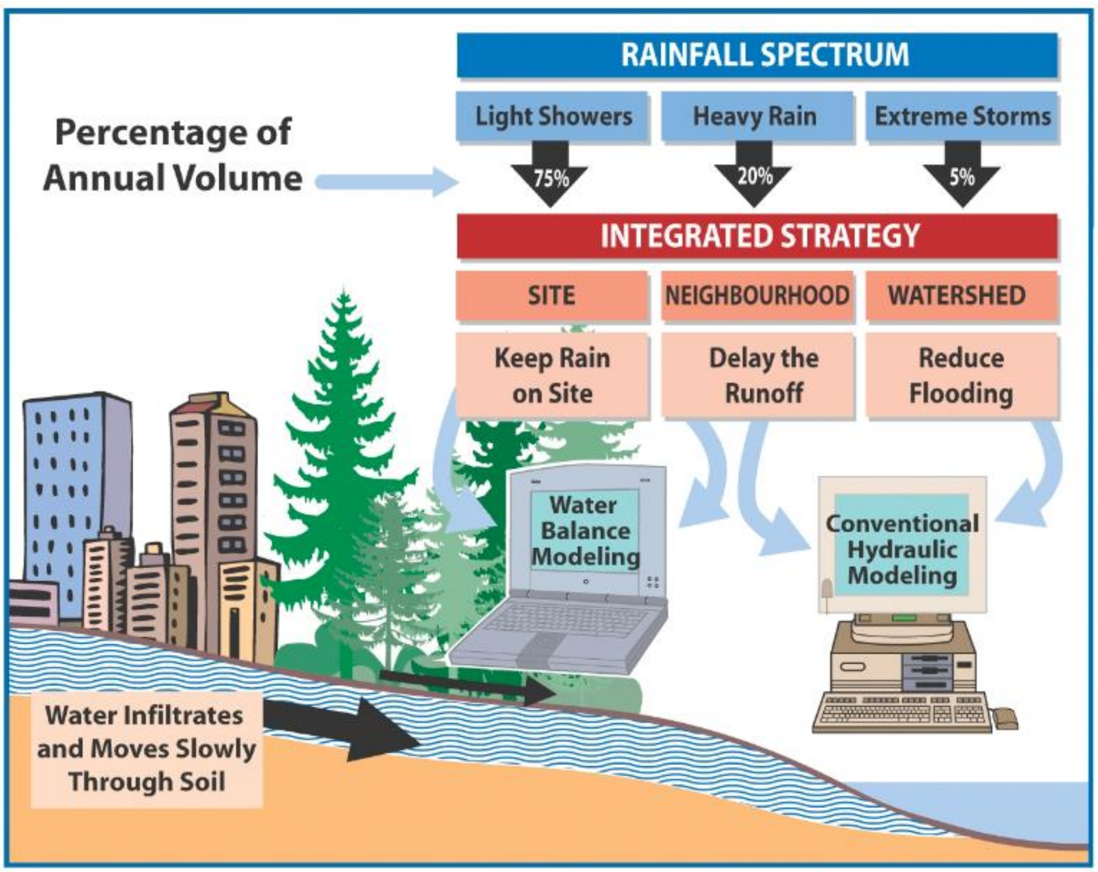

Figure 7: Integrated approach used by British Columbia for Rainwater Management
Source: Stormwater Planning: A Guidebook for British Columbia

Different stormwater control measures need to be ensured for the effective management of to the cumulative effects. The multi-metric approach can be used for the restoration of the water ecosystem in the disturbed landscape Fanelli, (2017) caused due to urbanization, reduce the anthropogenic activities and to minimize the negative impacts of the urban outflow. The current trend is also towards the collective approach to manage the surface runoff as an integrated system of prevention and control practices to accomplish stormwater management goals Saraswat, (2016).

Stormwater management involves the different performance criteria which needs to be well-coordinated for development of design features such as; water conservation and efficiency, water quality, measuring and management of stormwater runoff and flow rates. Managing volume, flow, efficiency with respect of futuristic approach along with the quality monitoring covers the overall stormwater These criteria assist the development of optimized solution and to achieve the objective of integrated stormwater management. These four main areas if well managed can help in achievement of sustainable solution to the modern world stormwater management issue at regional and local level.

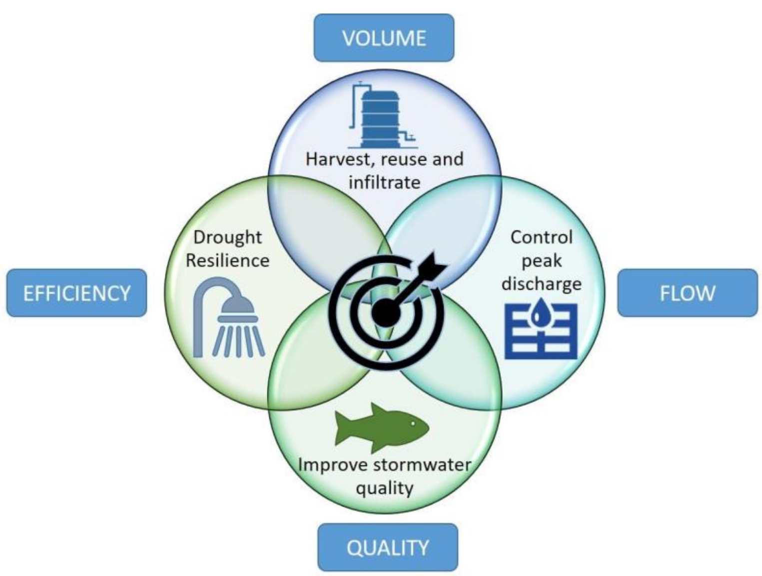

Figure 8: Target areas for SWM process in small scale development

Source: Archived from (watersensitivesa.com)

The blue framework of city captures many aspects of water security and management and specifically outline the extent of the watershed to which the principals of integrated water management can operate and compare their mitigation strategies and resilience in respect of social, environmental and economic factors and categories them as ‘water wise’ or ‘water sensitive’ cities. The desired outcome is to improve both natural and built environment and to maintain a nature’s balance to sustain life with quality living and also accommodate the future with the better approach. GIS applications are also being saturated with the water management. Water resource management itself has a lot of field area to work with and also play an important role in stormwater mapping, modelling and its management. GIS technologies are evolving with time and help the policy makers to determine the effective methods to manage the water related problems. GIS solutions of the stormwater includes the hydrological models, selection measures of water resources for multi-criteria decision support system and evaluation of these methods to calculate urban runoff Wilson, (2000).

GIS has multilayered functions in the management of SW. It can be used as the pre-processing, post-processing in the stormwater modelling and can also be used as the spatial databases. GIS can help in the different network, watershed analysis, morphometrics in the water resource sciences. GIS is now more complex geological method which is integrated with the hydraulic design and hydrologic models to deduce the different analysis. All these locations based and geophysical parameters are linked with the GIS capabilities whereas other parameters such as density flow, quantity quality factors are integrated using the other platforms. GIS can now help in the decision-making process and the policy making framework because of its regional variability. GIS can make its use to the time series information with respect to the locational values and simulation models.

GIS also provides the multi-criteria decision support system for handling the complex spatial problems like integrated stormwater management which involves the political, economic, social and aesthetics of the environment. This system involves the spatial information for the specific application and weights are assigned according to the priority by the knowledge experts. The resulted maps and charts help the policy makers to make the informed decisions about the situation to meet the community needs. However, Wang, (2004) explains that the complex technical solutions for the specific GIS application involves political, economic and social interactions of the community, which needs the necessary human judgement for selection of most relevant criteria to make the subjective decisions. The industrial and knowledge experts verify these criteria for its analysis and modelling with the assigned weights according to the specific characteristics and dynamics of the study area.

The study Jefferson, (2017) identifies that the pollutant load decrease by decreasing the runoff reduction rather than the low soluble concentrations. The collective interactions between natural and urban landscape in the urban setup has a critical role in effective management of stormwater and minimize the harmful impacts on the watershed or regional level. Cities have become a complex and have negative impacts such as increased runoff that causes the flash flooding conditions and also degrade the natural balance of the earth due to ineffective SWM infrastructure. O'Neill, (2018) study used the semi-distributed Tree-Hydro model for the City of Guelph's urban forest, which identifies that the tree canopy cover act as the SWM tool to reduce the surface runoff and help to make the informed decisions for urban SWM. Sustainability also refers to the condition where the earth is revered back to its original natural condition by minimizing the carbon footprint and making use of the reused material to meet the current demand with the available resources and also welcoming the future with the better livable space than the past. It also indicates the tree canopy is the natural habitat of the earth which is cut down for the urbanization and development process. It can help in the infiltration, transpiration process which maintain the natural water balance. Tree canopy also contributes significantly to keep balance the earth's average temperature and also help to cope up the climate change issue. This tree canopy when removed with the cemented or concrete buildings it interrupts the natural water balance and ultimately shift the rainfall patterns and temperature variation. Hence, the urbanization and population growth lead towards the climate change adaptation and the water management strategies for the future. Following figure explains the natural catchment in terms of forest canopy in respect with the natural catchment with city's infrastructure for reduced infiltration and increased rainfall runoff.

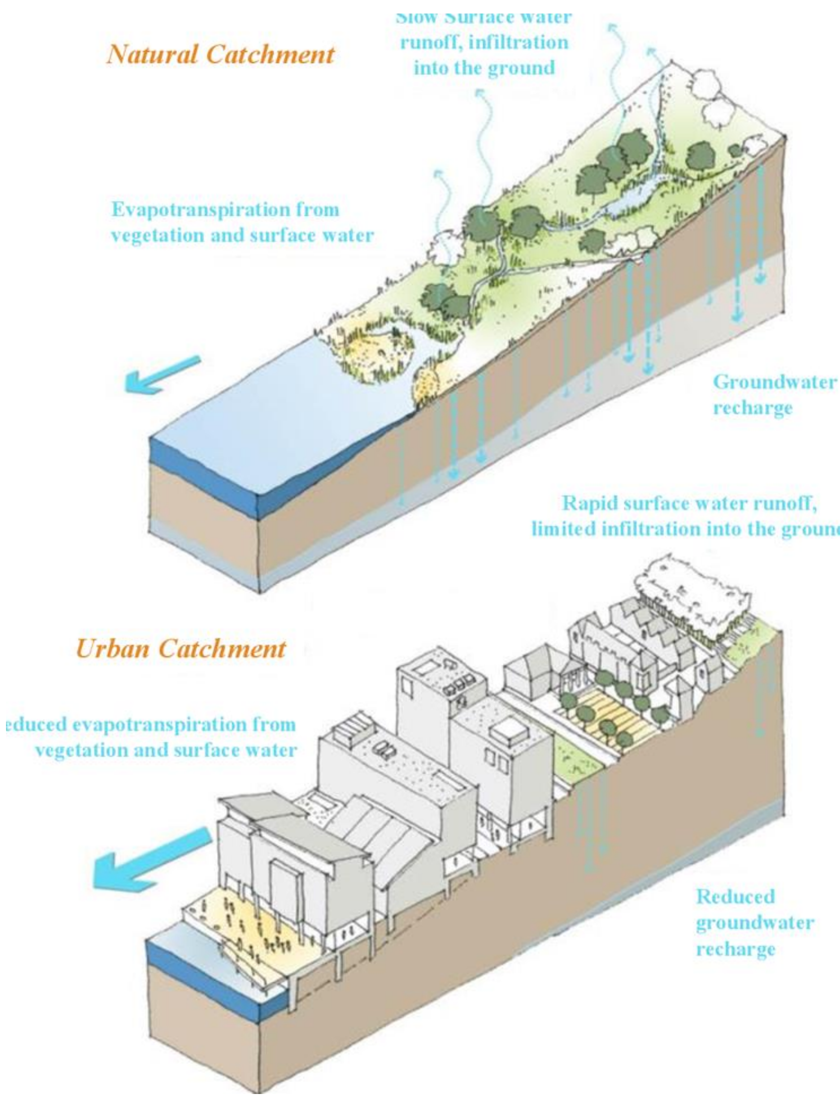

Figure 9: Difference between natural and urban catchment
Source: O'Neill, (2018)

Integrated system of water management is the relatively new approach that is being followed. It involves the different levels and increased collaboration among these levels. This strategy involves all the aspects of the water management and involve the public consultations, increased awareness, use of modern techniques with context to the regional variabilities. Integrated system has different levels such as the first one is the water supply level which aims to give access to the clean water to everyone that also meets the SDG. Second level is to develop a sewer city which has the collection of sewage at each water supply station. Drainage line are the next level that is laid with the sewer lines that collect the drain water for treatment and reuse. Interconnected city with the water supply and collection is developed which is termed as the water efficient design. Treatment of the waste water and reuse of service water for gardening, domestic use and car wash includes the water efficient design and well-connected city is almost the water sensitive city which is self-sustaining and resilient in terms of its regional context. This level is the integrated system of above and below ground water system. This integration touches the relevant and multifunctional institutions, economics, geophysical parameters, social participation and environmental features. Following figure also explains the integrated city design with the explained levels.

Figure 10: Different levels in integrated city design
Source: Archived from (integratedstormwater.eu)

Integrated system and sustainable management are desired to give the guidelines and support tools for the decision makers to choose the appropriate method and techniques that is best suitable in the regional context and gives the best outcome to the identified problem. This management process is expected to give the optimized solution that comes with the techniques which minimizes the harmful impacts and make quality living for the future generations with the adequate resource in reserve and earth in its balanced state.

2.2 Factors affecting SWM

Typically, stormwater application involves the range of indicators for its management and modelling. Gold, (2019) explains that stormwater management plan can be very effective if there is detailed information about the stormwater related indicators, area dynamics, surface hydrology and hydraulics, locational source for water pollution in the urban setup. Factors in the broader term are affected by the geophysical state of the study area, economic infrastructure and finances required for the management, environmental conditions such as hazard frequency and number of hazards occurring in the area, rainfall duration & patterns. Institutional factors play very important role in the management and monitoring and evaluation of the system. Biological and social factors also influence the management system such as public health, water quality monitoring and public awareness and consultation programs. Following figure highlights the major categories that affect the SWM in broader perspective.

Figure 11: Categorized factors that affect SWM

Stormwater indicators can be field based i.e., slope area parameters, rainfall patterns, soil infiltration capacity, impermeable surfaces or can also be categorized in biological, economical, technical, social and political terms. The technical indicators involve the crucial understanding of physical characteristics by hydrologic modelling to contribute to effective management of the stormwater management for administration.

A study Gallo, (2020) in which three highly urbanized watershed are modelled using the EPA's SUSTAIN system for stormwater treatment and analysis. The goal was to identify the key indicators that are related to surface water quality, measure the efficiency of the BMPs and to discuss the management plans for each watershed based on the identified indicators.

2.3 Institutional role in management

A study Ahmad, (2020) was conducted for the twin cities in Pakistan evaluated the potential of rainwater harvesting and its suitability to contribute to the urban storage, groundwater recharge and flood control measures. Another pilot study for the city of Lahore suggested that recharge wells can be used for water management and can also be used as an alternative fresh water supply for sustainable development and this technique should be a part of master planning of Lahore city Hussain, (2019). Different institutions work together in integrated manner with their identified domain and jurisdictions for the urban stormwater management. Research organizations play key role in identifying the emerging water related issues and future challenges in the urban setup and also respond to these problems with the alternative solutions. Integrated institutions work on the guidelines and policies to make use of the maximum benefit from the management and minimize the negative impacts.

Stormwater management not only rely on structural approaches for its efficient management but also on the active participation and coordination of different stakeholders and water related institutions. Studies

Saraswat, (2016), Hurlimann, (2009) considered the different aspects of community that are influenced by the range of factors for the stormwater management such as knowledge about the problems. Frequency of occurrences, water restrictions, institutional roles, other possible water sources and alternative approaches towards the specific planning problem. Japan and Thailand always aimed to control the runoff for municipal and commercial use while preventing the water related disasters in the urban system.

2.4 SWM as a key to meet sustainable goals

There is growth trend that the challenges of the modern world can be met by adopting a more integrated and step-wise approach towards the managing, allocating and protecting the water resources. The concept of integrated water resource management is incorporated in the agenda 2030. This approach must include all the stakeholder at different levels for equitable and sustainable management. Sustainability is relatively the new term of the modern time where the main goal of the different institutions and organizations is to make effort to develop cities safe, non-dependent and resilient to the climate actions. This multi-level, multi-dimensional approach is considered long-term and fundamental process which can help in socio-technical shift to more durable and viable modes of production and consumption Markard, (2012). The drainage water network designed were mainly focused on minimizing the runoff load and flood protection in the urban areas and didn’t consider sustainable development in mind. Sustainable urban SWM gives the solution of water management that is closer to the natural environment and habitat such as green swales, infiltration basins, green belts etc. as shown in the figure below.

Figure 12: Sustainable solutions for SWM
Source: Archived from (Green and Sustainable Services- LLC)

The sustainable management of stormwater is targeted to maintain the natural ecosystem and habitat of the specific area that minimizes the man-made effect on the land and negative effects of urbanization. It also understands the changes in urban environment with main aim to gain maximum benefit of new opportunities and to limit the certain negative effects of development. A sustainable system in the water management is not concerned about addressing the runoff problems and overcoming the contamination issues but only to maximize the utilization of the water resources and not to disturb the natural water cycle Sundberg, (2004). Modern stormwater management practices include the sustainable measures to ensure the effective working of the infrastructure, resources, institutions etc. Distributed system for water resource management is considered a sustainable method. A study Willuweit, (2016) was conducted on urban runoff patterns in Dublin, Ireland focused on climate change effects found that the climate change is likely to reduce the urban runoff whereas growth and urbanization are going to increase it. This study also stated that the decentralized policies are considered sustainable in terms of water resource management.

Modern stormwater management practices have emerged over time, informed by principles such as LID. Low Impact Development (LID) is an innovative approach for stormwater management that do not rely on the traditional methods but the newly developed techniques or strategies that are integrated throughout the urban landscape to actively manage the natural balance of ecosystem. LID techniques include the constructed wetlands, retention basins, green building infrastructure and other methods that are closely linked to the natural ecological and hydrological systems. A study Liu, (2015) states that LID techniques are efficient for managing the rainfall runoff, groundwater recharge, infiltration, storage, as well as improving the water quality by physical, chemical or biological processes. Water accessibility is the basic human right as it is essential for all aspects of life. Water resource management is overlapped in all forms of development (i.e., food security, health and well-being, poverty reduction, responsible consumption and production, peace and strong institutions etc.)

2.4.1 SDG 6: Clean Water and Sanitation

Figure 13: SDG 6 Clean water and sanitation
Source: Archived from (unwater.org)

The establishment of SDG 6 which ensure availability and sustainable management of water and sanitation for all, identifies the water and sanitation issue in the global agenda. Integrated water management has the first step to provide access to clean water to everyone. Clean drinking water is the basic human right and is the first and foremost step for efficient management. For efficient management of clean water access there are the five active indicators which needs the data about the accessibility, financing infrastructure to provide access to the remote and harsh areas, good governance to control water related issues in the area, innovative measures that provide the best cost-benefit solution and the capacity building of the community. Capacity development involves the institutional framework and the public participation at all levels to provide the buffer against the natural hazards to minimize the loss.

Clean water access is also followed by the water collection system, drainage system which is as important as the water supply. Sustainable goals focus on the water system efficient supply and management, efficient utilization and make the optimized use of the available resources. Estimates suggest that if the natural environment continues to be degraded and unsustainable pressures put on global water resources, 45 per cent of the global gross domestic product will be put at risk by 2050.

2.4.2 SDG 11: Sustainable Cities and Communities

SDG 11 ensure the sustainability in the city planning, infrastructure, working and the community development. Cities are like the nucleus or the power house of the cell, that performs the major task required for the working of the cell. It has the access to the daily life facilities and resource availability and sustainable and quality lifestyle. It includes the different paradigms such as urban planning, institutional setup, financial and economics, natural habitat, living lifestyle and facility management and resource adequacy and public engagement and community development for better outcomes.

Figure 14: SDG 11 Sustainable cities and communities
Source: Archived from (goumbook.com)

The SDG 11 also refers to the cities which are resilient to the disasters, climate change and are adopting sustainable development to make effort for strengthening of the local communities. Efficient infrastructure, strong managerial strategies, comprehensive energy systems and circulating economy helps to make the cities sustainable. Water resource management at the city level or community level also fall under this SDG.

Figure 15: SDG 11 World Statistics
Source: Archived from (healthsciences.usask.ca)

The above figure explains the world statistics that out of 9 billion population 2 billion population do not have the access to the waste collection services. 47% of the world population do not have access to the public transport or mass transit services for their movement and relocation. Population booms has affected the environmental quality degradation which effects every 9 out of 10 individuals globally. Most of the population like in the slum like conditions in cities and not have access to the basic life facilities such as clean water, sanitation, health facilities, education, employment etc. Cities have development the sustainable and for the planning and management but 15 countries are still in the implementation phase and has not achieved the aim of sustainable city.

Sustainability refers to the zero-carbon emission, which utilizes the renewable resources and uses optimized energy for its consumption and gives back zero negative impacts on the city life. It utilizes the modern techniques and renewable resources which are energy efficient and hence function at the minimum negative impacts. These cities are the aim of this goal which has the quality living conditions, mixed land uses access to all the basic amenities, resilient communities and efficient managerial institutions.

2.5 Barriers faced by SWM

Integrating the urban form with the governing institutes leads towards the more complex issues as the cultural, infrastructure, management are interwoven and highly persistent Brown, (2013). The progressive efforts for sustainable development in stormwater management are constraints by many factors such as institutional coordination, overlapping authorities, lack of finances, , uncoordinated decision-making, lack of viable alternatives, transparency issues, lack of public interaction, regulatory inflexibility Brown, (2009), increased frequency of natural hazards, low quality infrastructure, severe climate change impacts, uneducated public, weak economic circulation, growing inequalities etc. The significant challenge for water informed policy makers is the limited knowledge and guidance, unclear path dependency to institutionalize the alternative approaches and to adopt the passive management flow management.

Pakistan is predominantly an agricultural-based country and utilizes the fresh water for agricultural purposes. It is on the path of becoming the water scarce country in the future, the ultimate solution to this problem is the sustainable management of the fresh water, ground water resources, urban centers and agricultural water. If not properly managed the effects of the water crisis are very critical for the economic system, environment, ecosystem and also public health. Pakistan's majority of population do not have access to clean water. Several factors and barriers contribute to this water crisis such as rapid urbanization, population growth, traditional agricultural practices and equipment's, poor infrastructure, no monitoring or record keeping of the past events, lack of predictive planning, lack of coordination of administrative institutes, data deficiency, weak technical knowledge of the institutions, lack of knowledge of the decision makers, poor economic policies, lack of resources and finances, no public knowledge and participation for ongoing projects, water mismanagement in cities and most important climate change effects. Following are some barriers identified from the literature and reviewed.

2.5.1 Unplanned growth

Urbanization also corresponds to the growth of population. Development and increased population often unplanned in the developing countries and hence, leads to the negative impacts on the urban setup. Urbanization results in the increased impervious surfaces. It changes the natural water course and the hydrological cycle Walsh, (2005) which ultimately resulted in the increased runoff rates and volume. The negative impacts of the disturbed water cycle give rise to the number of problems including the higher risks of urban flooding Magume, (2015) soil or bed erosion Roy, (2008) and depleted water sources, limited ground water recharge hence, causing the water scarce conditions. Rapid development and urbanization have significantly increased the impermeable and concrete surfaces which hinders the infiltration of the soil, this hard surface of the cities is the one of the major causes of the urban flooding and mismanagement of the fresh water. Extreme weather conditions make the water flow uncontrollable for the infrastructure to handle and manage. This type of urban flooding is more localized and has potential to be frequent with more intensity.

2.5.2 Lack of institutional coordination

A study Nawab, (2009) discusses that the water crisis in Pakistan is due to the unrealistic management of policies, poor implementation and lack of public knowledge and participation. The study reveals that wide gap was found in the local people's expectations from the relevant institutions and their polices and services. This study suggests formulation of realistic policies, and decision plans with their regular updating infrastructures and systems also encourage public participation in policy making process. The institutions working for the stormwater management are unaware or have the overlapping role with different institute. Integrated, local culture-based solutions, regional context decisions should be promoted for the efficient water management rather than imposing the solutions and making no monitoring and upgradation. Different institutes operate in the overlapping localities and have the unclear decision-making options. An integrated management requires the integrated system of working which is well connected and interdisciplinary. The sustainable solution to the institutional management is the one window system that follows the predefined set of rules and working plan that is well-coordinated and well-structured. The sustainable solution ultimately aims to establish a framework which is interconnected that conserve the time resource and hence well managed.

2.5.3 Lack of finances

Rapid urbanization is generally unplanned in developing countries. Unplanned growth follows the range of negative impacts. Poor planning, uncoordinated authorities, non-transparent projects, poor economic structure leads to the resource wastage in terms of time, money and material. Developing countries have the limited resources for the regional or national level projects. The optimized planning and decision-making skills are needed at the policy making level that scrutinized the urgency of the issue, make optimized use of available resources and to mitigate the negative and harmful impacts. Urbanization leads to the overburdening the drainage network by expansion of cities and paved surfaces. Urban flooding causes the great deal of destruction in short period of time in the cities and also the resource wastage which can prove useful in the future development. Their impacts can be minimized with the infrastructure improvements and financial reliability of the related institutions for fund these structural improvements. Pakistan lacks the financial sources for efficient stormwater management in the big cities because of the poor institutional capacities and urban governance. Large number of respondents were willing for management strategies but only provided with the incentives Hasnain, (2018). Monitoring and regular upgradation of the system with the predictive planning is the key for best management.

2.5.4 Regulatory inflexibility

The negative impacts of development lead to the more complex issues. The stakeholders are reluctant to adopt the new strategies and practices. Major reasons for this are the lack of knowledge, coordination and understanding of the related institutions. The majority of stakeholders are unwilling to adopt to new strategies. Hasnain, (2018) stated that the policy process is complex and lacks the cohesive approach and also expressed that the policy implementation and monitoring stakeholders showed the poor commitment towards the stormwater management. A study Nawab, (2009) explains that the unrealistic policies and poor implementation are the major issues of the water crisis in the developing countries like Pakistan. It also explains that regulatory policies and services from the relevant institutions do not include the needs of the people hence, there services are of no use hence, wastage of the resources. This situation arises the environment of untrustworthiness among the working institutions, governance and the local people and maximize the regulatory gap in both groups. Stakeholder involvement in the decision-making process should be encouraged to provide the sustainable solution to the problem. Institutions needs to be working in integrated manner to provide the best management services that are cost-effective and eco-friendly also adapting to the changing environment and circumstances. The regulatory inflexibility comes from the poor coordination and knowledge transfer among the different actors or stakeholders.

2.6 Role of resilience in sustainable Urban SWM

Resilience is the ability or capacity to cope up and recover from the challenges faced by mismanagement or the unforeseen circumstances. LID emphasizes the non-structural SWM practices aiming to achieve maximize benefit prior to use the structural BMPs. Non-structural LID-BMP includes the minimal disturbance in the natural atmosphere, preservation of the sites in terms of archeology or history, reducing built surfaces, maintaining the natural habitat and vegetation. Structural approaches include the basins, filtration trenches, detention ponds, rain barrels, green roofs, existing infrastructure improvements for the capacity building to preserve and protect the natural water resources.

Concept of sustainable development has brought major changes in the field of planning and environment. Sustainable development is basically the long-terming planning which influences the present as well as the future. Sustainability in stormwater is considered when there is a balance between the level of provided services for water management such as adequate infrastructure load, minimal impacts on natural habitat, socially and economically stable. Frequent rainfall, urban flooding and climate change impacts have justified the concept of resilience in terms of stormwater management. Due to urbanization and large water volume the conventional systems no longer perform well in conveying the urban runoff. The integrated stormwater management and multi-criteria decision-making techniques (i.e., Analytical Hierarchical Process) to be applied for best management practices (BMPs), LID (Low Impact Development) by the knowledge experts to implement the sustainable stormwater management explained in the study by Birgani, (2013). Resilient strategies involve the LIDs, BMPs (structural, non-structural) and subjective decision making with the regional level priorities, managers personal preferences and experiences. These selection priorities also deal with technical, environmental, social goals accordingly.

CHAPTER 3: METHODOLOGY

This chapter typically highlights the study area, research design and main methodology used for this study. It also highlights the research schema of this study. The indicators obtained from the literature also mentioned in this chapter with their mean and SD values. The brief of data analysis and process is also explained at the end of this chapter.

Aim of this research is to identify the potential factors that affect the stormwater management and understand the practices and the policies for its management by the related institutions in Islamabad. Intent of this research is to evaluate the existing policies regarding stormwater management. Also, focus on measuring the institutional capacities and suggest some strategies for its efficient management.

This phase of research elaborates the line of actions to achieve the impartial and truthful results of the research based on the literature review, and the studies carried out so far. The following phase of research tries to provide the sound justification to adapt this methodology with reference to the context of similar study efforts at the international & national levels. The study anticipates the detailed illustration of overall research methodology schematics, and all the phases are explained to achieve the results.

This research is mainly exploratory to achieve the impartial and truthful results of the research based on the literature review, and the studies carried out so far. However, both qualitative and quantitative data will be considered under study. Literature review is the vital part of this research to provide the sound justification to adapt this methodology with reference to the context of similar efforts at the international & national levels. It also helped in formulating a framework for policymakers as well as numeric data to assess the institutional role in management practices and how well they are working. So, mixed method is best suited for this research as it integrates the both types of data which will help to analyze the existing problem and to formulate the strategy for effective management.

3.1 Literature Review

This phase of literature review validates the previous extensive literature to evaluate research objectives formulated and the selection of study area. This study consists of secondary and primary data. Primary data was collected from the questionnaire whereas secondary data was collected from the different online sources i.e., *Science Direct, Google Scholar, web of science* and international published report on *Sustainable Development Goals by United Nations (UNDP).* This study mainly focuses the research carried at national level to explore the trends, case scenarios, policies and strategies for efficient stormwater management. This study has a quantitative and qualitative approach to detect the various factors affecting the SWM and to the institutions that operates on SWM within study area.

3.2 Study Area

This study mainly focuses on Islamabad. Islamabad has been the capital of Pakistan since 1963. It is the first modern and planned city of Pakistan with wide roads and avenues, architectural designed public buildings and well-organized market centers. Doxiadis Associates, a Greek firm, devised a master plan of it based on the linear grid-system. Margalla Hills, northern end of Potohar Plateau, lie in the North of Islamabad with the Rawalpindi in its southern side. It covers the total area of 906 km^2 with 8-12% of tree cover.

City is divided into eight basic zones: Administrative zone, Diplomatic Enclave, Residential, Commercial, Industrial, Educational sectors and reserved green spaces. The city has the regional pattern of slope towards the south western end of the city due to the Margalla Hills and have the natural drains for stormwater discharge. The stormwater drainage system collects the storm drain from the residential and commercial areas and drain it to the nearest nalla in the localities. This discharge puts the pressure on the low-altitude plains of Rawalpindi for urban flooding. This discharge is the resource waste for the city and can be used for city demands in the future. There is a dire need for sustainable stormwater management of natural water resource for the growing population.

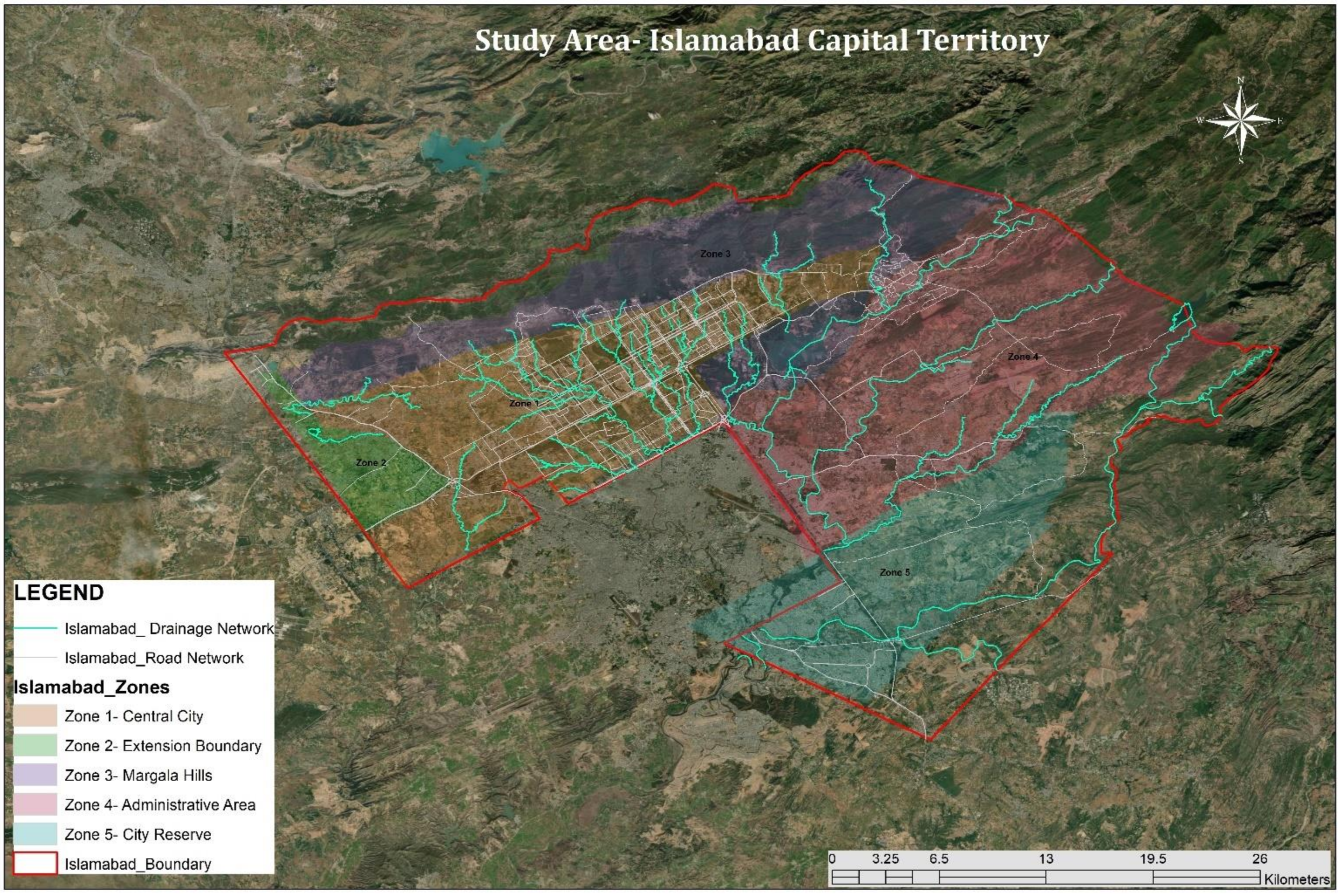

Figure 16: Study Area Map

3.3 Research Method

As mix method research, a technique used for hybrid research design was adopted for this research and an indicator-based approach was utilized to assess the indicators for efficient SWM, capacity of institutions and policy framework, the institutional survey was conducted. This approach is very applicable in conceptualization and operationalization of complex constructs like sustainable SWM.

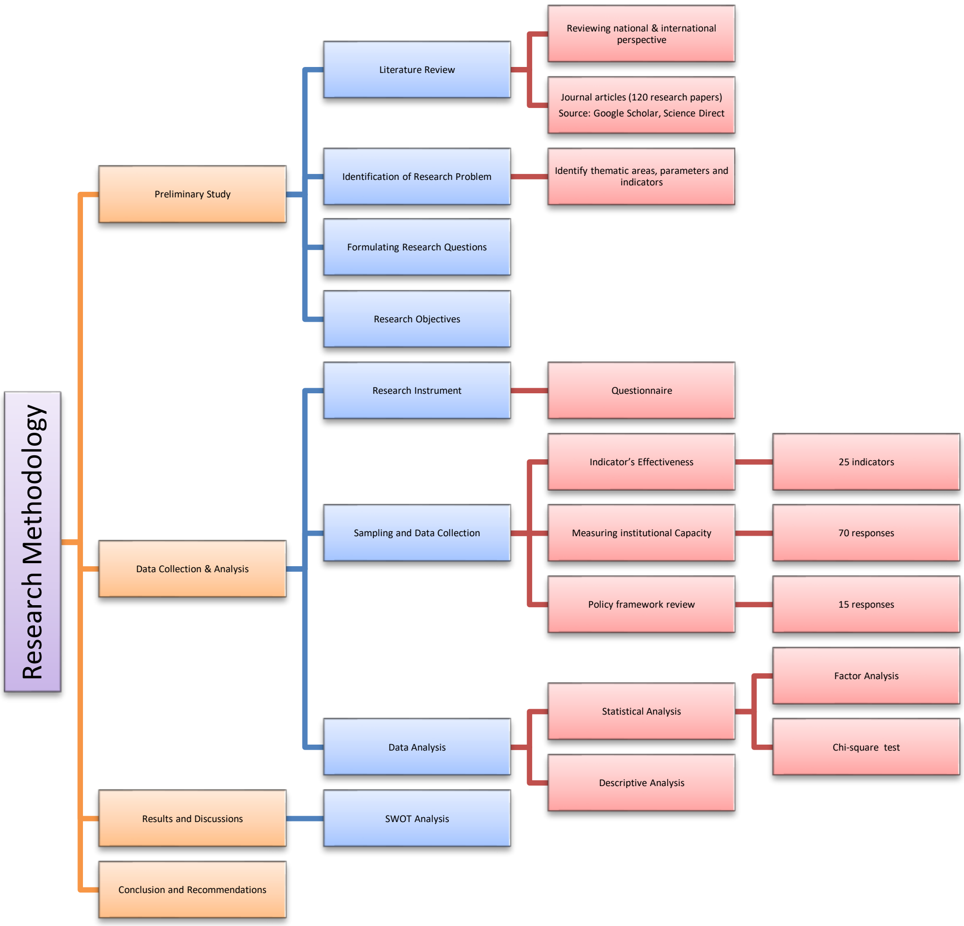

Figure 17: Research Schematic

Figure 2 above describes the research flow in the form of schematics dividing the research evaluation in literature review, data collection, data analysis and results deduced from the analysis. Initial literature review was conducted to identify the research gap, which was discussed with the industry experts and GEC members which led towards the selection of this particular topic and research objectives from the identified research questions.

Through literature review and expert opinion, indictors that effect the stormwater management were identified. A working definition for effective SWM in the case study was developed by analyzing the existing literature and industry expert opinion in local context. A questionnaire was designed for the verification of indicators by the experts extracted from literature review. Factors from the literature such as catchment area, basin slope, rainfall intensity, surface imperviousness, drainage area, soil characteristics, vegetation restrictions, growth boundaries were considered while making questionnaire. Also, with the literature review of articles and books, strategies were suggested for the improvement of SWM practices. In order to evaluate the existing policy framework, a focal group discussion with the administration of industrial professionals was also conducted. Questionnaires used to collect data are annexed with the thesis report. An initial survey was conducted to identify the major institutions that operate the SWM in the twin cities that fit the requirement of our research. The data collected was interpreted after analysis with the help of SPSS, leading to the conclusion and recommendations for effective management.

Table 1: Indicators with reference

Sr. No.	**Indicators**	**Reference**
1.	Catchment Area/ Basin Area	Burns, (2012); Zhang, (2020); Haris, (2016)
2.	Mean Slope of Sub Basin	Shishegar, (2021); Endreny, (2009); Saraswat, (2016)
3.	Rainfall intensity, duration and depth	Hou, (2020); Miller (2021); Kim, (2016); Shishegar, (2021)
4.	Drainage Area and Drainage Density	Saraswat, (2016); Jensen, (2018)
5.	Frequency of natural hazards	Fanelli, (2017); Bohman, (2020); Jensen (2018)
6.	Soil characteristics & Description (Infiltration, Permeability and Soil Type)	Romnee, (2015); Behrouz, (2022); Hou, (2020)
7.	Housing density and characteristics (Roof Type, Roof Area)	Barbosa, (2012); Miller, (2021)
8.	Water Quality & Quantity Monitoring	Jensen, (2018); Barbosa, (2012)
9.	Ground water recharge capacity	Kim, (2016); Brown, (2016)

10.	Event Mean Concentration (EMC) Total Mass Pollutant divided by Total Volume Discharge	Behrouz, (2022); Jacobson, (1991)
11.	Availability of database for watershed resources/ Building codes/ Land use plan	Fanelli, (2017); Goonetilleke, (2005)
12.	Innovative SWM Practices (BMPs, LID, Green Infrastructure)	Mugume, (2015); Jefferson, (2017); Brown, (2013); Liu, (2015)
13.	Rainwater recycling/ Reuse of Service water	Barbosa, (2012), Roy, (2008)
14.	Population growth (Urban Sprawl / Predictive Modelling)	Hussain, (2019); Kim, (2016); Bohman, (2020)
15.	Public Participation (Teaching Outreach Programs)	Goonetilleke, (2005); Brown, (2013)
16.	Impervious surface area (Regulations for Erosion & Sediment Control)	Saraswat, (2016); Fanelli, (2017); Liu, (2015)
17.	Percentage of open spaces/ grasslands	Jensen, (2018); Kim, (2016); Fanelli, (2017)
18.	Presence of water body (Physical Channel) near the urban settlement	Jefferson, (2017); Romnee, (2015)
19.	Restriction on local vegetation & forest removal	Kim, (2016); Mugume, (2015)
20.	Land use (Mix-Use), Landcover type	Barbosa, (2012); Jensen, (2018)
21.	Monitoring SW runoff impacts	Miller, (2021); Bohman, (2020)
22.	Developmental or Spatial Planning/ Local Land use Decision Making/ Extension of Growth Boundaries	Jefferson, (2017); Goonetilleke, (2005)
23.	Environmental Planning/ Ecosystem Management Provisions	Kim, (2016); Hasnain, (2018)
24.	Regular plan update and assessment	Brown, (2009); Jensen, (2018); Bohman, (2020)
25.	Financial and Technical Support	Saraswat, (2016); Hussain, (2019)

Table 2: Indicators with their mean and SD value

Sr. No.	Indicators	Mean	S.D.
1.	Catchment Area/ Basin Area	1.89	1.12
2.	Mean Slope of Sub Basin	2	1.06
3.	Rainfall intensity, duration and depth	1.77	1.1
4.	Drainage Area and Drainage Density	2.11	0.98
5.	Frequency of natural hazards	2.54	1.07
6.	Soil characteristics & Description (Infiltration, Permeability and Soil Type)	2.01	0.89
7.	Housing density and characteristics (Roof Type, Roof Area)	2.5	1.15
8.	Water Quality & Quantity Monitoring	2.63	1.02
9.	Ground water recharge capacity	2.33	1.09
10.	Event Mean Concentration (EMC) Total Mass Pollutant divided by Total Volume Discharge	2.66	1.01
11.	Availability of database for watershed resources/ Building codes/ Land use plan	2.16	0.88
12.	Innovative SWM Practices (BMPs, LID, Green Infrastructure)	2.21	0.99
13.	Rainwater recycling/ Reuse of Service water	2.27	1.06
14.	Population growth (Urban Sprawl / Predictive Modelling)	2.5	1.19
15.	Public Participation (Teaching Outreach Programs)	2.59	0.99
16.	Impervious surface area (Regulations for Erosion & Sediment Control)	2.13	1.13
17.	Percentage of open spaces/ grasslands	2.14	0.97

18.	Presence of water body (Physical Channel) near the urban settlement	2.17	1.1
19.	Restriction on local vegetation & forest removal	2.04	1.11
20.	Land use (Mix-Use), Landcover type	2.23	0.95
21.	Monitoring SW runoff impacts	2.5	1
22.	Developmental or Spatial Planning/ Local Land use Decision Making/ Extension of Growth Boundaries	2.39	1.16
23.	Environmental Planning/ Ecosystem Management Provisions	2.16	1.06
24.	Regular plan update and assessment	2.37	1.11
25.	Financial and Technical Support	2.11	1.19

Mixed method research design and indicator-based approach was used to identify the prominent indicators that effect the SWM.

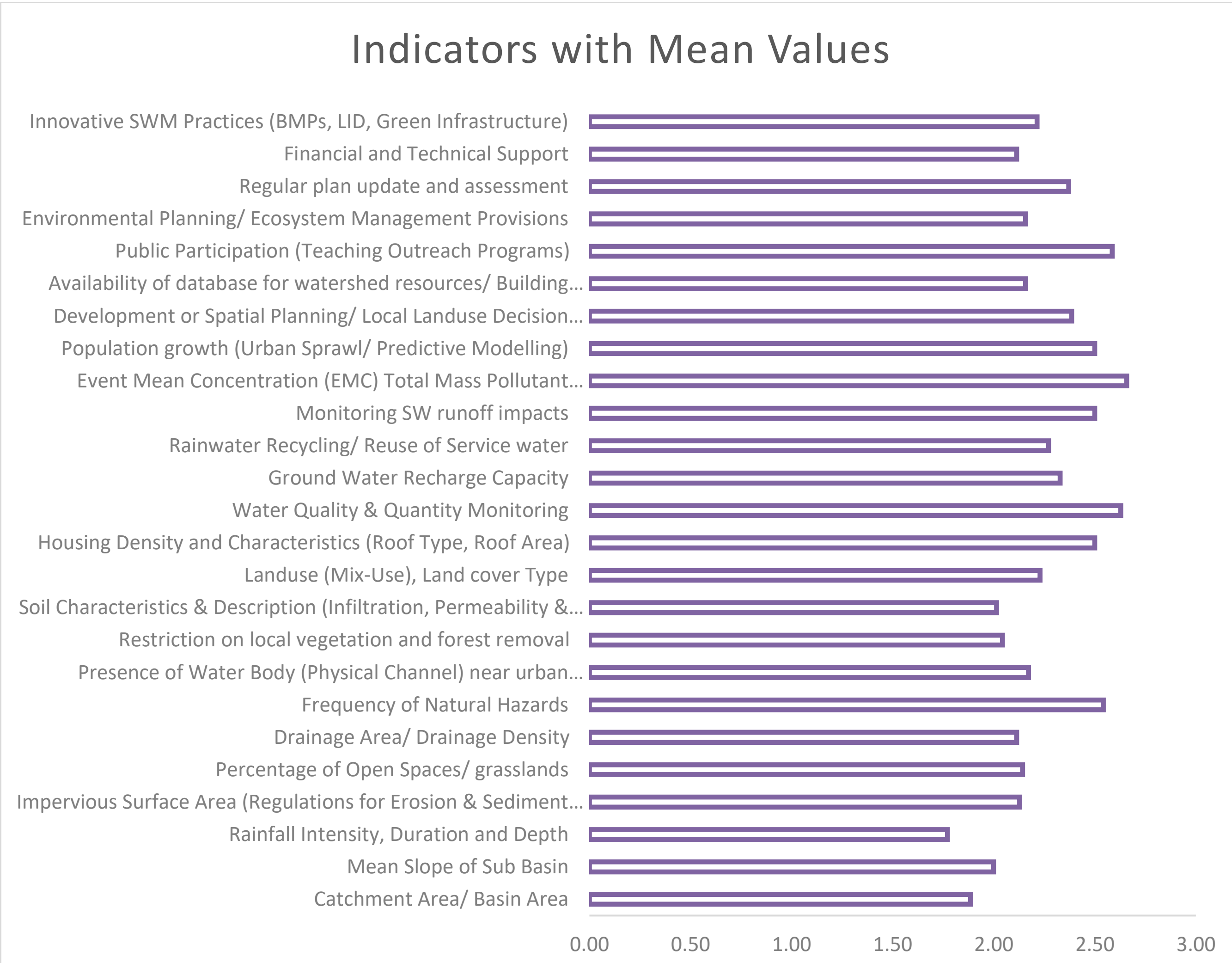

Figure 18: Indicators with their mean value

3.4 Sampling and Data Collection

The data collected for this research was from both primary and secondary data sources.

3.4.1 Primary Data Source

Primary data was acquired through structured survey from 69 different stakeholders such as students, professors, industry professionals, researchers and knowledge experts having the different educational background i.e., Bachelors, Masters and PhDs with different experience level for verification of indicators.

Two questionnaires were conducted in this research work, the first one focused on verification of SWM indicators and second one to measure the institutional capacity by the managing organizations. The second questionnaire was structured and interviews were conducted from the CDA professionals to assess the policy framework and the institutional role for SWM.

3.4.2 Indicators/ Secondary Data Source

Indicators were identified from the literature and categorized in the different thematic classes such as social, geo-physical, technical and institutional. Geo-physical indicators include the regional parameters of the stud area. Social indicators include the public participation and inclusion in stormwater management, technical indicators have some technological background for management of water resources such as planning, technical equipment's etc. Institutional indicators include decision making or policy related indicators.

Geophysical Indicators

This thematic class include the physical and geographical actors that play important role in water management. Indicators like catchment area/watershed area, slope of the sub-basin/watershed, rainfall intensity/duration, number of precipitation days, frequency of natural hazard in the area, drainage network and drainage outflow channel in peak flow, concreted surfaces, open areas and lands and presence of water body near the development. Percentage of open spaces and developed surfaces used in the identification of the areas for the infiltration sites, trenches or retention basins for maintain the ground water balance of the area. Water body near the developed area help to meet the water demand of the people and also help in the recharge capacity of the ground water. These factors vary with the region having different catchment area size and slopes and precipitation patterns. These factors help in the decision-making process and capability for efficient water resource management by studying the past events and predictive modelling.

Social Indicators

Social indicators include the indicators such as water reuse capacity of the community, public participation in the decision-making process and population growth rate. These factors help measurement of the community role in the water management decisions. These indicators help to create awareness about the water crisis issue to the general public which ultimately help in the community development by making reuse of the service water and water conservation strategies. It also helps the people to be aware about the natural hazards related to water management and its mitigation plans and develop resilience against the climate change actions.

Technical Indicators

Technical indicators include the technology parameters and modern techniques that have good cost-benefit ration and provide sustainable solution to the modern-day problems. This thematic area has the planning capability parameters, technical actors for efficient and sustainable water management. These indicators include elements such as soil characteristics, planning housing density, mix-land use, vertical development plans, water quality and quantity monitoring and its impacts study, peak water demand and flow, water reservoir capacities, event mean concentrations, availability of the past data and records for predictive studies, effective and sustainable innovative practices and measures to be carried out for SWM.

Institutional Indicators

Institutions play very crucial role in the water management. Different working institutions for water planning, management and development work together with coordination and identified authorities for efficient management. These include the prioritize the planning strategies, development programs, financial working plan, ensure sustainable approach to solve the specific problem and to apply the solutions having best cost-benefit ratio. Integrated approach of the institutions helps to conserve the resources and provide the maximum benefit and minimize the harmful impacts. The indicators also help in measurement of the capacity of the water management. These include factors such as planning approaches, restriction on the local vegetation, conservation plans for the future development, best resource utilization, priority management, building codes and development rules for permeable surfaces. It also deals implementing new technologies, update existing infrastructure and regular planning, monitoring and updating services.

These identified indicators were then used for designing the questionnaire as a reference for the further study of this research. It helped in the identification of the important factors for efficient management of SW and measurement of institutional capability. Following figure explains the thematic classes of the identified indicators.

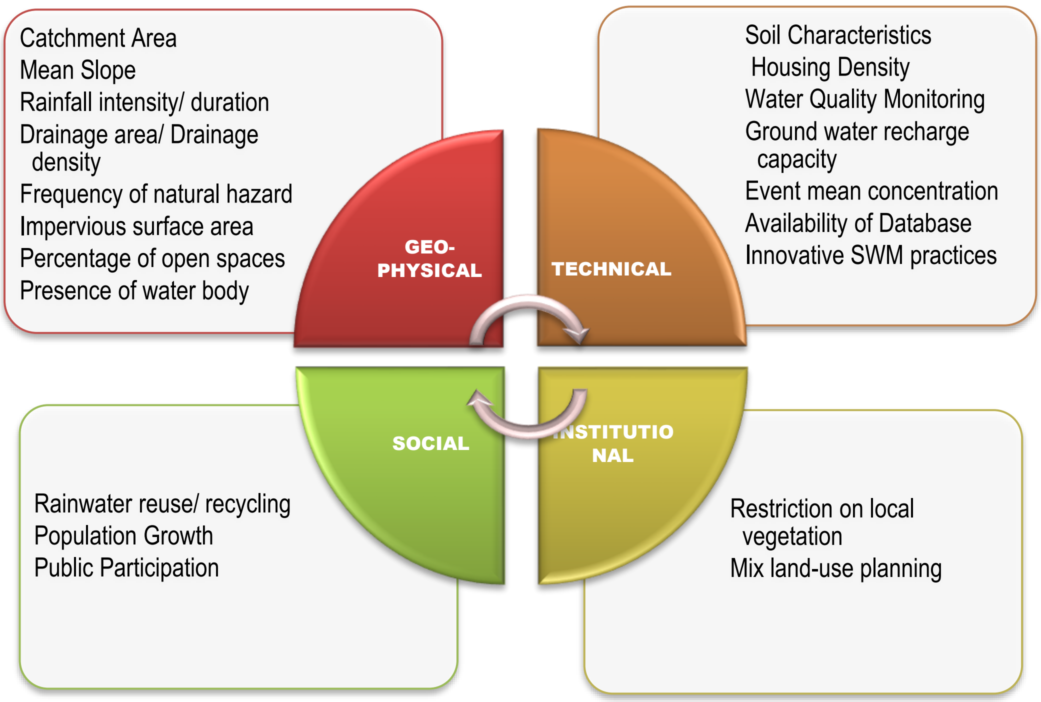

Figure 19: Indicators with thematic areas

3.5 Data Analysis and Processing

The data obtained from the secondary sources was then categorized in different thematic areas and used for questionnaire design for its verification. The quantitative resulted data from the questionnaire was digitized and analyzed using IBM SPSS 20 software. The data was analyzed by performing descriptive statistics, Principal Component Analysis (PCA). Reliability test was performed to check the reliability of the data. Factor analysis and other descriptive statistics were applied on the data including Mean, Median, Standard Deviation and various other techniques.

Data analysis along with literature review will help to devise strategies for efficient SWM. These strategies will be correlated with the existing policies at the end of the study.

3.6 Policy Content Analysis

Policy content analysis was performed through the literature review which helped to identify the indicators effecting the SWM worldwide. Literature review mainly focused on best practices of SWM carried out in different areas of the world in corresponding to the regional topography and dynamics. This will create the better understanding of the management practices for the industry experts so that they can implement the strategies used by other countries in Pakistan. This will help make policies which will support and help in improvement of existing system to conserve the natural water resource and to overcome the risks associated with SWM such as flash flooding, ground water depletion etc.

3.7 Strategic Recommendation

Strategies are formulated at the end of this study which will be recommended to be incorporated in the policies of related organizations. These strategies would be inferred from best practices of SWM in different regions through literature review, indicators and institutional assessment from the questionnaire survey conducted while keeping the existing topographic conditions and climate change impacts.

CHAPTER 4: DATA ANALYSIS

This chapter contains the data analysis and its interpretation. The analysis is conducted on data obtained from the literature review, field survey and personal interviews from the various industry experts. The analysis ranges from the content, factor analysis and descriptive in accordance with the data. The first half consists of the data demographics and indicator's effectiveness from the factor analysis. Second half consists of the policy review for SWM with the data descriptive. Lastly, the strategies and recommendation for the sustainable SWM are discussed according to the analyzed data.

4.1 Demographic Data of Respondents

The study's objective was to measure the indicators effectiveness by verifying the indicators obtained from the extensive literature review. The questionnaire included the questions asking about the education, designation and experience of the respondent. The data collected from the questionnaire had total of 70 responses from the different GIS experts, industry professionals from urban, water and civil engineering background, academia professors and researchers, students enrolled in relevant fields such as civil engineering, GI engineers, and urban planning. The organization field was classified in 5 classes i.e., GIS Consultation Firm, Construction Consultation, Public Organizations such as CDA, PCRWR, academia and the Corporate Services. Education of the respondents was classified in 3 classes i.e., bachelors, MPhil, MS and the PhD scholars. The respondent's role or designation was classified in 5 classes to be industrial GIS expert, engineering & management, planners, students with no industry exposure and the researchers with technical expertise and field knowledge.

Table 3: Respondents Profile

Respondent's Profile	Category	Frequency (N)	Frequency (%)
Organization Name	GIS Consultation Firm	11	15.7
	Construction Consultation	18	25.7
	Public Organization	20	28.6
	Academia	16	22.9
	Corporate Services	5	7.1
Education	Bachelors	36	51.4
	MS/M-Phil	24	34.3
	PhD	10	14.3
Designation/Role in Organization	GIS Expert	16	2.9
	Engineering & Management	34	48.6
	Planner	4	5.7
	Student	5	7.1
	Teaching & Research Assistant	11	15.7
Experience	< 5 years	39	55.7
	5-10 years	18	25.7
	10-15 years	2	2.9
	>15 years	11	15.7

The above table explains the descriptive statistics of the respondent's profile which includes variables such as organization name, education level, designation or role in organization, number of experience years. The table shows the frequency and the percentage value according to the categories of the variables.

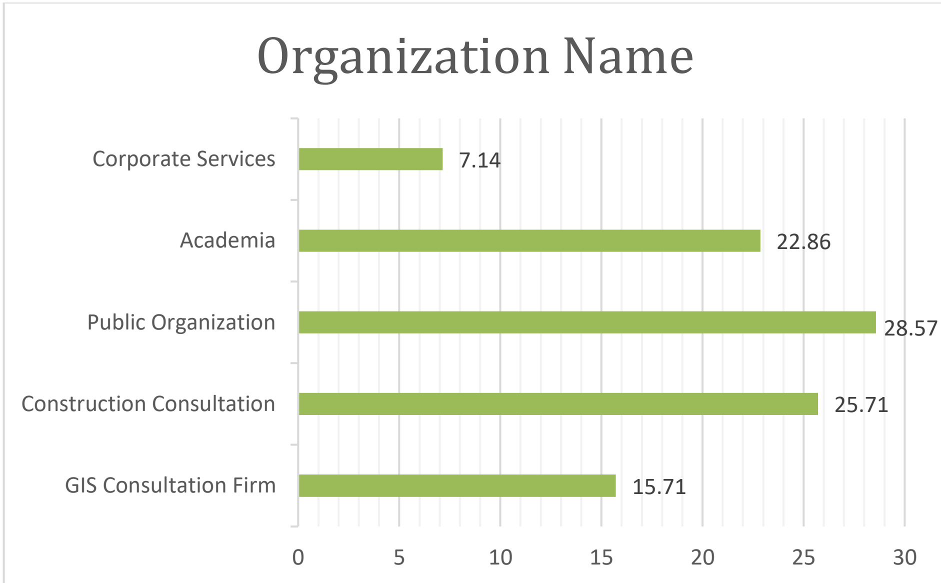

Figure 20: Respondents Organizational Background

Figure above shows the statistics of organization name, that the 20 responses from the total were from the public sector (28.6%) and construction consultation having 18 respondents comprising 25.7%. Out of the 70 responses 11 were from the GIS consultation firm (15.7%).

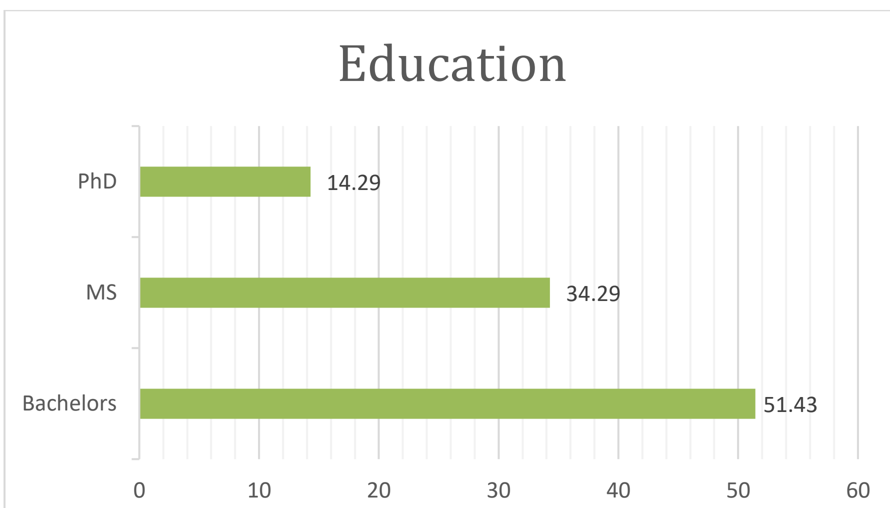

Figure 21: Respondent's Educational Background

Research identifies that the 36 respondents (51.4%) having bachelor's degree as the highest level of education, 24 (34.3%) were having M-Phil and only 10 (14.3%) respondents have the PhD degree.

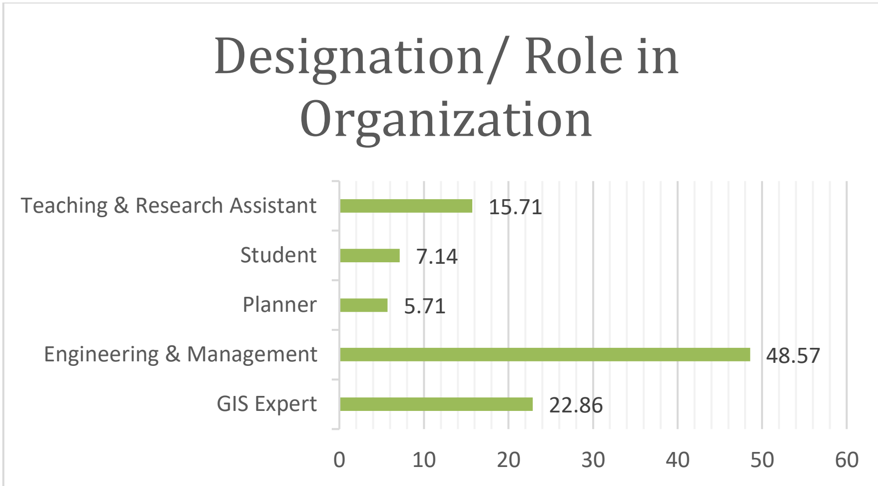

Figure 22: Respondent's Designation in Organization

The data was categorized for designation in the organization in 5 classes showing 16 (22.9%) respondents as GIS experts, 34 (48.6%) respondents were engineers or managers, 4 (5.7%) among them were from urban planning, 5 were students and the rest of 11 (15.7%) respondents were from academia a research assistants or professors.

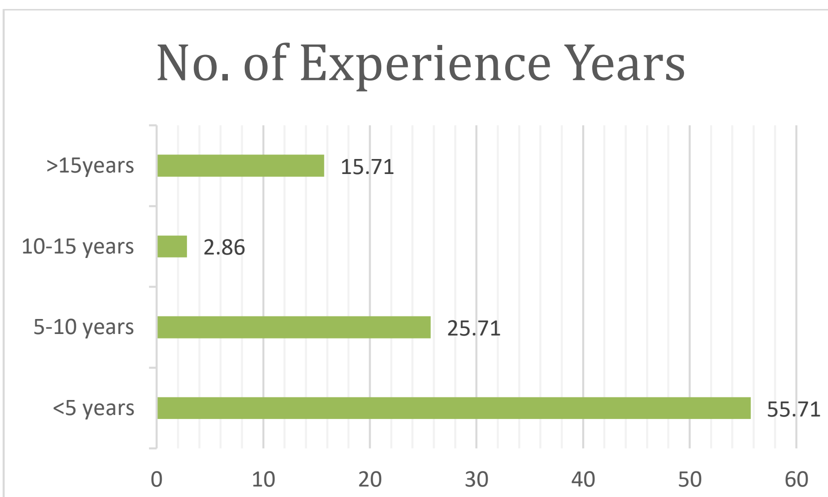

Figure 23: Respondent's experience

The experience variable data was collected in number of years. But for grouping the data to more manageable results the experience values were categorized in 4 classes ranging from 1 to 4. 1 class being from years of experience less than a year.

The indicators identified were 25 in total and were ranked in Likert scale ranging from very high to very low in 5 classes i.e., 1 to 5.

4.2 Factors affecting Stormwater Management

Data were analyzed using the IBM SPSS 20 software.

Principal Component Analysis (PCA) was performed to reduce the indicator's data to more manageable groups and to determine the latent factors that highly correlate with each other.

Cronbach's alpha co-efficient was calculated to check the reliability of data collected and value found out to be 0.945 which is high from the threshold value i.e., 0.7 verifying that the data is reliable for further analysis.

Keyser-Mayer-Olkin (KMO) and Bartlett's test values were calculated to identify the suitability of PCA and reliability of the data. The KMO value found out to be 0.839 which is above 0.6 showing the reliability of the data, while Bartlett's calculated value shows the statistical significance of sphericity. The Bartlett's test of sphericity value *(X^2)* is 276 and significance value (*p-value*) is less than 0.001 unveiling that the correlation matrix is not an identity matrix and PCA can proceed to examine the factor that effect the efficient management. The Principal Component Analysis categorizes the 25 indicators affecting the stormwater management into 6 indicators using varimax rotations with Eigenvalues greater than '01'. These 6 indicators explain 72.76% of total variance as shown in the table below.

Table 4: PCA of indicators effectiveness

Component	***Initial Eigen values*** Total	% of variance	Cumulative %	***Rotation Sums of Squared Loadings*** Total	% of variance	Cumulative %
1	10.493	43.722	43.722	3.837	15.988	15.988
2	2.068	8.617	52.338	3.770	15.707	31.695
3	1.551	6.463	58.801	2.916	12.149	43.844
4	1.193	4.969	63.771	2.548	10.617	54.461
5	1.137	4.739	68.510	2.267	9.444	63.905
6	1.021	4.256	72.766	2.127	8.861	72.766

All variables were retained with no factor loading below 0.5

Table shows that the variance among the extracted components. Initial Eigen Values variance is from 43.72% to 72.76% and the rotated sums of squared loadings is from 15.98% to 72.76%.

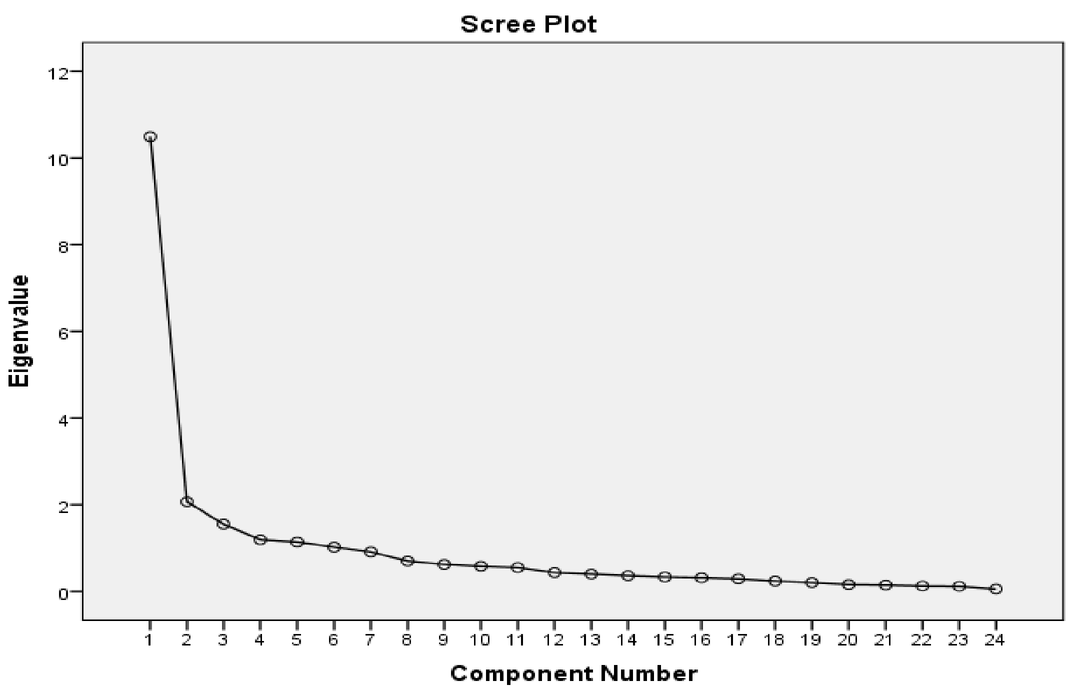

Figure 24: Eigen value of the components

Above figure demonstrate the eigen values of the components. 6 components are extracted on the base of eigen value. 6 components explain the 72.76% of the data from the 25 indicators.

Table 5: Factors affecting SWM

FACTORS	Mean (X)	Factor loadings					
		1	2	3	4	5	6
Mean Slope of Sub Basin	3.99	.848					
Impervious Surface Area (Regulations for Erosion & Sediment Control)	3.86	.676					
Soil Characteristics & Description (Infiltration, Permeability & Soil Type)	3.97	.669					
Rainfall Intensity, Duration and Depth	4.22	.617					
Ground Water Recharge Capacity	2.33	.565					
Development or Spatial Planning/ Local Land-use Decision Making/ Extension of Growth Boundaries	3.59		.664				
Population growth (Urban Sprawl/ Predictive Modelling)	3.49		.655				
Frequency of Natural Hazards	3.46		.622				
Restriction on local vegetation and forest removal	3.93		.616				
Presence of Water Body (Physical Channel) near urban settlement	3.83		.601				
Monitoring SW runoff impacts	3.51			0.681			
Availability of database for watershed resources/ Building codes/ Landuse Plan	3.84			.740			
Drainage Area/ Drainage Density	3.88			.706			

Catchment Area/ Basin Area	4.13			.653			
Financial and Technical Support	3.88			.523			
Event Mean Concentration (EMC) Total Mass Pollutant divided by Total Volume Discharge	3.38				.763		
Water Quality & Quantity Monitoring	3.38				.714		
Rainwater Recycling/ Reuse of Service water	3.71				.664		
Public Participation (Teaching Outreach Programs)	3.39					.817	
Regular plan update and assessment	3.62					.554	
Environmental Planning/ Ecosystem Management Provisions	3.84					.519	
Housing Density and Characteristics (Roof Type, Roof Area)	3.5						.769
Landuse (Mix-Use), Land cover Type	3.77						.727
Percentage of Open Spaces/ grasslands	3.86						.510

Above table shows the ranking of the efficient stormwater management indicators as the mean value with their factor loadings i.e., rainfall intensity, duration and depth with mean value of 4.22 (X=4.22). Rainfall being the most important factor for the stormwater management secure the utmost important factor in terms of the indicator’s effectiveness for efficient management. Catchment area/Basin area being the second most important factor with mean value of 4.13 (X=4.13). Other important factors include mean slope of sub-basin, soil characteristics, restriction on local vegetation, drainage area and drainage density, financial and technical support, impervious surface area, percentage of open spaces, availability of database for water resources respectively. Indicators having the least mean values include the event mean concentration (EMC) and the water quality and quantity monitoring.

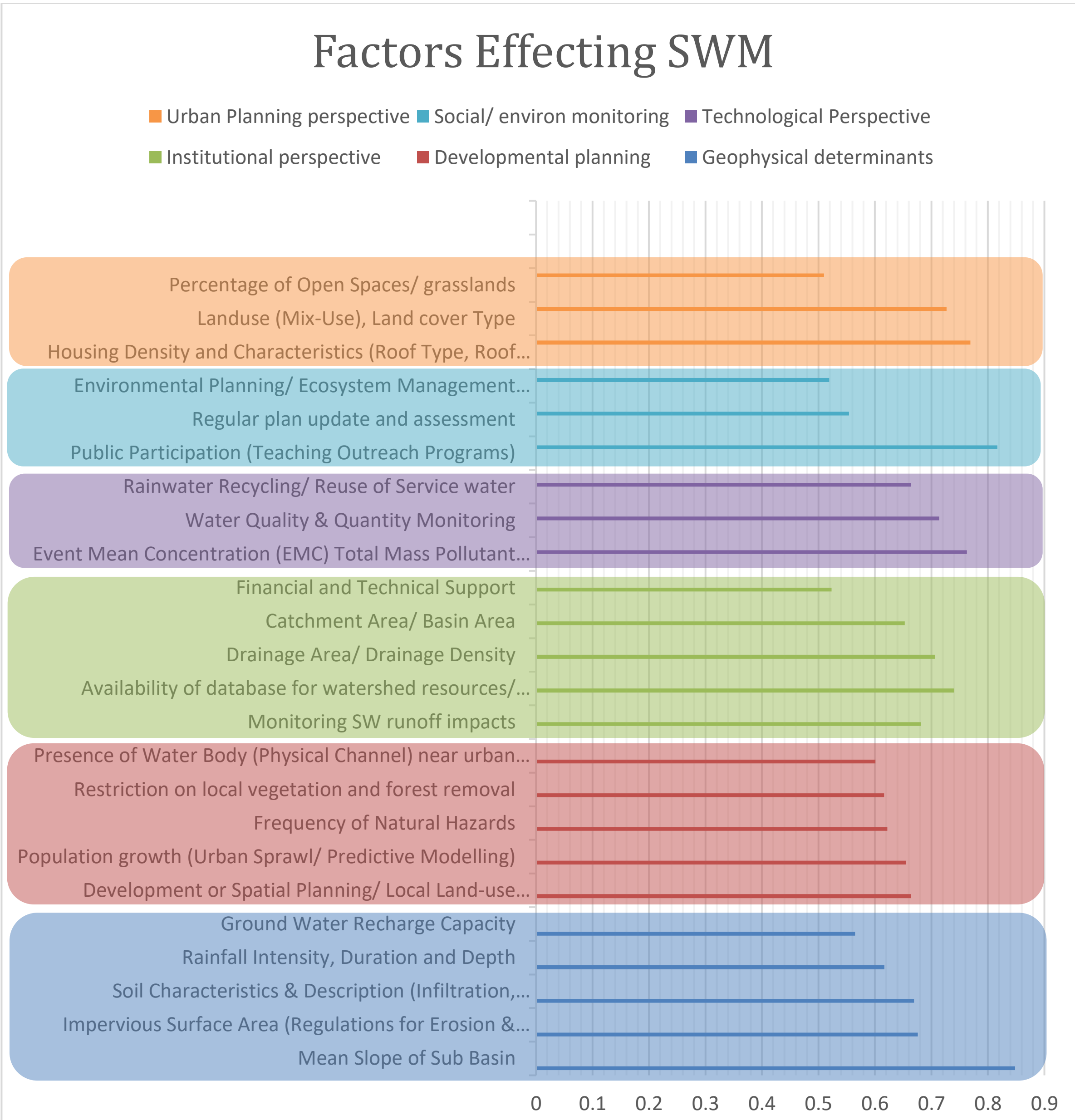

Figure 25: Indicators with their factor loadings

Above figure explains the indicators with their 6 factor loadings. These factors were named according to the underlying indicators such as urban planning perspective which includes housing density, landuse-landcover assessment, percentage of available open spaces etc. Social/environmental monitoring has the indicators like public participation, regular plan update, and reuse recycling of service water. Technological perspective has indicators such as mean event concentration, institutional perspective, developmental planning and geophysical determinants of the study area such as slope, soil characteristics, recharge capacity and impervious surface area on field. Out of these factors, urban planning is the most important factor for efficient stormwater management. Social/environmental planning, technological perspective, geophysical are also important for SWM.

4.3 Role of indicators in evidence-based policy development

In the paradigm of evidence-based policy development, indicators can be quite effective in the process to identify the problem, evaluation and monitoring of existing policy framework, and contributing to giving alternatives and better policy outcomes Jensen, (2018). Indicators also help in functioning of complex phenomena's into easily communicable quantitative factors which can help policy makers and decision making.

The City Blueprint Framework (CBF) has the different regional level indicators that measures the city level integrated water resource management and compares them with the social, environmental, cultural and technical aspects of the city and categories the city water system as 'water-wise' or 'water sensitive' cities. Indicator for urban water security can be extracted from the composite indicators i.e., ADB, WHO water security index which has the national level water ranking. However, this data can be used for the national level planning and management.

Water index and composite indices can also be helpful for the policy review and decision making at local and international level but has a limitation of its usage in terms of water management because of its conflation with economic poverty and water crisis. Water security indicators are generally linked to city-level or regional level policy objectives whereas water utilities often target city water management in terms of supply and demand, it doesn't incorporate the resources linked for water management.

4.4 Policy Framework Review and Measuring Institutional Capacity

For measurement of institutional capacity for stormwater management, interviews were conducted from the relevant professionals from the CDA, that is working in Islamabad for management of stormwater. Overall, 10 responses were conducted for policy framework review from the industry experts. The profile of expert is shown in the table below.

Table 6: Respondent's Profile

Category	Value	Mean (X)	S.D.	Frequency (N)	Percentage (%)
Education	Bachelors	1.4	0.699	7	70
	MS			2	20
	PhD.			1	10
Experience	0-10 years	2	0.667	2	20
	10-20 years			6	60
	Above 30 years			2	20
Role/Designation	Asst. Director	2.1	0.876	3	30
	Dy. Director			3	30
	Director General			4	40

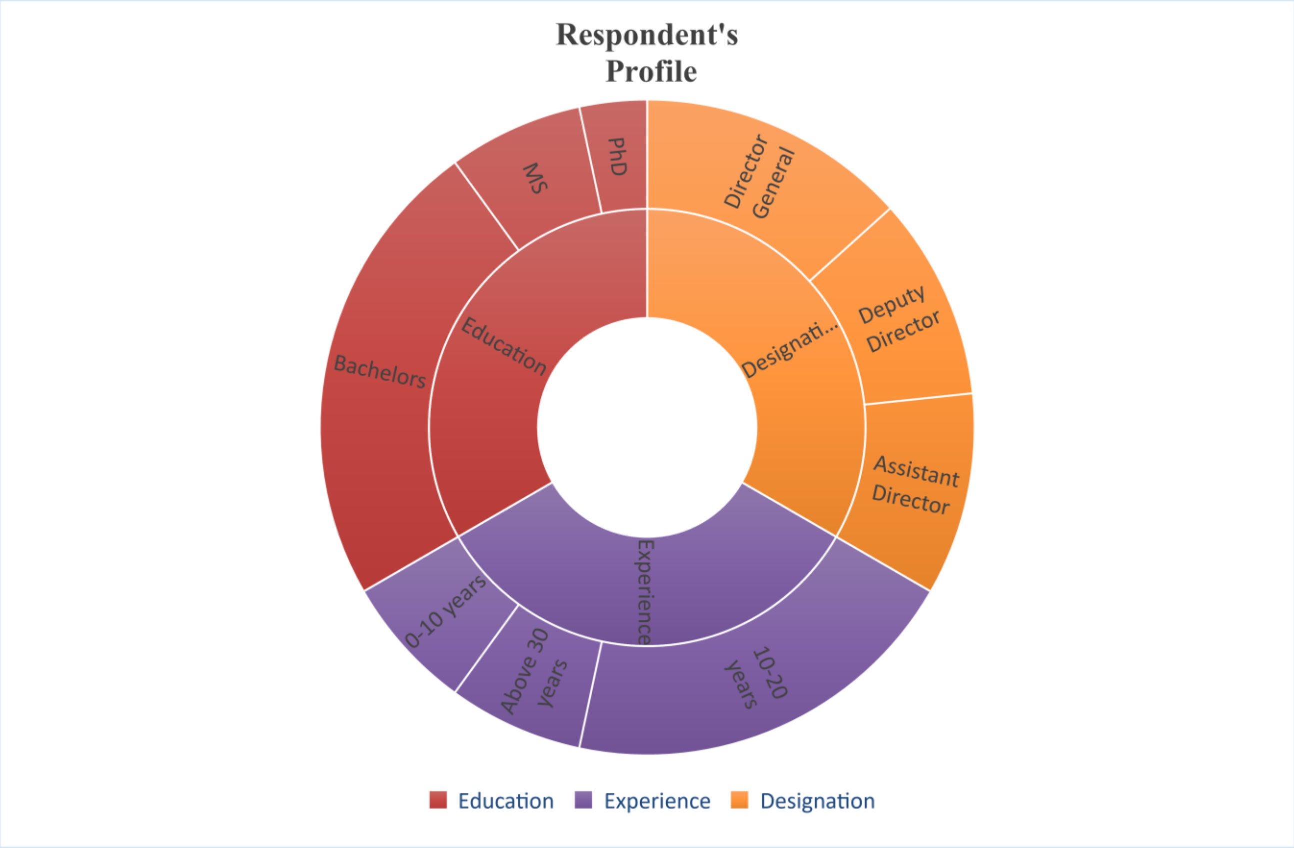

Figure 26: Respondent's Profile Chart

This profile shows that the majority of respondents were having the bachelor's degree as their education. They had civil engineering background and working in the CDA with planning and development wing. Out of 10 respondents 3 were assistant directors, 3 were deputy directors and 4 were director general in different working departments of CDA. Assistant Directors having 0-10 years of working experience mostly whereas deputy director and director general having more than 10 years of professional experience in CDA.

The first part of the questionnaire was to evaluate the policy framework working in the CDA for the SWM. First statement was about the effectiveness of SWM in urban areas and 60% of respondents were satisfied, only 20% were dissatisfied. The restriction on local vegetation was agreed upon by 70% of respondents. 50% of respondents were agreed that the policy addresses the regulations for erosion and sediment control.

Statement 4 was about the policy having the provision for preservation of open spaces on which 70% of respondents were agreed leaving 30% disagreed. The 60% of professionals were agreed that the policy offers area to floor ratio for permeable surfaces. The policy about the development away from the floodplains only 40% of industry experts agree on that and 30% were disagreed. Almost 60% of respondents agree that the policy encourage the availability of septic tanks for SWM in urban areas. 40% of respondents believe that the policy addresses the designs for the redevelopment of urban areas, to which 30% disagree. Policy about the mix-landuse development, 40% were satisfied from this policy leaving 30% dissatisfied. 70, 50 and 60% of respondents were satisfied from the policy providing building code regulations, long-term ecosystem and innovative SWM practices (LID/ Green Infrastructure) respectively.

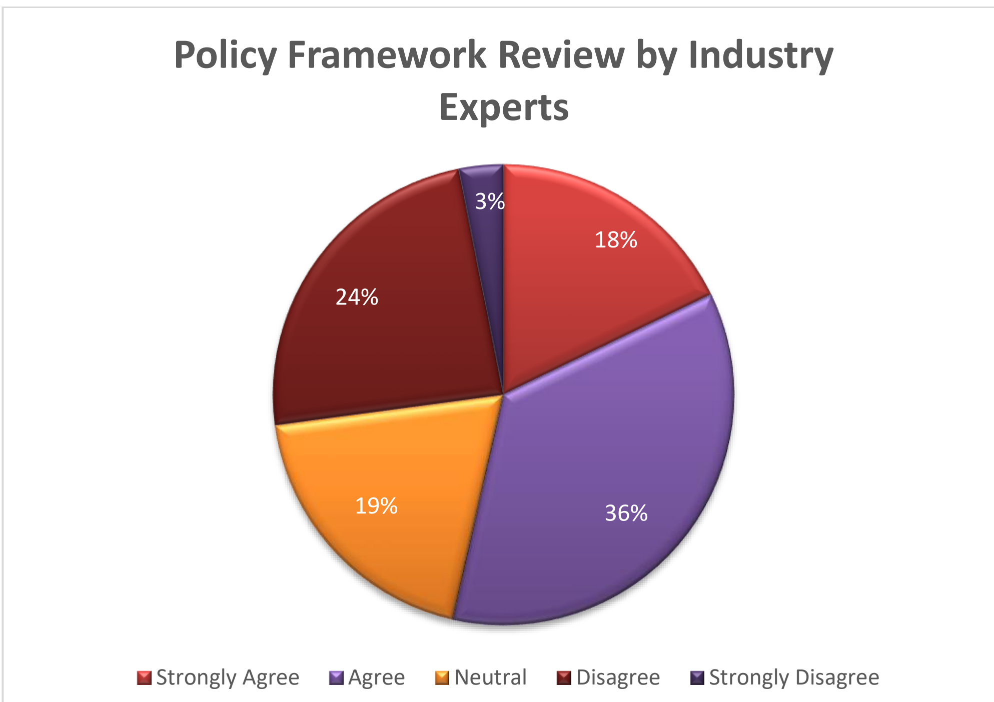

Figure 27: Review by the industry professionals

. Above figure explains the industry expert's opinion on the policy framework of CDA about SWM operating in the study area. The graphs that the majority of the respondent's agree (either strongly agree or agree) i.e., 53.1% with the ongoing policy framework whereas 19.2% were neutral and 26.9 were disagreed.

The second part of the questionnaire was to measure organizational capacity. This part consists of 16 questions about the organization capacity. The responses from the industrial experts were collected in yes or no statement.

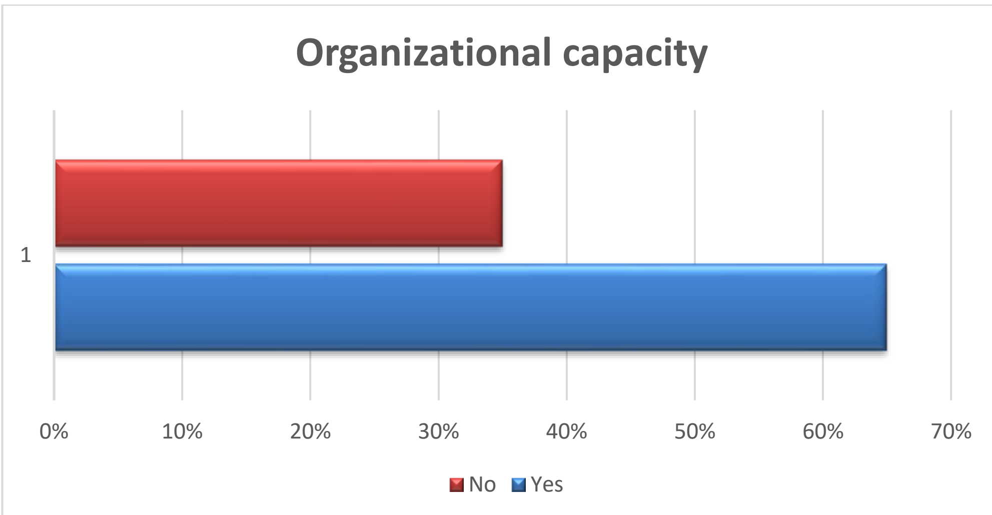

Figure 28: Measuring Organizational Capacity

When analyzed the data, it showed that the 65% of the respondents believe that the organization has the good capacity to deal with SWM in the twin cities whereas 35% of respondents didn't believe that the organization has the capacity to deal with SWM.

4.5 SWOT Analysis for Sustainable Urban Stormwater Management

SWOT analysis is considered to be divided in the group of four factors. Two of these factors are characterized as internal and two are external. This study Kordana, (2020) indicates that each internal and external includes the positive and negative elements. The positive internal element is the strength of the project, and positive external element is the opportunity of the project associated with its implementation. The negative internal factor is the weakness of the project. The opportunities and threats are the external factors that are not influenced or controllable. The strengths along with the opportunities help to overcome the potential threats related to the project. Weaknesses of the project are the limitations and wasting the available opportunities.

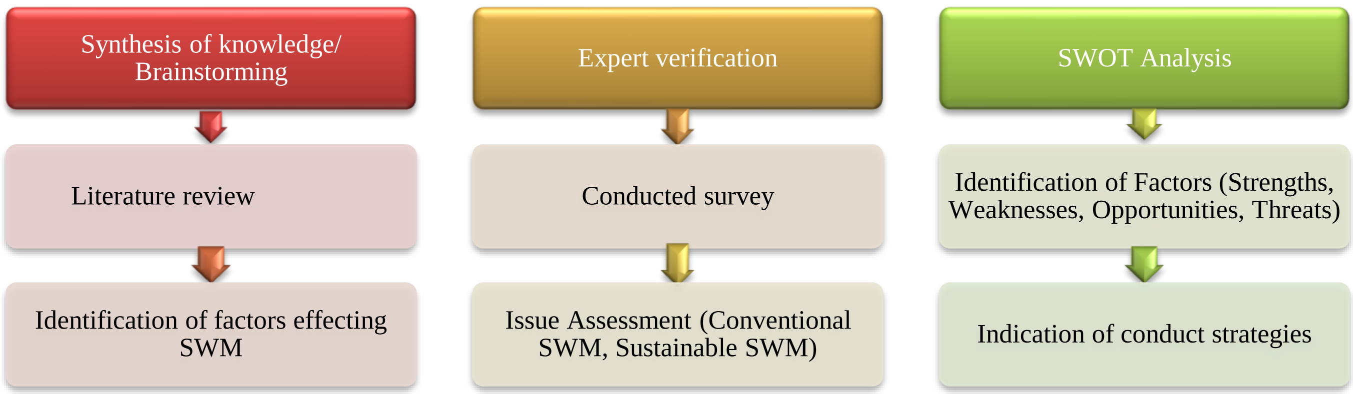

Figure 29: SWOT Analysis for Sustainable Stormwater management

The data obtained from the literature and the expert opinion survey was taken in consideration for analysis. The balance of these factors is created by SWOT analysis and can be treated by the detailed analysis of the application for the specific area. This results in the formulating the innovative strategies and practices for the SWM. In the study area, the normal practice of SW discharge is through the physical channel or drains by the underground piping system. Therefore, the sudden change in the existing system by terminating the conventional drainage system is not practical hence, the sustainable solutions are to be carried out gradually with the technical, economic and social support.

Strengths of the sustainable SWM is that is the ultimate solution to the modern-day problems and widely accepted in the engineering perspective. It can be coordinated well with the existing conventional SWM system or drainage system. As the study area utilizes the underlying pipe system to drain off the stormwater in the nearby physical channel, it is unpractical to believe that the system to be changed rapidly rather it is a gradual process that needs extensive technological, economic and financial studies. Retention system rely on the availability of land that is used in conventional system and hence, the sustainable solution is to cooperate with the existing infrastructure with regular update and innovative practices. Improved coordination between the working institutions, reduces the potential risks associated with the water scarcity Kordana, (2020). Coordinated system can built capacity to adopt to the fluctuation in the SW flow and also help to mitigate the strategies and help in the resilience measure for SWM.

Infiltration of polluted SW leads to the ground water pollution, hence the water discharged in the drainage, infiltration or retention system should be pre-treated to avoid the negative impacts and to minimize the destruction of natural ecosystem. Discharging the whole volume in drainage system can result in the hydraulic overloading, infrastructure damage that follows under the weakness of this system. Lack of available land for the sustainable solutions and lack of unified system for designing the SWM system also classified as the weakness. This management requires the detailed financial and technical analysis, resource availability to support the development of modern technologies.

Threats are the external uncontrollable factors that include the unpredicted scenarios can lead to the significant loss and also degrade the natural regional ecology. Climate change impacts leads to the extreme temperature and precipitation events that follows the peak flow volume and overloading of the hydraulic system, which results in the increased flood risk and degraded environment.

Ecological awareness in the society can reduce the negative impacts of the climate change and SWM. Natural infiltration and retention system appropriately designed and incorporated can help in maintaining the aesthetics of the catchment area Kordana, (2020). Restriction on the land development also minimizes the losses associated with the urban flooding and land degradation. This sustainable solution is best solution for local or regional development. Following table explains the four factors of SWOT analysis for implementation of sustainable urban SWM.

Table 7: SWOT Analysis for Sustainable Urban SWM

Strengths (*S*)	**Weaknesses (*W*)**
1. Approved and effective solution from engineering perspective 2. Incorporated with the existing conventional SWM system 3. Improved practices result in reduction of water scarcity 4. Coordination in the system help in the capacity enhancement for the future events 5. Integrated institutions and stakeholders in the decision-making process	1. Sustainable solutions dependent on the soil permeability and availability of the land 2. Retention facilities needs the pre-treatment facilities before discharge 3. In case of unfavorable environment, detailed technical and financial studies needed 4. Lack of integrated solutions of the designing of SWM 5. Lack of available land for construction of detention tanks, ponds and basins
Opportunities (*O*)	**Threats (*T*)**
1. Encourage the ecological awareness in society 2. Integration of infiltration and retention system improves the regional aesthetics 3. Restriction of physical, infrastructure and economic losses associated with the urban flooding 4. Availability of resource data, clear understanding will help to overcome the barriers related to SWM 5. Best possible solution for the regional development and planning	1. Unpredictable climate change negative impacts lead to the system failure 2. Hydraulic overloading caused by increased flooding causes the environmental degradation of the catchment area 3. Lack of resilience measures can lead to significant loss

4.6 Sustainable Urban Stormwater Management

The results of the analysis conclude that sustainable urban stormwater management requires a broad, multi-disciplinary, flexible approach for its management. It needs to be integrated within the natural and built environment as well as its managing institutions. The conventional SWM can be integrated with the sustainable approach with the detailed technological and economic point of view, cost benefit analysis and prioritizing according to the specific area and conditions applied. The sustainable solution depends on the land availability which can be used by updating the existing infrastructure with technological advanced strategies. Therefore, sustainable solution should have a backing of strong ecological, economic, environmental and social studies to work more efficiently than the conventional system. Coordination of the working institutions and the involvement of the stakeholders play important role in the sustainability management. The best solution is to balance between potential profits and losses and the preferences of the decision makers and stakeholders which allows the efficient management.

Best practice of sustainable management is the integration with conventional system such as development of permeable surfaces at the pavements, parking lots and roads, rain gardens, infiltration trenches, dug-holes, swales and retention ponds etc. This approach utilizes the land of the conventional system with the engineered innovative techniques to maintain the natural balance. LID encourage non- structural methods such as increased vegetation, swales, natural grassland and organic solutions. Following figure explain some of the sustainable practices used for efficient SWM.

Figure 30: Sustainable Practices for efficient SWM

Source: Archived from (Green sustainable services SSL)

Green infrastructure is also considered as efficient SWM practice that includes green roofs, green building, zero carbon footprint or energy efficient buildings, roof gardens etc. Permeable surfaces, potholes, infiltration trenches all are structural methods of LID that results in the soil infiltration and to control the urban runoff.

Sustainable urban stormwater management is the concept that make sure the safe water supply and consistent water resources available for future generations for which the carbon emissions, carbon footprint and water wastage needs to be reduced for its efficient long-term management. The main principal found through analysis and the respondent's comments support the sustainable water management; solutions to promote recycling reuse of water, reduce the water wastage at household level, program design to create awareness among stakeholders and educate the public regarding the health and water crisis and hazardous risks attached in case of poor management. Following are some solutions for sustainable urban water management.

- Wastage monitoring and control measures for the urban peak flow to accommodate the water in the non-rainy seasons
- Recycling and reuse awareness to minimize the excessive usage habits and utilization within optimized limits
- Require long-term plans and policies for efficient management, regardless of the government change these policies work out fine on their own in the institutions
- Maintenance mechanism to overcome emergency situation, evacuation or alternatives needs to be studied to incorporate wide range of parameters
- Invest in training and equipment/technical design with the technical studies and ther regular testing and upgradation
- Ensure public awareness and active participation in the policy making and implementation phase
- Involvement of stakeholders and private sector using latest technologies to get the maximum benefits from the advanced techniques
- Invest in environmentally sound & cost-effective technologies for recycling of service water and their regular check for their long-term working
- Develop an infrastructure for sustainable and effective management of water resources with timely updates and monitoring to keep notified about the modern technologies and urrent practices with their setbacks

CHAPTER 5: CONCLUSION

Even though the institutions are aware of the growing problems such as population growth, rapid urbanization, climate change and are working for it to overcome, but the research shows that with these growing problems there is still a dire need for physical implementation of the management practices to conserve the water for sustainable future. Rapid urbanization and growing population in the cities need water to meet their daily needs. Climate change is the irreversible phenomena and is affecting the natural water balance i.e., rainfall, droughts, temperature etc. which in turn is affecting the cities resources of water reserve. Proper water management in its physical form is not being implemented in the study area and it needs urgent attention for sustainable future development. Therefore, the govt authorities should take action and play role in backing up the stakeholders by providing the adequate resources, timely trainings, record monitoring for its efficient working. Regular monitoring, corrective improvements of existing measures with strengthened implementation of current practices on field is needed for the effective outcome of the management system.

Various stakeholder involvement can help in the identification of different perspectives, characteristics and alternative plans on the ongoing policy and management that require the immediate attention for the efficient water management process and service delivery.

This research identifies that the current system is working but there is still room for improved and advanced methods for efficient stormwater management and to meet the cities growing water demand. Additional inquiries should be directed to check the coordination of the organization for SWM in case of emergency. This study has suggested that the advanced methods and techniques are need of the hour for improved service delivery and sustainable future.

Major indicators effecting the SWM were identified from the literature and verified for the industry experts. Using Principal Component Analysis (PCA) and Mean Value Method, 25 indicators have been examined as major factor effecting the efficient SWM. The results showed the six clusters with geophysical factors, technological, social/environmental factors, urban planning factors, institutional factors and development planning factors. Moreover, the data also suggested that the existing practices are overburdening the system and an integrated water management mechanism should be generated with proper management plans, guidelines, policy implementation strategies to improve the existing situation. Moreover, the institutional awareness data also suggested that the 65% of respondents believe that the policy framework is satisfying but 35% of respondents believe that there is a chance for policy development, integrated water system can be developed with advanced techniques for efficient water management.

Stakeholders and public private partnership should be encouraged to use the latest technology and techniques to overcome the water crisis issue. Small dams' construction, pothole construction, rain gardening, treatment plant for storm sewer, separate system for domestic and storm sewer, public awareness, increased permeable surface area, construction of septic tanks, infiltration ponds, retention basins, water treatment plants, rooftop harvesting needs to be enforced in the policy implementation for all types of building units to mitigate storm over municipal water says the director of sector development department in the CDA. One respondent stated that it will be very useful if timely efforts are done by considering all the important stakeholders.

All these techniques are inclined towards the reuse of service water, resource use to its fullest form ensure the conservation of water which will ultimately help in the water management at the city level. This study also suggest that the trained professionals should be appointed, long term plans and maintain an emergency mechanism. It is also suggested that the proper monitoring of the coordination of organizations should be done to avoid the communication gap in time of emergency.

Most importantly the proper implementation is needed to overcome the loopholes in the existing system which will help in the sustainable management of SWM. Therefore, the government authorities should take charge and play an important role in backing up the SWM by providing timely workshops, physical plan implementation, monitoring and control of the system, financial resources. Keen monitoring can resurface more issues regarding awareness and management which could further improve the current practices.

Low-impact development and best management practices BMPs should also be used in accordance with the regional dynamics which works best for the best outcome. LID is an innovative urban SWM solution that depress the negative influence of water system caused by urbanization and allow to restore the natural underdeveloped state to the largest degree possible. LID is the similar idea as the water sensitive urban design (WSUD) and sustainable urban drainage system (SUDS). LID has the multiple purposes such as management of urban runoff, improved ground water recharge capacity, improved natural habitat and aesthetics of the community. LIDs are more emphasized on the non-structural practices for SWM whereas BMPs are more inclined towards the structural approach for SWM such as construction of basins, natural filters, permeable surfaces etc. The aim for LIDs and BMPs is to minimize the natural site disturbance, preservation of rainwater as a natural water resource, flattening slopes, reducing the impervious cover and maintaining the natural vegetation ultimately goal is to enhance the sustainable development.

Pakistan should impose a water emergency situation because of the growing water crisis, it should be managed at the priority. If this issue not dealt urgently, this can cause the conflict between the provinces and effect the social cohesiveness which will ultimately result in weakening the economy also a threat to its stability. Last but not the least in order to fulfil the last objective of this study of promoting sustainable SWM all the results of this analysis should be taken into consideration and steps should be taken by the national, local organizations dealing with the water management. By doing so, the current practices will be improved and the system will work in more efficient manner.

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ANNEXURE

Annexure 'A' Questionnaire for indicator's effectiveness

Sr. No:_______________

This questionnaire is for the MS Urban and regional planning research on the topic of "Sustainable Urban Stormwater Management" being conducted at NIT-NUST, Islamabad. This questionnaire is about the measurement of indicators effectiveness by the industry experts for stormwater management in urban areas. This survey will take only 5-10 minutes of your time. Be assure that all answers you provide will be kept in the strict confidentiality.

PART A- PERSONAL INFORMATION	
1. Organization Name	
2. Age (No. of years)	
3. Education (Profession)	
4. Experience (No. of years)	
5. Role in Organization/ Designation	

How much do you think the following indicators are effective for efficient Stormwater Management?

Please check the relevant box for each answer.

1. Very High 2. High 3. Moderate 4. Low 5. Very Low

PART B: Indicators (Choose One Option)	**1**	**2**	**3**	**4**	**5**
1. Catchment Area/ Basin Area					
2. Mean Slope of Sub Basin					
3. Rainfall intensity, duration and depth					
4. Impervious surface area (Regulations for Erosion & Sediment Control)					
5. Percentage of open spaces/grasslands					
6. Drainage Area and Drainage Density					
7. Frequency of natural hazards					
8. Presence of water body (Physical Channel) near the urban settlement					
9. Restriction on local vegetation & forest Removal					
10. Soil characteristics & Description (Infiltration, Permeability and Soil Type)					
11. Land use (Mix-Use), Landcover type					
12. Housing density and characteristics (Roof Type, Roof Area)					
13. Water Quality & Quantity Monitoring					
14. Ground water recharge capacity					
15. Rainwater recycling/ Reuse of Service water					

16. Monitoring SW runoff impacts					
17. Event Mean Concentration (EMC) Total Mass Pollutant divided by Total Volume Discharge					
18. Population growth (Urban Sprawl / Predictive Modelling)					
19. Developmental or Spatial Planning/ Local Land use Decision Making/ Extension of Growth Boundaries					
20. Availability of database for watershed resources/ Building codes/ Land use plan					
21. Public Participation (Teaching Outreach Programs)					
22. Environmental Planning/ Ecosystem Management Provisions					
23. Regular plan update and assessment					
24. Financial and Technical Support					
25. Innovative SWM Practices (BMPs, LID, Green Infrastructure)					

In your opinion, what other indicators are important for Urban Stormwater Management?

Annexure 'B' Questionnaire for policy framework review

Sr. No:_______

This questionnaire is for the MS Urban and regional planning research on the topic of "Sustainable Urban Stormwater Management" being conducted at NIT-NUST, Islamabad. These questions are regarding the individual perspective of the planning professionals about policy implications for stormwater management in urban areas and also measures the institutional capacity in planning SWM. This survey will take

PART A- PERSONAL INFORMATION	
6. Organization Name	
7. Age (No. of years)	
8. Education (Profession)	
9. Experience (No. of years)	
10. Role in Organization/ Designation	
11. Email Address	

Please check the relevant box for each answer.

3. Strongly Disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly Agree

PART B: EXISTING POLICY FRAMEWORK REVIEW (Choose One Option)	**1**	**2**	**3**	**4**	**5**
2. The policy framework for the stormwater management in the urban area is quite effective					
4. The policy addresses restrictions on local vegetation and forest removal					
4. The policy addresses the regulations for erosion and sediment control					
5. The policy incorporates the provisions for the preservation of open spaces					
6. The policy offers the area to floor ratio for the permeable surface					

26. The policy offers restriction of development near sensitive water body					
27. The policy incorporate the regulations which encourage the development away from the floodplains					
28. The policy encourage the availability of septic tanks for SWM in urban areas					
29. The policy address the innovative designs for the re-development /renewal of urban area					
30. The policy encourages the mix-landuse development					
31. The policy provide any building code regulations for water-efficient facilities					
32. The policy address the long-term ecosystem management					
33. The policy incorporate Innovative SWM practices (BMP/LID/Green Infrastructure) while planning the water system					

PART C: MEASURING ORGANIZATIONAL CAPACITIES	**Yes**	**No**
1. Organization has the population growth/ consensus data		
2. Organization has predicted data for future population growth boundaries		
3. Organization has the current land-use/ land-cover plan		
4. Organization regularly plans and updates the databases with new developments in urban region		
5. Organization has the updated databases for the water resources and wetlands		
6. Organization holds the capacity for spatial planning procedures		
7. Organization offers the restriction for separate discharge of stormwater and sewage water		
8. Organization hold any treatment system to treat stormwater before discharging in the physical channel		
9. Organization has any double lane channel (Fresh Water, Treated Water) for water supply in urban setup		

10. Organization holds any future plans for ground water recharge capacity		
11. Organization has the capability for hazard (pluvial flooding) mapping		
12. Organization has capacity for the rainwater recycling or reuse of service water		
13. Organization takes any measurements for water quantity and quality monitoring for stormwater runoff		
14. Organization has the capacity to monitor the stormwater runoff impacts		
15. Organization holds any training programs/ session/awareness campaigns for water related awareness for public		
16. Organization has the strong financial and technical support for storm-water management		

If any comments or Suggestions you'd like to add: