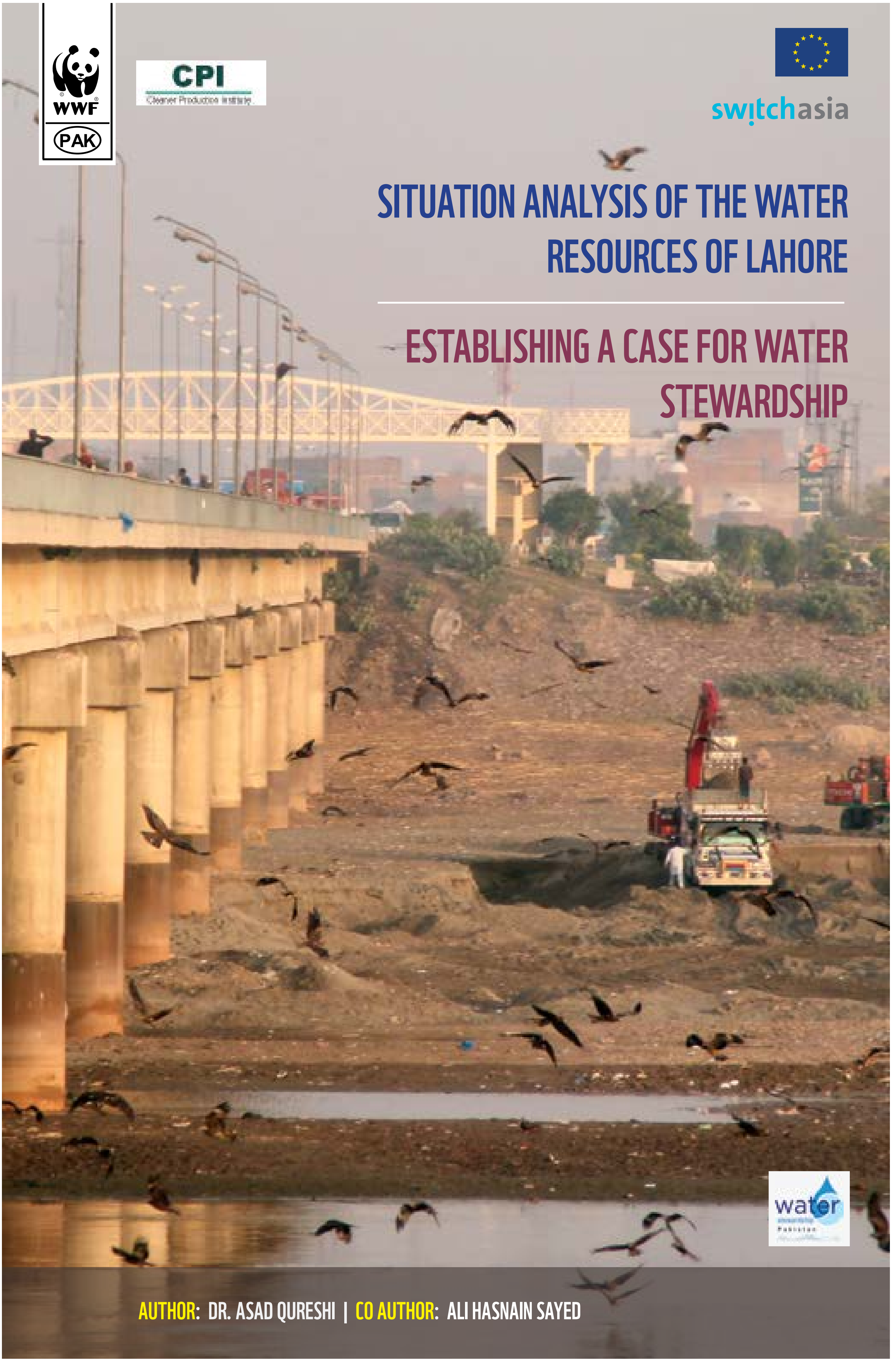

SITUATION ANALYSIS OF THE WATER RESOURCES OF LAHORE

ESTABLISHING A CASE FOR WATER STEWARDSHIP

AUTHOR: DR. ASAD QURESHI | CO AUTHOR: ALI HASNAIN SAYED

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Preface

WWF-Pakistan, in collaboration with Cleaner Production Institute (CPI) and WWF-UK, launched a project funded by European Union, entitled "City-wide Partnership for Sustainable Water Use and Water Stewardship in SMEs in Lahore, Pakistan". The project aims to contribute towards improving environmental sustainability and livelihood, and support sustainable economic growth and development in Pakistan.

An important component of the project is to conduct a study, namely "Situation Analysis of the Water Resources of Lahore: Establishing a Case for Water Stewardship". The purpose of the study is to develop a comprehensive document on the basis of available information regarding the water sector of Lahore. The report provides basic information about the water management situation and risks (physical, reputational, regulatory and institutional) of Lahore, and presents evidence base to support the identification and implementation of water stewardship activities. The scope of this study includes comprehensive water accounting of Lahore, including description and volumetric quantification of significant water resources, stores, discharges, sinks and losses. The document also identifies key present and future water risks to the domestic and business sectors at the city-level, both in terms of water quantity and quality. Identification of potential risk management and mitigation strategies is also the focus of this document.

The study was conducted by water expert, Dr. Asad Sarwar Qureshi and co-authored by Mr. Ali Hasnain Sayed, Manager Water Security and Stewardship at WWF-Pakistan.

Abbreviations and Acronym

ABBREVIATIONS AND ACRONYMS	
ADB	ASIAN DEVELOPMENT BANK
AF	ACRE FEET
BCM	BILLION CUBIC METER
BOD	BIOCHEMICAL OXYGEN DEMAND
BRBD	BAMBAWALA-RAVI-BADIAN-DEPLAPUR
COD	CHEMICAL OXYGEN DEMAND
CUMECS	CUBIC METER PER SECOND
DHA	DEFENSE HOUSING SOCIETY
EPA	ENVIRONMENTAL PROTECTION AGENCY
GOP	GOVERNMENT OF PAKISTAN
INCID	INDIAN NATIONAL COMMITTEE ON IRRIGATION AND DRAINAGE
IWASRI	INTERNATIONAL WATER LOGGING AND SALINITY RESEARCH INSTITUTE
JICA	JAPAN INTERNATIONAL COOPERATION AGENCY
LDA	LAHORE DEVELOPMENT AUTHORITY
LPCD	LITER PER CAPITA PER DAY
MCM	MILLION CUBIC METER
MPM	MOST PROBABLE NUMBER
NESPAK	NATIONAL ENGINEERING SERVICES OF PAKISTAN
NGOS	NON-GOVERNMENTAL ORGANIZATIONS
PEC	PAKISTAN ENGINEERING CONGRESS
PCRWR	PAKISTAN COUNCIL FOR RESEARCH IN WATER RESOURCES
PCSIR	PAKISTAN COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH
PHED	PUBLIC HEALTH ENGINEERING DEPARTMENT
PID	PUNJAB IRRIGATION DEPARTMENT
PINSTECH	PAKISTAN INSTITUTE OF NUCLEAR STUDIES AND TECHNOLOGY
PMD	PAKISTAN METEOROLOGICAL DEPARTMENT
POWP	PAKISTAN OPERATORS WATER PROGRAM
PPB	PARTS PER BILLION
PPM	PARTS PER MILLION
SMO	SCARP MONITORING ORGANIZATION
TSS	TOTAL SOLUBLE SALTS
USAID	UNITED STATE AGENCY FOR INTERNATIONAL DEVELOPMENT
WAPDA	WATER AND POWER DEVELOPMENT AUTHORITY
WASA	WATER AND SANITATION AGENCY
WB	WORLD BANK
WHO	WORLD HEALTH ORGANIZATION
WSP	WATER STEWARDSHIP PROJECT
WWF	WORLD WIDE FUND FOR NATURE

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The authors extend their sincere thanks to WWF-Pakistan for giving the opportunity to work on this very important topic. The support provided by WWF professionals i.e. Dr. Ejaz Ahmad and Sohail Ali Naqvi, was of immense value in shaping up and completing this study. The comprehensive reviews of drafts of this report by Dr. Conor Linstead from WWF-UK are greatly acknowledged. We are also thankful to CPI team specially Mr. Azherrudin Khan and Mr. Shafqatulllah for their support. We would like to acknowledge Saba Dar and Sarah Ephraim for proof reading the report.

The authors are also thankful to different organizations such as Punjab Irrigation Department (PID), Water and Power Development Authority (WAPDA) and Water and Sanitation Agency (WASA) for providing the required data, and sparing time for discussions on different aspects of water supply and sanitation issues of Lahore. The feedback provided by the participants of the stakeholders' workshop is also greatly appreciated. The authors are also indebted to many researchers and professionals whose findings have helped in understanding the water and sanitation problems of Lahore and to complete this report. Last but certainly not the least; the authors would like to thank Mr. Ali Hassan Habib, former Director General of WWF-Pakistan for his overall guidance and support during the course of this study.

Author's Profile

Dr. Asad Qureshi holds a PhD degree in Water Resources Management from the Wageningen University, Netherlands. He has extensive experience in agricultural and urban water resource management in South-Asia, Central Asia and Middle East. He has long been associated with projects which involve technical, economical and socio-political aspects of surface and groundwater management and impact evaluation of water user associations in Pakistan and Central Asian countries. Most recently he was a team member of the USAID funded project which developed Master Plan for the Peshawar city for 2032. He has managed projects covering irrigation management, drought management, conjunctive water management, management of salinized and waterlogged soils, groundwater management, climate change and adaptation, impact assessment of irrigation infrastructure development, water user associations and wastewater management. He also served as Country Head of IWMI offices in Pakistan, Iran and Central Asia.

Dr. Qureshi was also member of the USAID led Future Harvest Consortium to Rebuild Agriculture in Afghanistan (FHCRAA), which prepared report on "needs assessment for land and water rehabilitation in Afghanistan". He has over 120 publications (journal papers, conference papers, project reports etc.) covering all aspects of water, environment and climate change management.

Co-Author's Profile

Ali Hasnain Sayed is an engineer by education and a development practitioner by profession. He holds a master in Environment and Sustainability from Monash University, Melbourne Australia. He has gained thirteen years of professional experience both in Pakistan and abroad, gaining a extensive practice in the fields of environment, law, water-food- energy security nexus, education, policy management, sustainable development and resource management. He has dynamic professional training from around the globe. Ali has been associated with governments, bureaucracy, civil society, corporate sector and regulatory regimes on mainstreaming developmental issues at the policy level. Currently with his job at WWF – Pakistan, he is practicing and professing Policy level environmental and developmental considerations and safeguards regarding to water – food – energy security nexus.

He has been involved in trainings and academics since 2005. He was one of the founding members and instructor at Sui Northern Gas Pipelines Training Institute in 2005. He has taught at Monash University, Australia and is currently teaching as a visiting faculty at Forman Christian College (A Chartered University) and a part of the team which is setting up the environmental science department at the University.

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Conversion Table

Parameters	Conversion	
Discharge	1 m^3/sec	35.29 ft^3/sec
Discharge	1 MCM/day	1,000,000 m^3/day
Discharge	1 MCM/day	409 cusec
Volume	1 MAF	1,234 MCM
Volume	1 m^3	1,000 liters
Volume	1 m^3	35.29 ft^3
Volume	1 AF	43,560 ft^3

Executive Summary

WWF-Pakistan, in collaboration with Cleaner Production Institute (CPI) and WWF-UK has launched a European Union funded project, entitled "City-wide Partnership for Sustainable Water Use and Water Stewardship in SMEs in Lahore, Pakistan". The project aims to contribute towards improving environmental sustainability and livelihood, and support sustainable economic growth and development in Pakistan. An important component of the project was to conduct a study, namely "Situation Analysis of the Water Resources of Lahore: Establishing a Case for Water Stewardship". The scope of this study includes comprehensive water accounting for city of Lahore, including description and volumetric quantification of all significant water sources, stores, and discharges, sinks and losses. The study has collated and presented information on

- The local and regional climate change scenarios and their likely impact on water resources
- River Ravi and groundwater hydrology of the catchment of Lahore's water resources
- Water quality issues including identification of key sources of pollution
- Water abstraction, consumption, trends in water use and water balance by different sectors
- Institutional and technical operation of the municipal water and waste water infrastructure in Lahore and how it is linked to wider policy context including plans for new infrastructure
- Strategies for future management and mitigation

This report has also identified gaps in current knowledge at present and analyzed the collated information in order to identify the key water risks at the city level and problems and challenges faced by Lahore both in terms of water quantity and quality. A root cause analysis has been used within the report to pinpoint the specific factors that would need to be addressed by the city-wide partnership in order to mitigate the identified risks. The output of this study is a comprehensive report that will act as an authoritative reference document for the city-wide partnership and other interested stakeholders on the wider water context of Lahore.

In the context of global climate change, rapidly rising population and urbanization across the developing world, water scarcity is increasingly viewed as the arena in which these variables will play out with potentially disastrous future social and environmental consequences. Pakistan is one of the countries which could face severe food and water crises as we advance in the 21st century. Due to increased competition for water resources by domestic and industrial sectors, major cities in Pakistan are already facing acute shortages of water. This has resulted in groundwater over-extraction, deteriorated water quality and extensive decline of groundwater-tables. Corporate water users increasingly perceive water scarcity, quality degradation and floods as direct business risks whereas indirect regulatory and reputation risks arise when water becomes a shared resource with communities and ecosystems. Institutional factors, such as weak regulation and governance, are often identified as significant contributors to the manifestation of these risks. The Water Stewardship Project being implemented by WWF-Pakistan is contributing towards improved environmental sustainability and livelihoods as well as supporting sustainable economic growth and development in Pakistan. An integral component of the project is building a city-wide partnership consisting of SMEs, public authorities, chambers of commerce, industrial associations, supporting institutions, and multi-national corporations in order to ensure sustainable management of the city's water resources. WWF-Pakistan believes that engagement with these sectors is vital to consolidate support for the project and its aims and objectives. A core group consisting of stakeholder organizations will be formed which would serve as the initial steering group responsible for defining the terms of reference of the partnership and the decision-making approach.

This project aims at providing an authoritative reference document, for use by stakeholders and participants of this project to develop a water stewardship strategy. This report provides basic information about the physical water and institutional water management situation and risks (physical, reputational, regulatory and institutional) of Lahore, and provides a robust evidence base to support the identification and implementation of water stewardship activities.

SOURCES OF WATER

The total surface water diverted to Lahore is 6.02 million cubic metre per day (MCM/day) and is mainly used for agricultural purposes. The Bambawala-Ravi-Badian-Deplapur (BRBD) Canal mainly feeds the command area of Upper Bari Doab Canal on the Pakistan side of the Pak-India border. The Upper Bari Doab Canal irrigates command areas of Lahore Branch, Khaira distributary, Butcher Khana distributary, Main Branch Lower and other smaller channels. The remaining flow of the BRBD Canal supplements Depalpur Canal.

The Lahore aquifer is broadly viewed as a single contiguous, unconfined aquifer. Groundwater for drinking purposes is extracted from a depth of 120-200 metres (m). It is pumped for Lahore's domestic, industrial and commercial purposes. In order to deal with the vagaries of surface water supplies, more than 10,000 tube wells have been installed for agricultural purposes. The average annual rainfall of Lahore is 715 mm. However, its recharge to groundwater in urban areas is minimal due to urbanization. In general, groundwater discharge is higher than recharge, which is the main reason for the rapid depletion of groundwater in the city.

SOURCES OF POLLUTION AND QUALITY OF SURFACE WATER AND GROUNDWATER

The entire municipal waste from Lahore city is collected through a network of 14 main drains and discharged into the River Ravi without any treatment. The industrial waste is directly discharged into the canal system by 271 industrial units. These industries include textile, chemical, food processing, pulp and paper, poultry, dairy, plastic, paint, pesticides, leather, tanneries and pharmaceuticals.

The second biggest source of pollution is the Hudiara Drain. Currently, there are around 100 industries located along the Hudiara Drain, which discharge wastewater directly into the River Ravi. Most of these industries are low-polluting, with 30–35 industries, categorized as high-polluting, including textile processing units, carpet industries, tanneries, food processing units and dairies.

In general, the groundwater quality is good near the River Ravi and gradually deteriorates in the south and south-western direction. Many studies have found higher arsenic levels (> 50 parts per billion) in pumped groundwater in Lahore. The quality of shallow groundwater is generally considered poor as these tube wells are adversely effected by seepage from sewerage/drainage systems. Since WASA extracts water from deep tubewells (> 200 m), the quality of pumped groundwater is relatively good. In the surrounding areas of Lahore, arsenic concentration is much higher than the WHO standard. The highly arsenic contaminated groundwater is found at shallow water-table depths of up to 30 m and the main anthropogenic source of arsenic is air pollutants derived from kiln factories, with fertilizers being a possible secondary source. Minor amounts of sulphate (SO_4) are also derived from air pollutants and fertilizers. Household wastewater also contains SO_4 but not arsenic.

DOMESTIC WATER USE

The water supply for domestic and industrial uses mainly comes from the groundwater. WASA is responsible for water supply to most urban parts of Lahore city. In addition, Lahore Cantonment Board, Walton Cantonment Board, Defense Housing Authority, Model Town Society, Pakistan Railway and a large number of private housing schemes are responsible for supplying water to their respective areas. In rural areas of the district of Lahore, the Public Health Engineering Department (PHED) is responsible for the installation of water supply schemes.

WASA supplies drinking water to more than 6.0 million people by means of 484 tube wells. These tube wells are located in different areas and their depth varies between 150 to 200 m. Over time, water demand has increased from 180 litres per capita per day (lpcd) in 1967 to 274 lpcd in 2013. The total groundwater extraction from these 484 tubewells is about 2.2 million cubic metres per day (MCM/day). WASA tube wells run 14-18 hours per day and water is distributed from source to households through a network of 7,700 km long water supply lines and 600,000 connections. Only 78 per cent of households in the WASA serving area are connected to the piped water whereas in non-WASA areas this facility is available to 50 per cent of households. The remaining 50 per cent of households get water from hand pumps, public water stand posts or directly through groundwater pumping by using small suction pumps.

In the absence of any municipal water act or water-right law, groundwater is pumped indiscriminately by private housing schemes and industry. Private housing societies pump 0.37 MCM/day to supply water to their residents. In areas where the water supply network is not available, estimated extraction is 0.35 MCM/day. Therefore, the total groundwater extracted by private housing schemes is approximately 0.71 MCM/day. The water in rural areas of Lahore is supplied by PHED. There are 16 rural water supply schemes completed by the department. According to PHED, 13 out of these 16 schemes are non-functional due to non-payment of electricity bills. In conclusion, total domestic water use in Lahore is estimated at 3.79 MCM/day (1,384 MCM/year).

INDUSTRIAL WATER USE

There are 2,700 registered industries in Lahore, out of which 75 per cent (2025) are categorized as large scale factories, which are the main users of groundwater. The textile industry makes up 20 per cent of the total industry and uses 69 per cent of the total industrial water consumption. Textile spinning, textile processing and textile weaving are the major consumers of water. The rest is shared by the chemical sector (10 per cent), the paper industry (5 per cent), the food industry (5 per cent) and other industries (11 per cent). Others include electronic, marble, leather, steel and paper industries. The analysis of this study shows that groundwater extraction for industries is in the order of 0.92 MCM/day (335MCM/year).

COMMERCIAL AND INSTITUTIONAL WATER USE

For commercial and institutional water uses (hospitals, educational institutes, mosques, shops and restaurants, public parks, offices, bus stands, railway stations and other similar places), WASA has provided 32,500 connections. Generally, water for commercial and institutional use is considered around 20 per cent of the domestic water use. Therefore, water usage for commercial purposes for Lahore city is estimated to be 0.77 MCM/day (277 MCM/year).

AGRICULTURAL WATER USE

The total surface water diverted to Lahore for irrigation is 6.02 MCM/day. However, water available for agricultural use is only 3.0 MCM/day as the rest is lost en-route as seepage from main and distributary canals, percolation losses from watercourses and farmer fields. In addition, about10,000 tubewells are also pumping groundwater for agricultural use. The total groundwater extraction from these tubewells is estimated to be 1.70 MCM/day (623 MCM/year).

COLLECTION AND DISPOSAL OF WASTEWATER

The wastewater generation in Lahore is estimated at 231 litres per capita per day (WASA Report, 2013). The total generation of wastewater is about 8.0 MCM/day and almost all is disposed of into the River Ravi without any treatment (JICA, 2010). Some industries discharge their wastewater on land or in soakage pits which results in groundwater pollution. For the disposal of wastewater, WASA has installed 12 major disposal stations with a total discharge capacity of 5.7 MCM/day. In comparison, the wastewater generation in Faisalabad is 3.0 MCM/day, out of which about 20 per cent is treated before being discharged into water bodies (Pakistan Water Operators Partnership, POWP, 2013). The wastewater discharged into the River Ravi contains liquid and solid waste from domestic, industrial, and commercial premises, including but not limited to toilet waste, grey water (household wastewater of kitchens, bathrooms and laundries), sludge, trade wastes and gross solids. The Babu Sabu drain is the largest contributor of organic load to the River Ravi (154.7 tons/day) while Shahdara drain is the lowest contributor with only 3.27 tons/day. According to very conservative estimates, approximately 730 tons/ day of Biological Oxygen Demand load is added to the River Ravi.

DISCHARGE AND RECHARGE TO GROUNDWATER

The total groundwater discharge from the aquifer for domestic, industrial and agricultural purposes is 7.17 MCM/day (2,619 MCM/year). Except for partial reliance of the agricultural sector on surface water resources, all other sectors (i.e. domestic, industrial and institutional) are totally banking on groundwater to meet their demands. The largest share (53 per cent) of this extracted water is consumed by the domestic sector. The industrial sector consumes 13 per cent, agriculture uses 24 per cent and the remaining 10 per cent is consumed by the institutional sector.The average recharge to groundwater is 6.50 MCM/day (2,372 MCM/year). The recharge from the River Ravi is estimated to be 1,937 MCM/year, from canals 148 MCM/year, from rainfall 137 MCM/year and groundwater return flow 150 MCM/year. Despite a reduction in Ravi flows due to upstream water use by India, the main recharge (82 per cent) to groundwater is contributed by the river. The rainfall and canal system contribute only 12 per cent whereas the return flow from irrigation fields is about 6.0 per cent. This clearly shows the importance of Ravi flows in sustaining the Lahore aquifer.

The overall water balance for Lahore and its aquifer is given in the table below.

Components	Inflows	Outflows
Overall Water Balance		
River Ravi	0.00	
Canals (For Irrigation)	3.00	
Rainfall (Urban And Non-Urban)	3.46	
Contribution From River Ravi	5.31	
Contribution From Irrigation System (Main Canals And Distributary)	0.40	
Regional Groundwater Inflow	Unknown	
Runoff (From Rainfall And Other Sources) + Soil Storage		1.50
Evapotranspiration From Agricultural Crops		2.60
Wastewater Discharge To Ravi (From Domestic, Industrial And Commercial)		8.07
Total	12.17	12.17
Groundwater Balance		
Groundwater Recharge		
Recharge From Rainfall	0.38	
Return Flow From Irrigation Fields	0.41	
Recharge From River Ravi	5.31	
Contribution From Irrigation System (Main Canals And Distributary)	0.40	
Groundwater Discharge		
Groundwater Abstraction For Domestic Water Supply	3.79	
Groundwater Abstraction For Industries	0.92	
Groundwater Abstraction For Commercial And Institutions	0.76	
Groundwater Abstraction For Agriculture	1.70	
Total	6.50	7.17

Net Groundwater Balance (Discharge - Recharge) 0.67*

*This Shows That Daily Discharge From The Lahore Aquifer Is 0.67 MCM More Than The Daily Recharge. Therefore, On An Annual Basis, 247 MCM Of Groundwater Is Abstracted In Excess Of Groundwater Recharge Which Is Equivalent To 0.55 m Water Table Drop Per Year.

The difference between recharge and discharge is 0.67 MCM/day (247 MCM/year), which is equivalent to a 55cm (0.55m) per year drop in aquifer levels. In the 'business as usual' scenario, this value will increase further as the water demand will escalate owing to a rise in population. It should be noted that this water table drop is averaged over the whole Lahore district area. However, in urban parts of the city, the water table drop may be higher due to excessive pumping and insignificant recharge. In rural areas, where recharges from the irrigation system and agricultural fields are substantial, a decline in the water table may be less significant.

KEY PRESENT AND FUTURE WATER CHALLENGES DEMOGRAPHIC AND SOCIAL CHALLENGES

The population of Lahore is expected to increase to about 22 million by 2025, out of which 84 per cent will most likely be living in urban areas. This massive increase in population during the next decade is expected to put enormous pressure on the water, sanitation, energy, transport, education and health sectors. Provision of housing will be a major problem in most urban areas. Inflow of migrants from neighbouring rural areas will exert extra pressure on the economy as more people enter the job market.

GROUNDWATER AVAILABILITY AND QUALITY CHALLENGES

Due to excessive pumping, the water table depth in the central part of the city has gone below 40 m, and it is projected that by 2025 the water table depth in most areas will drop below 70m. If present trends continue, the situation will become even worse by 2040, when the water table depth in a significant part of the study area will drop below 100m or more. Extraction of water from these depths will not be technically or financially feasible. With the persistent energy crises, groundwater pumping from excessive depths will be a huge economic burden on WASA and other organizations. In addition there will be a growing risk of deterioration of groundwater quality.

LOCAL AND REGIONAL CLIMATE CHANGE

The bulk of water of the Indus is derived from snow and ice melt. The western Himalayan glaciers act as a reservoir for the Indus basin, capturing snow and rainfall and releasing it into rivers that flow into the plains. Therefore, any changes in the available water resources through climate change or other human interventions will lead to serious challenges of food security and livelihood for millions of poor. Glacial retreat and changes in precipitation patterns from anthropogenic climate change are also expected to significantly alter river basin behaviour and jeopardize hydropower generation.
Current water management practices may not be robust enough to cope with the impacts of climate change on a reliable water supply, flood risk, health, agriculture, energy and aquatic ecosystems. Improving water management will probably be the best strategy to cope with projected climate change. Public policy, so far dominated by mitigation, may benefit from a better balance between mitigation and adaptation. The development and introduction of climate adaptive measures will help reduce some of the potentially adverse climate impacts on food production and environmental degradation.

DEGRADING WATER INFRASTRUCTURE

Water availability in the Indus Basin is highly seasonal with 85 per cent of the total river flows occurring during the summer season (July-September). This makes storage critical for inter-seasonal transfer of water from surplus in the summer (kharif) season to meet shortages in winter (rabi) season to meet crop needs. It is estimated that the storage capacity of Pakistan reservoirs will be reduced by 57 per cent by the year 2025. The recent estimates suggest that to meet future water requirements, 22 BCM more of water will be needed. This will need to at least double the existing storage capacity.

The debate on small dams versus big dams in Pakistan has been going on for some time now. While small dams can be used to supply drinking water for rural communities, livestock, and production of fish, they have limited capacity to generate electricity. Large dams are considered feasible for the production of cheap energy but have serious social and environmental limitations. Therefore, Pakistan needs to introduce the concept of sustainable hydropower which essentially advocates integration of economic development, social development and environmental protection.

WATER-RELATED RISKS FOR INDUSTRY

Industries tend to face reputational, physical and regulatory risks due to water scarcity. Physical risks directly impact business activities, raw material supply, intermediate supply chain and product use in a variety of ways. The quality of water is critical in many industrial production systems, and contaminated water supply may require additional investment and operational costs for pre-treatment. Reputational risks are related to socio-cultural problems. Local conflicts can damage brand image, or in rare instances, even lead to a loss of operating license. Due to increasing pressure from civil society, companies may lose their licenses to use groundwater. These risks will increase as people become more aware of their rights to access water. Physical and reputational pressures affecting water availability and wastewater discharge can result in more stringent water policies. Water scarcity, coupled with increased concern among local communities about water withdrawals, will put pressure on local authorities and policy makers to consider water reallocations, regulations, and development of water markets. These risks can suspend permits to draw water and lead to stricter water quality standards.

WATER-RELATED RISKS FOR COMMUNITIES

It is anticipated that by 2030, WASA will have to extend its services to 9.0 million people compared to 6.0 million in 2013. This will increase the water demand to 3,200 MCM/year from a current level of 1,985 MCM/year and will require installation of 358 more tube wells by the authority, taking their total to 842. Similarly, the number of non-WASA tube wells will increase to 435 from the existing number of 240. Extensive groundwater withdrawal has formed a groundwater depression zone in the central part of the city where the water table has dropped below 40m. Continuous groundwater pumping from this depression zone is likely to induce a negative groundwater hydraulic gradient, which can accelerate the intrusion of saline groundwater from neighbouring Raiwind and Pattoki areas where groundwater is saline. This would be disastrous for local communities and industries as there is no quick and simple way available to clean the polluted aquifer.

WATER-RELATED HEALTH AND ENVIRONMENTAL RISKS

Lahore is in constant danger of health and environmental risks and ecosystem challenges due to huge discharges of untreated domestic and industrial waste. The River Ravi is considered as the most polluted river among the main rivers in Punjab. Recent water quality monitoring has shown the presence of faecal coliforms in drinking water. Presence of toxic heavy metals in irrigation water, especially downstream of the River Ravi, is also causing serious damage to animal life in surrounding areas. A direct economic impact of untreated wastewater is the loss of fishery catches, which affects incomes and has nutritional and health impacts on consumers.

The use of contaminated surface water from Ravi for irrigation and recreational purposes is also replete with serious consequences as this will have a direct impact on the ecosystem and human health. In peri-urban areas of Lahore farmers are using untreated sewage/industrial water for vegetable production and water-related diseases such as typhoid, cholera, dysentery and hepatitis are very common. Evidence also shows that, in Lahore, vegetables and fruits grown with wastewater are also prone to heavy metal contamination.

INSTITUTIONAL AND ORGANIZATIONAL CHALLENGES

Despite existing laws to regulate groundwater, its excessive pumping continues throughout the city. LDA has not notified any areas where groundwater extraction should be restricted. Keeping in view the growing crises of groundwater and its consequences on the future of water supply for Lahore, these regulatory organizations need to enhance monitoring of groundwater abstraction and identify critical areas where groundwater extraction should be restricted.

In a changing environment, we need a different type of state machinery which has the vision and capacity to meet the challenges of urbanization, industrialization, recognition of environmental needs and climate change. For this to happen, we need to invest in institutions to enable them to take on future challenges. The capacity of institutions needs to be developed to undertake systematic sets of legislation and organizational changes to solve entitlement, pricing and regulatory issues. Reforms should also aim at solving management issues as well as delivering benefits to the people. Without these chances of success will be very limited.

Lack of coordination between inter-departments has been one of the major bottlenecks in successful and effective implementation of various management strategies. The roles and responsibilities of different organizations need to be clearly defined to avoid overlapping and to ensure effective management of water resources at all levels. The appropriate institutional arrangements are also needed for the formulation and evaluation of strategic options and monitoring implementation of national policies for the public water sector.

STRATEGIES FOR FUTURE MANAGEMENT AND MITIGATION

MANAGING AQUIFER RECHARGE

For proper management of aquifer recharge, we need to define groundwater protection zones according to the safe yield of the aquifer. This can help to implement policy instruments such as a ban on boreholes and dug wells, defining the limits of withdrawal, imposing groundwater extraction fees, etc. Groundwater protection zones can be classified according to the level of vulnerability to groundwater extraction and should be protected from potentially polluting activities, viz. urbanization, solid waste dumping and chemical disposal, mining and quarrying. In Lahore, for example, central parts of the city where a groundwater depression zone is being developed should be defined as a "groundwater protection zone" and pumping should be regulated. Since groundwater plays an important role in economic development, the government needs to develop a strategy for long-term sustainability of this resource. Agriculture and industry depend heavily on groundwater, so policies dealing with agriculture and industrial development must try to incorporate the impacts of climate change on groundwater resources.

The importance of groundwater resources and the potential impacts of climate change on them should be discussed with all water users and stakeholders including government staff. All stakeholders need to be educated about the importance of groundwater to ensure sustainable management of its resources. Providing education and training to local communities about rainwater and runoff water harvesting for domestic use, agricultural use and for groundwater recharge will enhance the adaptation options to cope with current and anticipated future problems.

BALANCING DISCHARGE AND RECHARGE

To protect quantity and quality of groundwater resources, the following suggestions may be helpful:

- WASA should take measures to control demand by reducing per capita water availability by educating households to use water more wisely.
- For long-term sustainability of drinking water supplies, the possibility of supplementing groundwater supplies with surface water supplies should be explored, wherever possible. For Lahore, provision of surface water supply from the River Ravi or BRBD canal system may be considered after addressing quality concerns.
- New housing societies should also be made aware of the problem and their groundwater extraction quota should be fixed based on specified per capita demand.
- To increase recharge to groundwater, rainwater harvesting should be encouraged in all new and old housing schemes and in areas currently under WASA jurisdiction. For this purpose, special recharge zones may be developed to facilitate groundwater recharge. While doing so rights of downstream water users must be protected.
- In order to promote the culture of water conservation, a metering system should be introduced to charge water on a volumetric basis. This will help in reducing water use, in the same way as is being done for electricity, gas and other utilities.
- WASA, LDA and EPA should enforce environmental laws to restrict industries not to dispose of their waste in drains, canals or other water bodies without treatment.
- Water should be treated as an economic good and its exploitation rights be given through a proper permit system and compatible prices especially to the industrial sector. At the same time, existing environmental laws need to be implemented seriously.

PROTECTING SURFACE WATER AND GROUNDWATER QUALITY

Water quality challenges need to be addressed in an integrated manner and by adopting pollution prevention strategies. Water pollution can be reduced by eliminating contaminants at source which is the most effective way to protect water quality. The prevention of pollution at source is a cost effective solution as less money is required on waste handling, storage, treatment, remediation, and regulatory monitoring. Industrial units need to recycle wastewater generated from one process into other processes if it satisfies water quality standards.
Water quality solutions include:

- Regular monitoring of water quality. For this purpose, capacity of institutions (staff, laboratories, technologies, finances) should be enhanced.
- Water quality rules and regulations should be enforced in order to prevent the discharge of untreated effluents from industries and municipalities.
- An appropriate solid waste management system should be introduced to prevent the dumping of solid waste into water bodies and leachate generation.
- A sustainable pollution control strategy needs

to be devised in order to reduce wastewater volumes. This approach may include the segregation of wastewater streams, process modification techniques and recycling and reuse of wastewater.

- Proper education and awareness campaigns about the importance of water-quality need to be launched. Media and non-governmental organizations (NGOs) can play a vital role in this aspect.
- An integrated water resource management approach should be adopted by involving all stakeholders for the protection of water quality. The linkage between research and development needs to be strengthened.
- Intelligentsia/academia should be encouraged to conduct research on finding indigenous low-cost water treatment solutions for the industry.

MANAGEMENT STRATEGIES FOR INDUSTRIES

Despite looming water challenges, businesses and investors are largely unaware of water-related risks and do little to develop strategies to cope with this challenge in future. Keeping that in perspective, WWF-Pakistan with the support of the European Union is implementing a project City Wide Partnership for Sustainable Water Use and Water Stewardship in SME's of Lahore – Pakistan. The project is geared towards water cooperation by facilitating effective water resource management in SMEs of Lahore and adjoining areas thus trying to formulate a mechanism of water cooperation between the public and private sector to become active stewards of water by taking into consideration future supply chain risks.

This project is expected to contribute to improving environmental sustainability and livelihoods and supporting sustainable economic growth and development in Pakistan. It will do so by supporting an improvement in the sustainability of production and consumption practices, with a particular focus on water use and water management in high water using, cross sectoral, urban based SMEs. The underlying cause behind the effort are the dynamics within water resources management which are changing with the entry of the private sector as corporate water users increasingly perceive water scarcity, quality degradation, competitive use by other sectors and flooding as direct business risks. The past few years has seen a radical increase in media and corporate recognition of the importance of water for society, economy and ecology, largely due to the increased understanding of the pressures and risks associated with Pakistan's freshwater resources. Corporate risk related to water is therefore an emerging issue and is likely to become more significant into the 21st century, due to increasing water stress internationally, investor perceptions and public awareness.

The following actions may help in the management and mitigation of water-related industrial risks in the context of Pakistan.

- Companies need to be conscious of their water footprints (i.e. water use and wastewater discharge) throughout their entire value chain, including suppliers and product use.
- Companies might assess their physical, reputational and regulatory risks and seek to align the evaluation with the company's energy and climate risk assessment.
- Engage key stakeholders (e.g. communities, NGOs, government bodies, suppliers and employees) as part of risk assessment, long-term planning and implementation activities.
- Industries can monitor their water resources and continue to develop strategies to maintain their water reserves and adopt management practices geared towards creating efficiency per unit of production.
- Industries can invest in treating wastewater at source and reuse it. This will build up their reputation in society and help in avoiding future water risks.
- To promote water conservation in the industrial sector, attention must be given to water intensive sectors such as textile processing, paper and pulp, leather and tanneries, sugar etc. because this is by far the most water consuming industries in the region. Freshwater use is in the textile sector can be reduced by 30-50 per cent by modernizing the processing sector, which accounts for 72 per cent of the total water used in textiles. Water conservation is also important to address environmental concerns of global textile buyers.

1.0 INTRODUCTION

World Wide Fund for Nature-Pakistan's (WWF-Pakistan) project City-wide Partnership for Sustainable Water Use and Water Stewardship in SMEs of Lahore, Pakistan (also known as the Water Stewardship Project (WSP) is intended to increase water cooperation by facilitating effective water resource management in Small and Medium enterprises (SMEs) of Lahore and adjoining areas and formulating a mechanism of water cooperation with the private sector to become active stewards of water.

Corporate water users increasingly perceive water scarcity, quality degradation and floods as direct business risks whereas indirect regulatory and reputation risks arise when water becomes a shared resource with communities and ecosystems. Institutional factors, such as weak regulation and governance, are often identified as significant contributors to the manifestation of these risks. In response, businesses are partnering with non-governmental organizations (NGOs), donors and governments in collective action to attempt to mitigate shared water risks. The project contributes towards improved environmental sustainability and livelihoods, and supports sustainable economic growth and development in Pakistan. It aims to support an improvement in sustainable production and consumption practices, with a focus on water use and water management in high water using, cross-sectoral, urban-based SMEs.

The objective of this study is to provide an authoritative reference document, for use by stakeholders and participants of the Water Stewardship Pakistan project on which future water stewardship decisions can be taken. The study collates key available information of the water resources of Lahore and also describes the physical water and institutional water management situation and risks (physical, reputational and regulatory risks) of the city. It also provides a robust evidence base to support the identification and implementation of water stewardship activities. This information aims to serve as the basis for future planning and involvement of water users and other stakeholders in the process of water stewardship.

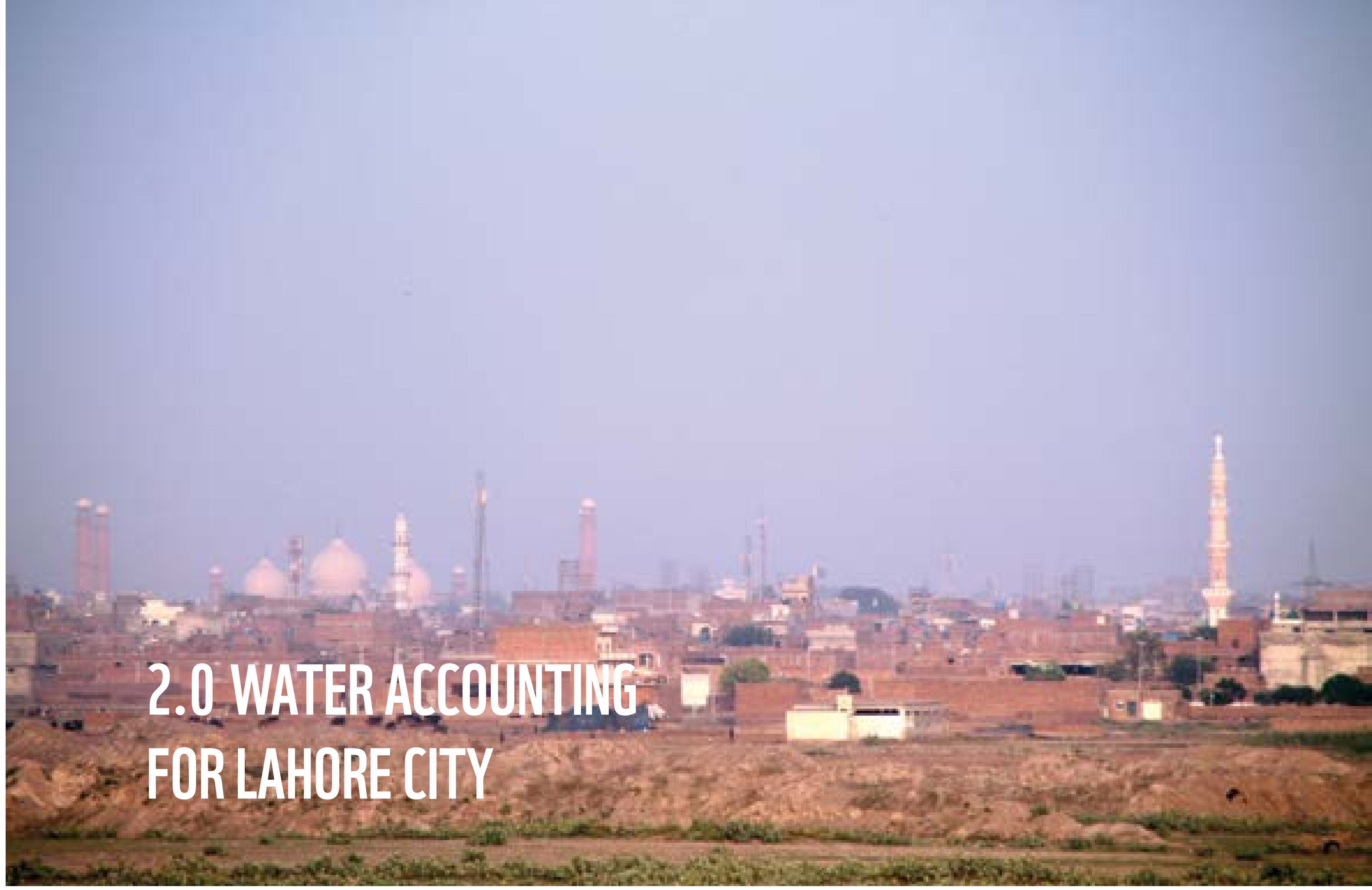
This study essentially has three tiers.

. The first is the acquisition of data from different sources;
. Second is the analysis of data to determine existing trends of water uses and water balance for the city of Lahore, potential risks due to

exacerbation of population, degradation of infrastructure, institutional incapacities or inefficiencies and other socio-economic factors; and

. Third is the evaluation of future scenarios and risk identification with regards to water availability, anticipated problems and possible mitigation measures.

The analysis provides the foundation for a broader view of water availability, water management issues of the domestic and business community, potential risks and the institutional water management situation. It is envisaged that the information provided in this report will be of great value for use by policymakers, stakeholders and participants of Water Stewardship Project.



2.0 WATER ACCOUNTING FOR LAHORE CITY

2.1 LOCATION AND DEMOGRAPHY

Lahore is located between 31° 32° 59" north latitude and 74° 20°37" east longitudes. The city is bound on the north and west by the district of Sheikhupura , on the east by the Wagah Border with India, and on the south by the district of Kasur . The River Ravi flows on the northern side of Lahore. The general altitude of Lahore is 208 to 213 metres (m) above mean sea level. The total area of Lahore is 1,772 km^2 which lies almost totally in Bari Doab Canal and River Ravi. The city has generally flat slopes towards the south and south-west at an average gradient of 1:30000. Lahore city covers a total land area of 404 km^2 and is still growing.

The total population of the district of Lahore was 6.3 million in 1998, which has increased to about 8.9 million in 2011. The recent estimate of the population is over 10 million, with a population density of about 7,000 persons per square kilometre. Lahore is ranked 42 in the most populated urban areas in the world ranking and is an important historical centre of South Asia. It is also estimated that about 82 per cent of this population lives in the urban areas and the remaining 18 per cent resides in rural areas. Migration of people from the country side in search of jobs and education has mainly contributed to the sharp increase in population.

Figure 1 shows Lahore city with its main roads and housing schemes.

2.2 SOURCES OF WATER

2.2.1 SURFACE WATER RESOURCES

Historically, the water supply to Lahore city was provided by the River Ravi. The city's first 'modern' clean drinking water system was installed by the British in 1876. This system transported water from the River Ravi to the tank of Lakhpat Rai (also known as Pani Wala Talab), which has the capacity of 250 m^3. However, over time these facilities were abandoned and no further arrangements were made to continue feeding residents of Lahore with surface water. In addition to management neglect, loss of water use rights from Ravi as a result of the Indus Water Treaty was the biggest setback for Lahore. The persistent decrease in Ravi flows over time not only made it impossible to divert water for the city needs but also drastically reduced the recharge to the underground aquifer.

In the Indus Water Treaty of 1960, water rights of three eastern rivers (Ravi, Beas and Sutlej) were given to India. The Indus River and its tributaries (Indus Basin), on an average, bring 190 billion cubic metres (BCM) of water annually. This includes 179 BCM from the three western rivers

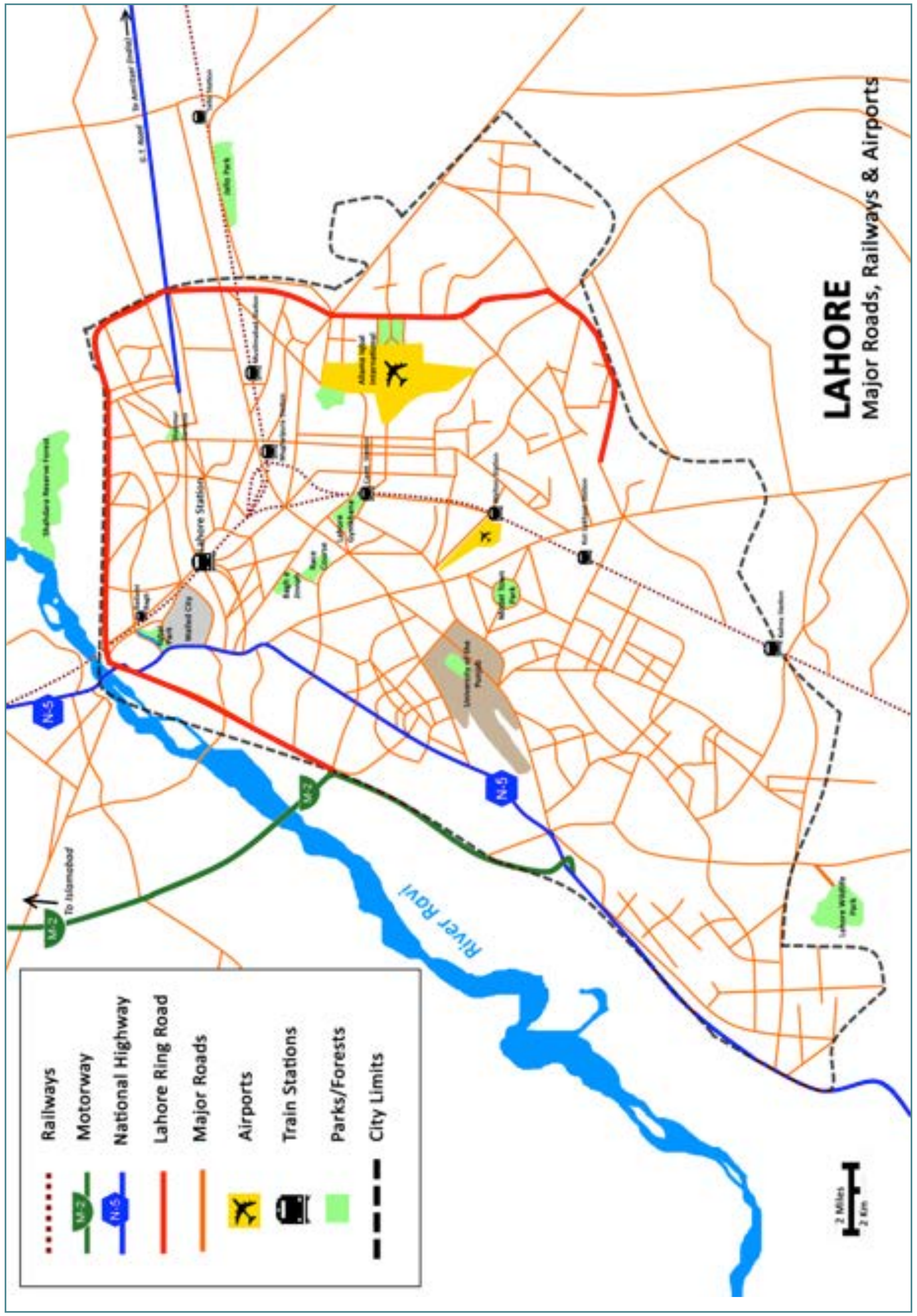


Figure 1: Map of Lahore with boundaries (Retrieved and updated, WASA master plan of existing sewerage)

(Indus, Chenab and Jhelum) whereas the three eastern rivers contribute only 11 BCM. Most of this, about 129 BCM, is diverted for irrigation. About 50 BCM flows to the sea and about 11 BCM are system losses, which include evaporation, seepage and spills during floods. Currently, 93 per cent of the total water withdrawal (176.7 BCM) is allocated for the agricultural sector, 4 per cent (7.6 BCM) is for domestic use and the remaining 3 per cent (5.7 BCM) is for industrial use (Bakshi and Trivedi, 2011). The demand for municipal and industrial supplies in urban areas is expected to increase to 14.0 BCM by the year 2025. As a result, irrigation water will face increasing competition from the municipal and industrial sectors (USAID, 2009).

The flow in the River Ravi mainly comes from Marala-Ravi Link Canal and five flash streams which flow into Ravi within Pakistan. These include Ujh, Bein, Basantar, Degh and Hudiara with likely maximum discharges of 605, 311, 216, 242, 26 MCM/day, respectively (Nazir and Akram, 2000). In recent years, the average flow of Ravi in Pakistan has declined due to climate change and the construction of irrigation and hydropower diversions in India. The recently constructed Thein Dam by India in 2000 has greatly impacted the flood hydrology which has reduced the groundwater recharge significantly in and around the city of Lahore.

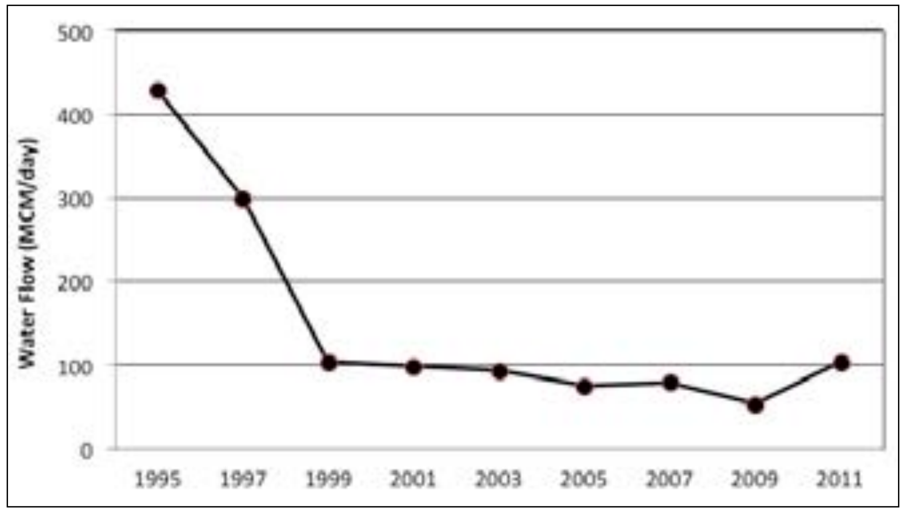


Figure 2: History of Water Flow in the River Ravi Source: Basharat and Rizvi, PEC, 2011)

The average flow in Ravi during 1922-1961 was 1,300 MCM/day which was reduced to 800 MCM/day between 1985 and 1995 and further declined to its lowest level of 175 MCM/day from 2000 to 2009. However, peak flows rising to more than 260 MCM/day were also observed during this period (Basharat and Rizvi, 2011). During the 2010 monsoon, a maximum discharge of only 75-100 MCM/day was reported in the River Ravi in spite of heavy monsoon rains on a regional scale (Khalid et al., 2013). This means that in future floods passing along Lahore will either be from the Ravi's tributaries downstream of Thein Dam or a flood which exceeds the available capacity of the Thein reservoir. Therefore, except flood events from during an extraordinary rainy season, no regular flows of appreciable amount are expected except that of Marala Ravi (MR) link releases from Marala Barrage.

The variation in the River Ravi inflow during the last two decades is shown in Figure 2. The dramatic decrease in Ravi flows after 1999 is due to the operation of Thein Dam in India which has affected the flow regime of Ravi.

The areas upstream as well as downstream of Lahore are bounded by the River Ravi in the northwest and the Sukh Beas drainage channel in the south. Therefore Lahore city is a part of the Bari Doab – (interfluvial lands) between the Ravi in the northwest and the Sutlej River to the south. The area is underlain by a significant thickness of alluvial deposits, up to 400 ms in depth. The main recharge to Lahore's aquifer comes from the River Ravi on the northwest and Bambawala-Ravi-Badian-Deplapur (BRBD) link canal (fed by Upper Chenab Canal off-taking from Marala Barrage) on the east. The area is commanded jointly by Lahore Branch, Khaira and Bucther khana distributaries and Main Branch Lower, all of them off-taking from BRBD link canal (Figure 3). Most storm water and drainage water is discharged in the Beas drainage channel on the south and the Ravi in the west.

Surface water rights in Pakistan are largely committed for agricultural uses. Big cities in Pakistan (including Lahore) do not have any direct surface water rights and are largely dependent on groundwater to meet their demands. Consequently, groundwater resources are widely abused resulting in increased water table depths and deterioration in quality. If not properly managed, this precious resource may become out of reach due to inflated pumping costs or unusable due to degraded quality.

2.2.2 GROUNDWATER RESOURCES

The Lahore aquifer is composed of unconsolidated alluvial soil of up to 400 m in thickness. Clay and

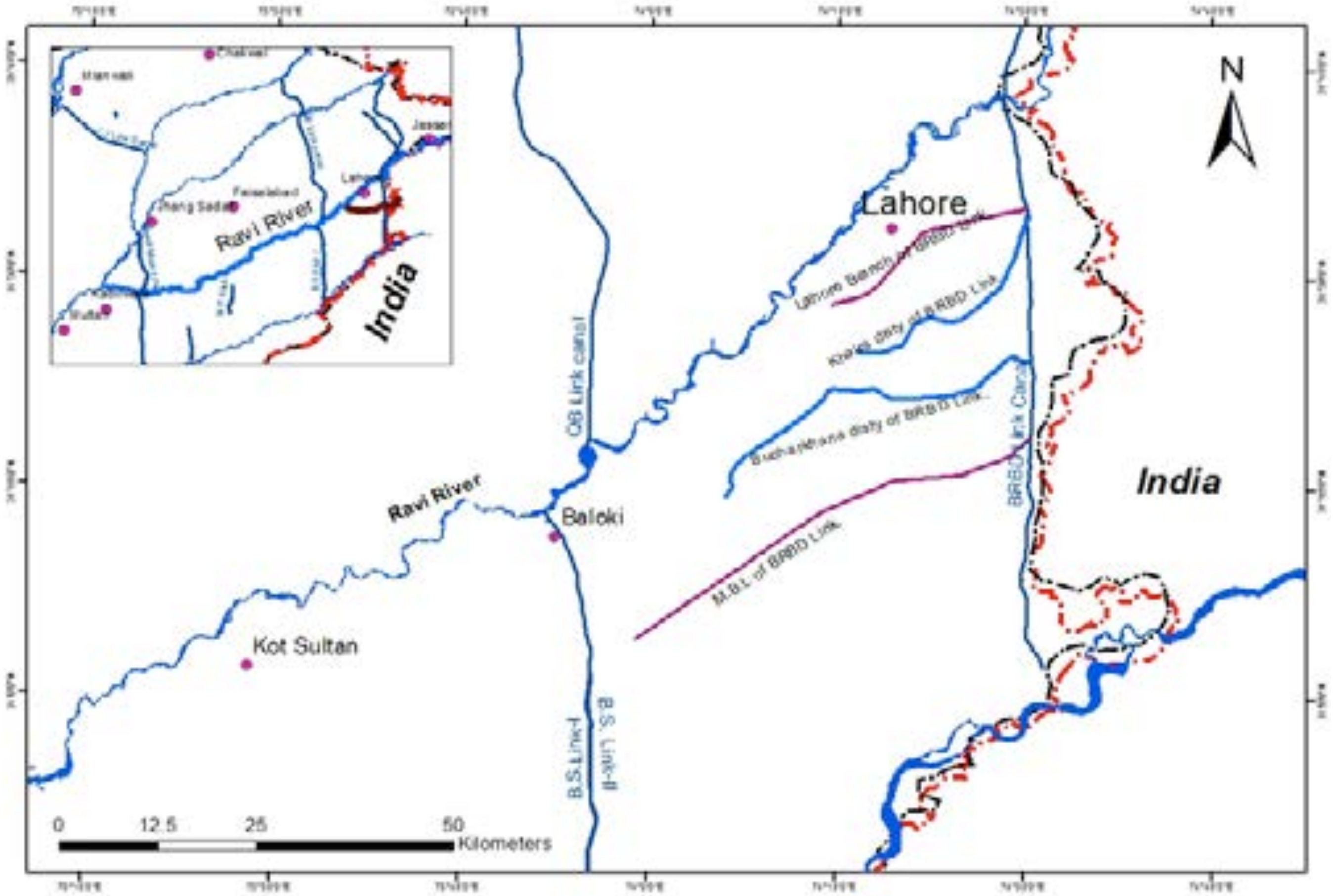


Figure 3: Canal system feeding Lahore city

silt formations occur as discontinuous layers with limited lateral extent and thickness of generally less than 5 m. At present the maximum observed depth of the water table in Lahore city is 40 m and in the area of Raiwind is about 12 m (Figure 1) (Basharat and Rizvi, 2011). The aquifer under and around Lahore city is about 400 m deep with high transmission of about 2,100 m^2/day (assuming 80 m thickness contributing to groundwater flow). The aquifer extends from Lahore to the Piedmont area of foothills in Jammu and Kashmir in a north eastern direction (about 100 km). This is also the direction of rivers and groundwater flow in general, whereas in the downstream direction it extends to the Arabian Sea at a distance of about 1,000 km (WAPDA, 1980).

On a regional scale, groundwater flow occupies the same flow direction as the canal irrigation network and is mostly parallel to the river network i.e. in a northeast to southwest direction. Irrigation canals are unlined and poor maintenance is a general problem. The alluvial sediments that comprise the aquifer exhibit considerable heterogeneity both laterally and vertically. Despite this, it is broadly viewed that the aquifer behaves as a single contiguous, unconfined aquifer. The specific yield varies from 22 to 35 per cent, the average being 26.3 per cent. Groundwater exists in 10 to 30 m depths below ground level. Water for drinking purposes is extracted from a depth of 120 to 200 m (NESPAK, 1988). However due to local variations in natural surface elevations and also in discharge and recharge patterns, the depth to water table varies considerably in the area.

Rapid population growth, intensive migration of people to Lahore and the establishment of several industries has increased water demand by manifolds. Mushrooming private housing socities, particularly on the periphry of cities, alongwith industrial activities has caused two fold stress on the underlying groundwater reservoir, i.e. increased groundwater pumping for domestic and industrial activities and reduced groundwater recharge from agricultural fields and rainfall due to most urban areas being covered by buildings and roads.

In the absence of any municipal water act or water-right law, groundwater is pumped indiscriminately by private housing schemes and industry. This unregulated and uncontrolled groundwater extraction causes a drastic lowering of the groundwater table depth in and around Lahore. In 1960, the groundwater table depth was 4.6 m. The extensive use of groundwater has led to the lowering of the water table by about half a metre per year during the last 30 years. In 1987, the depth of the water table ranged from 8 to 20 m, which has lowered to 51 m in 2011 (Khalid et al., 2013). The increasing depth of the groundwater table in different parts of Lahore is replete with serious consequences. Increase in the hydraulic gradients on the sides of the cone of depression can expedite the movement of saline water from surrounding areas to the aquifer.

2.2.3 SOURCES OF POLLUTION, SURFACE WATER AND GROUNDWATER QUALITY

SURFACE WATER QUALITY

In Pakistani Punjab, untreated municipal wastewater and industrial effluents are disposed of in the entire reach of the River Ravi (from Jassar to Kabirwala) (Figure 4). During extreme low flow periods (winter season); the river acts as a domestic wastewater and industrial effluent carrier from Kala Shah Kaku, Lahore Shiekhupura Road, Kot Lakhpat Industrial Estate and Multan Road. The sewerage and industrial waste of the entire city of Lahore and its adjoining towns like Shahdara is collected by 14 drains and discharged into the River Ravi without any treatment.

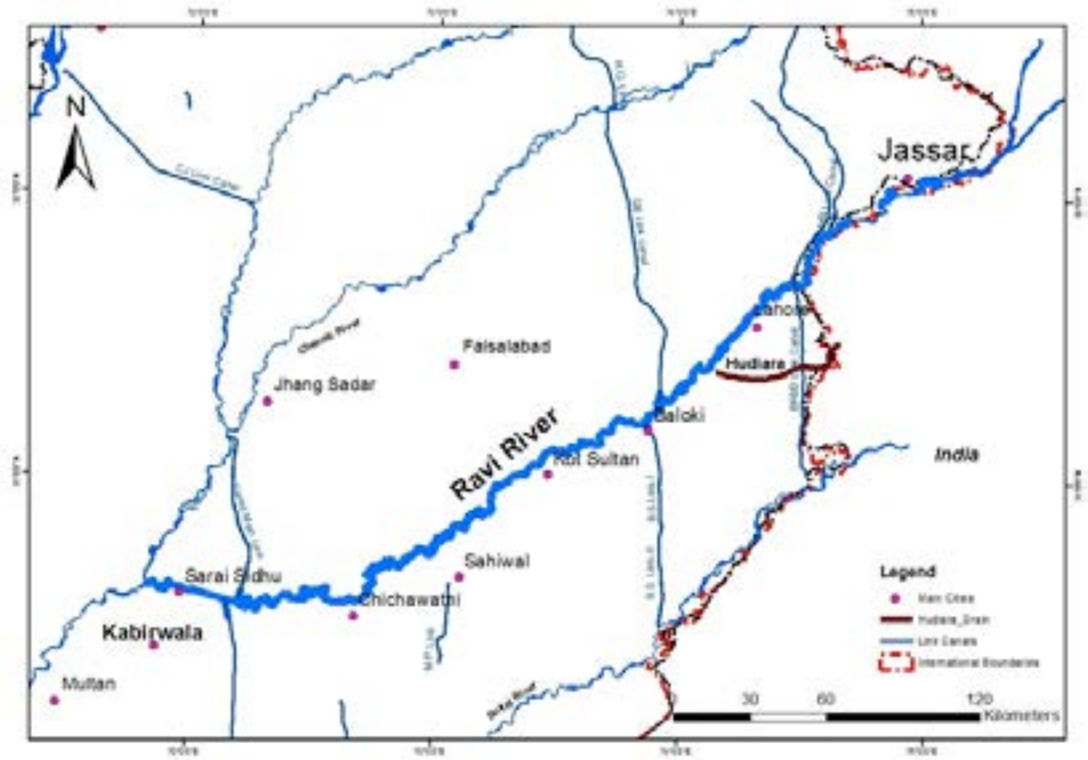


Figure 4: The Flow Path of River Ravi in Pakistan (entry point of Hudiara Drain is also shown)

According to the Punjab Irrigation Department (PID, 2008), about 8 MCM/day of untreated municipal waste from six municipal units is discharged into surface water bodies. Another 0.70 MCM/day of industrial waste is directly discharged into the canal system by 271 industrial units. These industries include textile, chemical, food processing, pulp and paper processing, poultry, dairy, plastics, paint, pesticides, leather, tanneries and pharmaceuticals. The effluents from these industries ultimately pollute the irrigation system and pollution spreads all over the canal commanded areas .

The quantity of wastewater is subject to seasonal variation and mostly depends upon the weather conditions. Lahore's 14 wastewater carrying drains contribute more than 56 per cent of Ravi's total pollutants (Malik, 2012) whereas the rest comes from other sources such as the local industry, direct outlets to Ravi and small housing schemes. Small workshops located around the Lahore canal also discharge their wastewater into the canal without any treatment (Aftab et al., 2011).

The second biggest source of pollution is the Hudiara Drain, which is a natural storm water channel. It originates from Batala in Gurdaspur district, India, and after covering a distance of about 45 km in Indian Punjab it enters into Pakistan near the village of Lallu. After flowing for nearly 58 km inside Pakistan, it joins the River Ravi near Mohlanwal village (WWF, 2007). Until 1980, the Hudiara Drain collected storm water for irrigation and domestic purposes and finally drained into the Ravi adding to the river's aquatic health. However, this is no longer the case. All along its route in India and Pakistan wastewater, sewage, and industrial pollutants are discharged into the drain without proper prior treatment. In India, Amritsar and many smaller towns and villages besides industries, discharge untreated wastewater into this drain. In Pakistan,

Pesticides from packing factories, zinc-cyanide from electro plating in pipe factories, detergents discharged from a chemical lab, gasoline from a pipe line break, alkaline paints from the drain of a paint manufacturing plants, fluid chicken manure from a poultry farm, leakage of wash water with caustic soda, dairy waste, drainage from a solid waste disposal operation are the major contributors in polluting the freshwater resource. These wastes deteriorate the quality of water and productivity of soil. Metals commonly find their way into water-ways after they have been disposed off in various industrial processes. Chromium is a major agent in tanneries, nickel is used in oil/ghee processing as catalytic agent, lead is used to seal food cans, and mercury is also used in various chemical industries. These heavy metals contaminate freshwater stream and cause numerous ailments of very serious nature.

both municipal and industrial discharge from a significant part of Lahore is carried to Hudiara Drain, mainly through Minhala Drain, Charrar Drain, Ferozepur Road Drain and Sattu Katla Drain. Consequently, Hudiara Drain has now turned into a major wastewater carrier.

Currently, there are around 100 industrial units located along the Hudiara Drain which discharge wastewater directly in it. Most of these are low-polluting, with 30–35 of them categorized as high-polluting, including textile processing units, carpet industries, tanneries, food processing units and dairies. Before draining into the River Ravi another drain, the Sattu Katla, discharges its effluent into the Hudiara Drain. Discharge of Hudiara Drain at the outlet structure of the River Ravi varies significantly. However, on an average it is estimated to be 1.3 MCM/day (Ejaz et al., 2010) but not all of the flow reaches the River Ravi as a significant proportion is intercepted by farmers to irrigate crops, especially vegetables.

In 2001, WWF-Pakistan tested grab samples collected from Hudiara Drain and its major tributaries to characterize wastewater entering into the River Ravi. As a result, significant reductions of Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) along the stretches of Hudiara Drain between major tributaries (Table 1) were found. This showed that Hudiara Drain acts as a long facultative (anaerobic) pond resulting in substantial biological treatment of wastewater.

Little information is available about the water quality of the River Ravi. The information available from the Punjab Irrigation Department (2008) and Japan Irrigation Cooperation Agency (JICA) (2010) reveals that BOD and COD values are within the WHO limits, however bacterial contamination is higher than WHO standards (Table 2).

Table 1: Characteristics of Hudiara Drain and its Tributaries (Source: WWF, 2001)

DRAIN AND LOCATION	SOURCE	PH	BOD (MG/L)	COD (MG/L)	TSS (MG/L)	CR (MG/L)	CU (MG/L)
HUDIARA DRAIN							
U/S OF BRB CANAL AQUA-DUCT	(A)	7.4	187	400	184	0.07	0.31
U/S OF THE CHARRAR DRAIN OUTFALL	(A)	8.0	33	107	142	0.03	0.13
D/S OF FEROZEPUR ROAD BRIDGE	(A)	7.5	128	286	196	0.13	0.07
U/S OF SATTUKATLA DRAIN OUTFALL	(A)	7.4	68	191	118	0.06	0.29
OUTFALL STRUCTURE	(A)	7.3	71	193	106	0.07	0.10
DOWNSTREAM END							
MINIMUM (04. 2000 - 03.2001)	(C)	7.0	42	96	30	< 0.1	0.02
MAXIMUM (04. 2000 - 03.2001)	(C)	9.5	225	580	800	0.3	0.28
MAJOR TRIBUTARIES							
CHARRAR DRAIN (D/S END)	(A)	7.6	414	923	239	0.10	0.13
FEROZEPUR ROAD DRAIN (D/S END)	(A)	7.7	302	707	512	0.19	0.16
SATTUKATLA DRAIN (D/S END)	(A)	7.5	113	308	127	0.08	0.38

(A) GRAB SAMPLING AND TESTING UNDER THIS STUDY (NOVEMBER - 2006)
(C) GRAB SAMPLING AND TESTING BY WWF-P (APRIL 2000 - MARCH 2001)

Table 2: Water Quality of River Ravi at the Ravi Syphon (Source: PID 2008, JICA 2010)

SOURCE	BOD MG/L	COD MG/L	TSS MG/L	MN MG/L	CU MG/L	AS µg/l	FE mg/l	FECAL COLI. MPN/100 ML[5]	TOTAL COLI. MPN/100 ML[5]
WHO LIMITS	80	150	200	0.50	2.0	1000	8	NIL	NIL
PID (2008)	2.5	8	90	0.07	0.06	-	0.94	-	-
JICA (2010)	3.2	7	81	BDL	-	3.42	1.86	≥ 240	≥ 240

BOD = Biochemical Oxygen Demand
COD = Chemical Oxygen Demand
TSS = Total Soluble Salts
Fecal Coliform is measured in Most Probable Number (MPN)/100 ml

The presence of heavy metals including Arsenic (As) is also mostly within safe limits. Data in Table 2 is based on samples taken from the Ravi Syphon, which is not located close to any urban area of Lahore city and where the possibility of domestic inflow and industrial wastewater is very low. In the downstream parts of the river where large amount of wastewater is discharged, the water quality is expected to be different. However, no such data is available.

GROUNDWATER QUALITY

In general the groundwater quality is good near the River Ravi and gradually deteriorates in the south and southwestern direction. The groundwater of Lahore city is recharged from the River Ravi, the irrigation system and rainfall. Regular groundwater water quality monitoring is carried out by Water and Sanitation Agency (WASA), Punjab Irrigation Department (PID), Pakistan Council of Research in Water Resources (PCRWR) and the Environmental Protection Agency (EPA).
According to the PCRWR report of 2009, groundwater from 183 tube wells of Lahore city was found to be contaminated with arsenic. In 2010, analysis conducted by the University of Engineering and
Technology revealed that out of 392 tested tube-wells, 168 have high concentration (above 50 ppb) of arsenic, while in 82 others the level of this poisonous chemical was between 10 ppb and 50 ppb.

The WHO standard for arsenic contamination is 10 parts per billion (ppb) whereas WASA considers 50 ppb a safe limit. The study of water quality conducted by the Pakistan Institute of Nuclear Science and Technology (PINSTECH) also indicated the presence of toxic metals in water. Arsenic was detected in most of the samples with the concentration range of 4-129 ppb. Hence, the possibility exists that the provincial metropolis will ace serious problems relating to the quantity and quality of groundwater in the near future.
Groundwater quality monitoring carried out by WASA (2011) shows that most of the parameters (except arsenic) are within acceptable limits of WHO (see Table 3). The quality of shallow groundwater is generally considered to be poor as these tube wells are impacted by seepage from sewerage/drainage systems. Since WASA extracts water from deep tube wells (> 200 m), the quality of pumped groundwater is relatively good (WASA Report, 2013). The groundwater quality of representative WASA tube wells at sub-division levels for the year 2011 is shown in Table 3.

In the surrounding areas of Lahore, arsenic concentration is much higher than the WHO standard (10 ppb). The highly arsenic contaminated groundwater (up to 2,400 ppb) is found in shallow water table depths of up to 30 m (Farooqi et al., 2007). The main anthropogenic source of arsenic is air pollutants derived from kiln factories, with fertilizers a possible secondary source. Minor amounts of sulphate (SO_4) are also derived from air pollutants and fertilizers. Household wastewater also contains SO_4 but not arsenic (Farooqi et al., 2007).

The PCRWR (2009) study also found that about 40 per cent of water samples had faecal coliform and arsenic concentrations higher than the WHO standard. Based on the monitoring of 204 WASA tube wells in 2008, EPA found 59 per cent unfit for drinking water (JICA, 2010). There is a difference in the definitions of WASA and EPA in declaring a tube well 'unfit' for irrigation. The EPA declares water unfit for irrigation on the basis of faecal coliform whereas WASA uses total coliform as the criteria. Due to these differences, the number of areas where drinking water is considered 'unfit' for irrigation by WASA and EPA may vary.

The shallow aquifer of Lahore city has become highly polluted due tointrusion of sewage water and the contamination level of faecal E. coli has crossed the recommended limits of WHO (Ahmad et al., 2012).
The deep aquifer is still safe from sewage water intrusion. Lahore canal is also polluted and recharges contaminated water into the shallow aquifer.

Faecal contamination in piped water is unsatisfactory in more than 50 per cent of household connections in Lahore before the monsoon season and this percentage increases to 75 per cent after the monsoon (Hyder et al., 2009). Various reasons for this bacteriological contamination include old and rusted water mains, water supply pipes close to sewer lines, intermittent water supply system, clogging of sewer lines and inadequate storm drainage.

Table 3: Groundwater Quality of WASA Tubewells for the Year 2011 (Source: WASA, 2011)

SR. NO.	LOCATION OF T/W	SUB DIVISION	PH	TURBIDITY NTU	TDS mg/l	Ca mg/l	Mg mg/l	SO_4 mg/l
			8.5	5	1000	250	0.5	250
1	Jahangir park	K. Nagar	8.7	0.5	481	52	23.5	7.1
2	Roza abu ishaq	Mozang	8	1.4	849	85	45	8.5
3	Taxali main road	City	7.4	0.49	185	38.4	15.8	7.13
4	Darbar panj pir	Mughalpura	8	1.47	449	27.2	16.8	4.5
5	Basti saiden shah	Shimla hill	8.5	0.14	161	32	17.8	5.6
6	Rustam park	Samnabad	8	0.57	462	37.6	24.4	5.1
7	Main bazar, ichra	Ichra	8.2	0.18	556	36.8	24	7.4
8	Awan chowk	Indus. Area	7.9	1.16	738	36	22.5	6.5
9	Out fall road	Ravi road	8.6	0	210	21.6	12	6.3
10	Latif chowk	Shahdara	7.7	0.94	436	62.4	19.2	9.8
11	H-block, ground	Gulberg	8.7	0.1	552	40	31.2	11.2
12	Mohallah singh saba	B. Pura	8.2	1.6	360	20	16	8.2
13	T/w #4, khokhar road	Data nagar	8.5	1.12	274	45	19	6.6
14	Jahanzaib block A.I.T	A.I.T	8.4	0.83	300	20.8	13.4	6.5
15	Gujjarpura	Misri shah	8.2	1.66	400	40	25	10.5
16	T/w # 3, well centre	Shadbagh	8.5	0.21	200	30.4	13.9	9.5
17	Mian meer darbar	Mustafabad	8.4	0.37	396	12	8	5.2
18	Bahar colony	Township	8.6	0.82	1487	39.2	28.3	9.1
19	Nasir bagh	Anarkali	7.3	2.24	582	104	67.2	11.3
20	Matches factory	Farkhabad	8.1	0.77	343	46.4	21.1	11.2
21	Ghaziabad bus stop	Tajpura	8.2	0.89	409	20	16	7.5
22	Awan town	Sabzazar	8.3	0.06	256	20.8	13	Nil
23	Maryam colony	Green town	7.8	1.75	806	36	33.6	8.5
24	A-block, johar town	Johar town	8.1	0.58	654	41	25	6.6

2.2.4 RAINFALL

The climate of Lahore can be described as semi-arid with a hot summer and cool winter. There are three main seasons in Lahore i.e. summer, winter and the rainy season (monsoon). During the summer Lahore experiences heat waves and sultry weather, when the mercury reaches up to 48° Celsius. The months of July and August experience the heaviest rainfall due to the monsoon. The month of December, January and February are the coldest months when the temperature falls to 1° Celsius and below. Average relative humidity is at a minimum in the month of May (32 per cent) which may reach up to 72 per cent during the month of December. Wind speed varies between 22km per day during winter and 124km per day during summer. However, on average, 60 per cent of the days of the year are calm and wind speed is negligible (Basharat and Rizvi, 2010). The average annual rainfall of Lahore is 715 mm (1971-2000). The monthly variation in the rainfall in Lahore city is given in Figure 5.

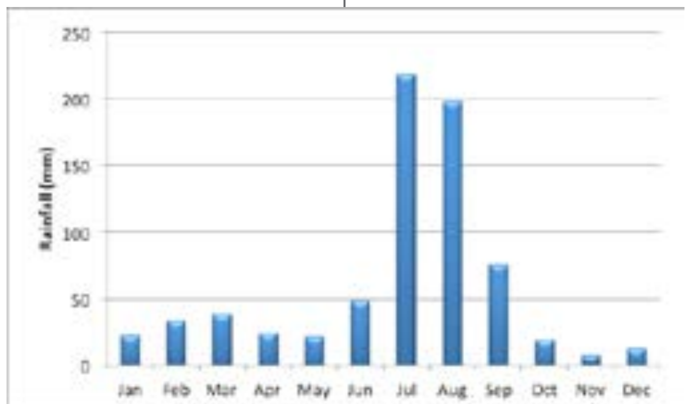


Figure 5: Mean Monthly Rainfall (mm) for Lahore (Source: Lahore Meteorological Station)

3.0 WATER USAGE AND CONSUMPTION IN LAHORE CITY

3.1 DOMESTIC WATER USE

Domestic water supply to Lahore has always been through extraction of groundwater. The water supply of most urban parts of Lahore city depends on WASA. In addition, Lahore Cantonment Board, Walton Cantonment Board, Defense Housing Authority, Model Town Society, Pakistan Railway and a large number of private housing schemes are responsible for supplying water to their respective areas. In rural areas of the district of Lahore, the Public Health Engineering Department (PHED) is responsible for the installation of water supply schemes.

As per WASA claims, safe drinking water is supplied to 5.77 million people (89 per cent of the total population under its jurisdiction) by means of 484 tube wells. These tube wells are located in different areas and their depth varies between 150 to 200 m. About 50 per cent of tube wells have a discharge capacity of 10,000 m3/day, 40 per cent are of 5,000 m3/day capacity and the rest are below 5,000 m3/day (WASA Report, 2013). Changing lifestyles have increased the demand for water over years. In 1967, WASA supplied water at the rate of 180 litres per capita per day (lpcd) , which has increased to 274 lpcd in 2013. The total groundwater extraction from 484 tube wells is 2.2 MCM/day. The groundwater extraction in 1967 was 123,000 m3/day, which means an annual increase of 46,000 m3/day.

On average, WASA tube wells work for 14-18 hours per day. However, in summer their working hours increased to 20 hours per day. In most areas, the distribution system is directly attached to the source (tube wells). Water storage reservoirs are lacking therefore water is delivered intermittently. WASA water supply lines are approx. 7,700 km long and 600,000 connections deliver drinking water from the source to households (WASA Report, 2013). Only 78 per cent of households in the WASA serving area are connected to the piped water whereas in non-WASA areas this facility is available to 50 per cent of households. The remaining 50 per cent of households get water from hand pumps, public water stand posts or directly through groundwater pumping by using small suction pumps.

Domestic water demand is delivered at the boundary of the consumers including water losses in the distribution system. The Non-domestic demand comprises mostly of commercial, institutional, offices, public places (parks, lawns, green belts and religious places etc.) and industrial uses etc.

The average daily per capita water consumption depends upon a number of factors such as population and its socio-economic condition, source availability, the size of service area, extent of affordability, climate etc. According to WHO guidelines, water requirements should be established on water needs, sources of water availability, water supply organizations and the programme to implement the water supply schemes. WHO (2003) suggests four levels of water supply based on access to water which are: i) no access (below 5 lpcd); ii) basic access (about 20 lpcd); iii) intermediate access (50 lpcd); and iv) optimal access (100-200 lpcd).

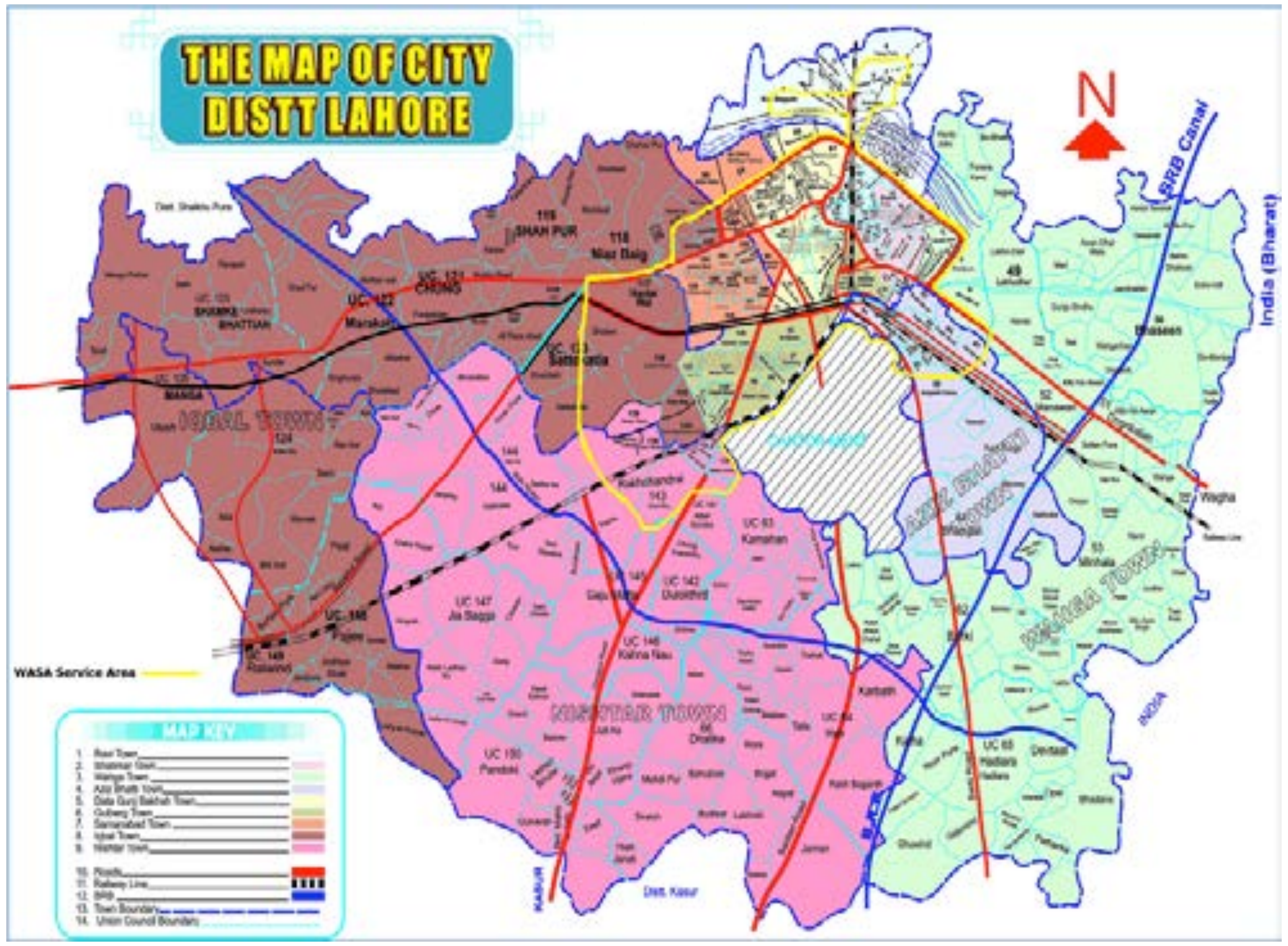


Figure 6: Map of Service Area of WASA, Lahore (Source, WASA)

The quality of WASA supplied water is generally good. The water quality of Nishtar Town is considered the best whereas it is relatively poor in Samnabad and Gunj Buksh Towns. The quality of water in slum areas is bad in colour, odour and taste due to mixing of wastewater with groundwater. Most of the water in these areas is pumped from shallow depths (mainly through hand pumps or small pumps of low discharge capacity) where the chances of seepage of wastewater to groundwater are relatively high. WASA supplies water to six towns i.e. Ravi Town, Shalimar Town, Gunj Buksh Town, Aziz Bhatti Town, Iqbal Town and Nishtar Town (Figure 6). The greatest groundwater extraction is in Gunj Buksh Town (492,000 m³/day) whereas the lowest is in Shalimar Town (182,000 m³/day). The greatest quantity of unaccounted for water is reported in Gunj Buksh Town (55 per cent) whereas for all other towns, it is less than 30 per cent. Half of WASA house connections are unmetered. In the metered connections, only 15 per cent of the meters are in working condition (JICA, 2010). The per capita water use for consumers of unmetered connections is higher because they are charged on a flat rate basis rather than the volume of water they actually use. Therefore they are less concerned about water conservation in their daily routine.

In addition to house connections, WASA has 15 lorry filling points for the Fire Department of the City District Government. No exact data is available on the water use by these filling points. WASA also has about 25 tankers of 7 m³ capacity. These tankers are used to water green belts along roads and for other emergency purposes. If we assume that all of them are used at least once a day, total water use will be 175m³/day.

The urban areas of Lahore city which do not come under the jurisdiction of WASA have their own water supply system. Water usage by the Lahore Cantonment Board, Walton Cantonment Board, Defense Housing Authority, Model Town Society and Pakistan Railway are given in Table 4.

A large number of private housing societies have installed their own pump stations with capacities of the order of 0.06m³/sec. Based on one month's data (November 2010) of groundwater pumping by WAPDA Employees Cooperative Housing Society, the per capita consumption in the area comes out to be 315 lpcd. Assuming a pumping rate of 0.20 m³/sec, it is estimated that all societies are pumping groundwater at the rate of 4.25 m³/sec. Assuming 20 per cent of Lahore's population is without piped water supply, and using 200 lpcd, the total groundwater use rate by this population comes out to be 4.0 m³/sec.

Table 4: Groundwater Extraction Capacity of Non-WASA Areas of Lahore (Source: JICA Report, 2010 & Punjab Agricultural Census 2010)

Area	No. of Tube wells	Total Capacity m³/day
Lahore Cantonment Board	53	244,512
Walton Cantonment Board	53	259,200
Defense Housing Authority	20	97,632
Model Town Society	15	77,760
Pakistan Railway	52	200,448
Total	193	879,550

Other private housing schemes have their own tube wells to supply water to their residents. No exact data is available for their water consumption. However, according to an estimate, their daily extraction is 367,200 m³/day . In areas where the water supply network is not available, people use hand pumps and shallow pumps to extract groundwater for their use. The estimated groundwater extraction from private housing schemes is 345,600 m³/day (Basharat and Rizvi, 2011). Therefore, total groundwater extracted by private housing schemes is approximately 712,800 m³ per day.

In conclusion, domestic water use in Lahore is 3.79 MCM/day (1,384 MCM/year). Domestic water demand consists of different water uses within a house such as drinking, cooking, bathing, and personal hygiene, etc. The demand varies basically as per the living standards of the population. For slum areas, daily water consumption can be up to 318 litres whereas for non-WASA and WASA areas, it is 174 and 269 litres, respectively (Table 5).

The biggest share of water is used for washing clothes (23.8 per cent), bathing (32.5 per cent) and house cleaning (15.7 per cent). In WASA service areas, about 8.5 per cent of the total water consumption is used for car washing. Interestingly, water consumption in slum areas is much higher than WASA and non-WASA area. The water use for washing clothes and bathing is far higher than WASA and non-WASA areas.

In addition to greater water losses in the system network, the higher water consumption in slum areas is related to their diversified household activities (JICA Report, 2010). In slum areas, water is not delivered through house connections. The water is pumped directly from the groundwater with the help of small pumps or hand pumps. Many people living in slum areas rear animals at home to earn their living by selling milk, eggs and meat. Women living in slum areas often wash clothes for commercial purposes. As most of the connections in the slum areas are unmetered, water used for these activities is not measured. This is probably the reason why water use in slum areas seems higher than WASA and non-WASA areas.

The water supply system in rural areas of Lahore is not well established. The Public Health Engineering Department (PHED) is responsible for establishing water supply schemes. These schemes generally consist of one tube well and a storage reservoir. There are 16 rural water supply schemes which have been completed by PHED. Total spending on these schemes is about Rs. 2,000 million and serves a population of 400,000. Maintenance and operation is the responsibility of the user's community. However, according

Table 5: Breakdown of Water Consumption in a House in WASA, Non-WASA and Slum Areas. Source: Modified and updated from JICA Report of 2010

Activity	Slum Areas		Non-WASA Areas		WASA Areas	
	Volume (litres)	Percentage (%)	Volume (litres)	Percentage (%)	Volume (litres)	Percentage (%)
Cooking	4.30	1.35	4.30	2.45	12.30	4.57
Drinking	15.80	4.96	14.80	8.50	20.20	7.50
Clothes Washing	114.5	36.0	37.00	21.30	64.00	23.80
Gardening	1.10	0.35	2.20	1.25	4.80	1.78
Car Washing	2.10	0.67	7.25	4.20	23.00	8.55
Bathing	110.50	34.75	73.60	42.30	87.25	32.45
House Cleaning	68.50	21.54	30.25	17.40	42.25	15.70
Other Uses	1.20	0.38	4.60	2.60	15.20	5.65
Total	318	100	174	100	269	100

The number of industries differs in literature going up to 6,000. However, industries which consume significant amounts of water are taken as 2,025. Smaller industries which do not use significant amount of water are not considered for the estimation of industrial water use.

to PHED, 13 out of these 16 schemes are non-functional due to non-payment of electricity bills. There is no data available on water extraction from tube wells installed in the rural areas. These schemes are built by the government through PHED whereas operation and maintenance lies with the communities. However, due to lack of organizational capacity of rural communities, operation and maintenance of these schemes is generally poor which eventually make them non-functional.

3.2 INDUSTRIAL WATER USE

There are about 2,700 industrial units registered in Lahore, out of which 75 per cent (2025) are categorized as large scale factories (JICA, 2010). These large industries are the main users of groundwater (Basharat and Rizvi, 2011). The textile industry makes up 20 per cent of the total industry and is the largest user of water (69 per cent of the total industrial water consumption). Textile spinning, textile processing and textile weaving are the major consumers of water. Water is also pumped by industries other than textile. These include the chemicals sector (10 per cent), paper industry (5 per cent), food industry (5 per cent) and other industries (11 per cent). Others include electronic, marble, leather and steel.

Water consumption by industries is not well established. According to WASA, there are over 4,000 private tube wells in Lahore with a total discharge capacity of 480,000 m^3/day, which supplies water to industries and other private businesses (JICA, 2010). In general, each industry has installed 1 to 4 pumping units with a capacity ranging from 1,200-2,500 m^3/day depending on the scale and type of processing involved in the industry (Basharat and Rizvi, 2011). According to conservative estimates, if the average capacity of these pumps is assumed to be 1,800 m^3/day with a utilization factor of 25 per cent, groundwater pumping by these industrial units will be 0.92 MCM/day (335 MCM/year).

3.3 COMMERCIAL AND INSTITUTIONAL USE

Commercial and institutional water uses include hospitals, educational institutes, mosques, shops and restaurants, public parks, offices, bus stands, railway stations and other similar places. WASA has 32,500 commercial connections, which is little over 5 per cent of total connections. Separate estimates of commercial and institutional water use are barely available. Generally, commercial and institutional uses of water are account for about 20 per cent of domestic water use. The total domestic water use in Lahore is 3.80 MCM/day (see section 3.1). Assuming this standard, water usage for commercial purposes for Lahore city is estimated to be 0.76 MCM/day (277 MCM/year).

3.4 AGRICULTURAL WATER USE

With the establishment of Lahore Development Authority in 1975 (the Lahore Improvement Trust was converted into LDA), the city started expanding and a number of private housing schemes were established in Lahore. The Lahore Cantonment Board, Housing and Physical Planning Department, Defense Housing Authority, Cooperative Housing Societies and different public sector organizations got involved in housing and land development (Anjum and Hameed, 2007). Due to this rapid urbanization, cultivated land of Lahore city was squeezed. As shown in Table 6, in 1972, 94 per cent of the total area of Lahore consisted of cultivated land. This was reduced to less than 30 per cent in 2010.

Table 6: Urbanization of Cultivable Land in Lahore (Source: Khaliq-uz-Zaman, 2012)

Period	Total Area Ha	Cultivable Area Ha	Percentage of Cultivable Area
1972	177204	166862	94.2
1973-80	177204	163413	92.2
1981-90	177204	114298	64.5
1991-2000	177204	81040	45.7
2001-2010	177204	52232	29.5

In Lahore, land development was undertaken through the Housing and Physical Department, LDA, DHA, Private Developers and Cooperative Housing Schemes. About 8 per cent of land was developed by private cooperative housing schemes, 5 per cent by LDA, 6 per cent by DHA and 81 per cent by the mixture of government authorities and informal sectors (Khaliq-uz-Zaman, 2012).

About 3,000 hectares (ha) of agricultural land on the outskirts of the city is converted to urban use annually. If the present trend of urbanization continues, the remaining total cultivated area of 52,332 ha will be exhausted by year 2030 (Bajwa et al., 2007). This expansion in urban areas has put enormous pressure on water and energy resources of the city. Fast conversion of agricultural land into urban areas has also affected crop production. About 114,630 ha has gone out of cultivation due to the development of housing schemes. Table 7 shows the percentage change over time in the production of different crops grown in Lahore as a result of decreased cropped area.

Table 7: Percentage Change Overtime for Different Crops (Source: Khaliq-uz-Zaman, 2012)

Crop	Production in 000 tons		Percentage Change over Time
	1986-87	2007-08	
Wheat	155	89	- 42.7
Rice	83	53	-35.9
Maize	19	6	-68.1
Sugarcane	50	17	-64.9
Vegetables	7485	2825	-62.3
Fruits	44335	32199	-27.4

The canal irrigation system in the area was established in 1859 with the construction of the first weir-controlled perennial irrigation channel - the Upper Bari Doab Canal off-taking from the River Ravi at Madhopur (now part of India). After partition, as a result of the 1960 Indus Water Treaty, the Bambawala-Ravi-Badian-Deplapur (BRBD) Link Canal was constructed (with a discharge capacity of 9.76 MCM/day) to feed a command area of Upper Bari Doab Canal on the Pakistan side of the border.

The Upper Bari Doab Canal irrigates command areas of Lahore Branch (0.98 MCM/day), Khaira distributary (0.34 MCM/day), Butcher Khana distributary (0.60 MCM/day), Main Branch Lower (3.88 MCM/day) and other smaller channels with a combined capacity of 0.20 MCM/day. The remaining flow of the BRBD Canal supplements Depalpur Canal (Basharat and Rizvi, 2011). This irrigation system also serves as a potential source of recharge to groundwater (see Figure 2 for detailed layout of the irrigation system).

The total surface water diverted to Lahore for irrigation is 6.02 MCM/day while actual water is much less due to water seepage and recharging to the groundwater that is subsequently used by people, businesses or agriculture. Due to age and poor maintenance, the delivery efficiency of the irrigation system is low, ranging from 35 to 40 per cent from the canal head to the crop root zone (Tarar, 1995). In practical terms, therefore, a large quantity of surface water is currently lost enroute, which, if salvaged, could be profitably used by the farmers. According to different estimates, more than half of diverted water is lost as system losses before it reaches the farm gate (IWASRI, 2006). Therefore actual water available for agricultural use is only 3.0 MCM/day.

In addition to these surface water resources, a large number of tube wells are also installed for irrigation purposes in Lahore. According to the Punjab Bureau of Statistics (2008), there are approximately 200,000 irrigation tube wells in Bari Doab, out of which 6,000 are located in Lahore district. The average discharge capacity of these tube wells is 1,200 m^3/day and have an operation rate of 0.14. This means that the average discharge of these irrigation tube wells is approximately 1.0 MCM/day. Due to continuous decline in surface water over the last decade, groundwater extraction for irrigation has increased many fold.

The current estimates of groundwater extraction for irrigation are much higher because groundwater use for irrigation has increased rapidly during the last few years. Generally with a decrease in cropping area, intensification has increased and farmers usually do not leave any fallow land and grow 2-3 different crops together, which increases irrigation water use. During the last 20 years, the number of irrigation tube wells in Punjab has increased by 10 per cent per year (Qureshi et al., 2010). Assuming this rate of increase, the current number of irrigation tube wells in rural Lahore can be estimated to be 10,000 with a corresponding discharge of 1.7 MCM/day. However, these estimates may vary from year to year depending on rainfall patterns and subsequent flow regimes in rivers.

3.5 SUMMARY OF WATER USE

Table 8 summarizes the discussion on water use by different sectors in Lahore city. The largest amount of water (surface and groundwater) is used for irrigation. As there is no provision of surface water for domestic purposes, the greatest amount of groundwater is used for domestic purposes. Next in importance is industrial and then commercial use. Out of total groundwater extraction, 53 per cent is used for domestic purposes, 13 per cent for industry, 10 per cent for commercial and institutions and the remaining 24 per cent is used for irrigation.

Main Canal: The main canal takes its supply directly from the reservoir or river. The capacity of main canals in Pakistan varies from 0.50 MCM/day to 30 MCM/day. Most of the main canals are unlined.
Distributary: Distributaries off-take from main canals and generally carry discharges between 0.10MCM/day to 0.70MCM/day. These are provided with outlets for delivery of water to watercourses.
Agricultural Field: An agricultural field refers to land where crops are regularly grown.

Table 8: Summary of Water Use in Lahore City

Sector		Water use (MCM/day)	Water use (MCM/year)
Domestic use			
	WASA	2.20	803
	Non-WASA	0.88	321
	Private Housing Schemes	0.71	260
	Sub-Total-1	3.79	1384
Non-Domestic use			
	Industrial	0.92	335
	Commercial and institutional	0.76	277
	Sub-Total-2	1.68	612
Agricultural use			
	Agricultural use (Groundwater)	1.71	623
	Agricultural use (Surface Water)	3.00	1095
	Sub-Total-3	4.71	1719
Total groundwater extraction in Lahore		7.18	2619
Total water use in Lahore (surface + groundwater)		10.18	3716

3.6 RECHARGE TO GROUNDWATER

Seepage from rivers, lined or unlined channels, rainfall and agricultural fields is vital to recharge groundwater, which is the major source of drinking water for most cities including Lahore. The exact estimation of recharge to groundwater from these water bodies is a complex procedure and not much has been done on this subject in Pakistan. Recharge to groundwater in urban areas is relatively insignificant due to large scale infrastructure development without any provisions for groundwater recharge zones.

Different approaches have been developed for the estimation of recharge to groundwater from different sources. In Pakistan, seepage is usually calculated as a percentage of the available volume of water at the head of main canals, distributaries, watercourses and agricultural field . In 2005, the Water and Power Development Authority (WAPDA) conducted a detailed study to estimate recharge to groundwater from different sources in order to prepare a Drainage Master Plan for the Indus Basin. They estimated that seepage losses from main canals and distributaries are 15 per cent and 8 per cent of their total flow, respectively. They further estimated that only 75 per cent of seepage losses contribute in recharging the aquifer whereas the rest is stored in the soil profile.

No independent studies have been carried out to estimate recharge to groundwater from the River Ravi. Therefore, for first approximation, recharge from the River Ravi can be considered equivalent to main canals. This approach for estimation of recharge from the River Ravi seems reasonable as most major canals are also unlined and have discharge going up to 30 MCM/day. Figure 7 shows the 35 year flow record of the River Ravi. Except for the monsoon months of August and September, the flow in the Ravi is negligible. The discharge of Ravi varies from a minimum of 15 MCM/day in November to over 216 MCM/day in August with an average value of 69 MCM/day. Except for the monsoon month of August, the discharge remains about 49 MCM/day (about 20,000 cusecs). Considering the WAPDA criteria, seepage losses are taken as 15 per cent of the total flow volume of 69 MCM/day and 75 per cent of seepage loss is assumed to recharge groundwater.

The recharge to groundwater from rainfall varies from 10to 25 per cent depending on its amount, intensity and location. In urban areas where most of the land is occupied with buildings and roads, recharge is not more than 10 per cent of the total rainfall whereas in the contiguous agricultural area, recharge can be up to 25 per cent (IWASRI, 2006). The remaining rainwater vanishes in sinks and low lands as runoff from where part of it evaporates.

The annual rainfall in Lahore is reasonable enough to recharge the groundwater aquifer. However, the existing landscape does not allow any recharge to groundwater in urban areas of Lahore and most rainwater is lost to drains due to fast runoff. The recharge to groundwater from rainfall in irrigated agricultural areas varies from 10 to 24 per cent of the total annual rainfall (Basharat and Tariq, 2011). By creating favourable conditions, about one-fourth of the average annual rainfall (178 mm) can be recharged to groundwater . For Bari Doab, the specific yield varies from 22 to 35 per cent, the average being 26 per cent. Assuming this specific yield, this recharge would be enough to build up the groundwater table up to 0.70 m each year. Therefore, by providing suitable provisions in parks, roads and other public places for rainwater harvesting, recharge to groundwater can be accelerated to control the declining groundwater table depth (Sheikh, 1971).

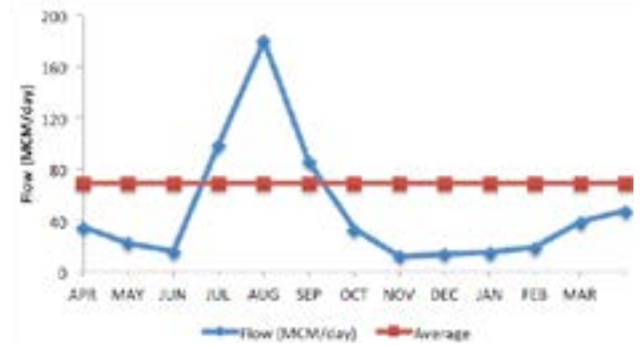


Figure 7: History of Flow in River Ravi at Balloki (Source: Punjab Irrigation Department)

From all potential sources, average recharge to groundwater is 6.50 MCM/day (2,372 MCM/year) (Table 9). River Ravi contributes approximately 82 per cent of the total recharge to groundwater whereas recharge from rainfall and irrigation canals is only 11 per cent of the total. The remaining amount is contributed by groundwater return flow from agricultural fields. These are average values and may change from year to year based on rainfall patterns and its impact on the flow regime of the river. This clearly shows the importance of the Ravi flows in sustaining the Lahore aquifer. The increasing recharge from the River Ravi is good for the Lahore aquifer; however, it reduces flow for downstream users. The mixing of drainage water in the River Ravi has serious implications for downstream water users because of pollution.

The substantial contribution of the River Ravi in recharging the Lahore aquifer suggests that we should stop discharging untreated wastewater into the river as it can have serious consequences for millions of people in and around the city that rely on groundwater as their principal source of drinking water.

3.7 EVAPO-(TRANSPIRATION) AND GROUNDWATER OUTFLOW FROM THE AREA

Ninety per cent of the urban area of Lahore city is covered with buildings and roads. Due to the large depth of groundwater outflow through

Table 9: Estimated Recharge to Groundwater from Different Sources.

Water Source	Volume of available water (MCM/day)	Volume of infiltration (MCM/day)	Total recharge to GW (MCM/day)	Total recharge to GW (MCM/year)
River Ravi	47	7.07	5.31	1937
Canals	0.84	0.126	0.095	61
Distributaries	5.18	0.414	0.311	380
Rainfall (urban area)	2.44	0.24	0.12	45
Rainfall (non-urban area)	1.02	0.51	0.255	93
Return flow from agri. GW use			0.41	149
Total			6.50	2372

Explanations:

1. For the calculation of total volume of available flow, River Ravi, canals and distributaries are assumed to run for 250 days in a year. For the remaining days, flows are considered to be negligible, especially during the winter canal closure period and when flows in the River Ravi are extremely low (November to February and May to June).
2. Seepage from the River Ravi and canals is taken as 15 per cent of the total flow, whereas for distributary it is taken as 8 per cent. The seepage from rainfall is taken as 10 per cent of the total for urban areas and 25 per cent for non-urban areas.
3. The recharge to groundwater from the River Ravi, canals and distributaries is taken as 75 per cent of the total seepage losses. For rainfall, recharge to groundwater is taken as 50 per cent of the total seepage loss.
4. Total non-urban area is taken as 522,32 ha and urban as 124,972 ha (Table 6).
5. 24 per cent of the total extracted groundwater is taken as the return flow to the aquifer.

According to WAPDA (2005), about 50 per cent of total average rainfall infiltrates soil and 50% of this infiltrated rainfall contributes in recharging groundwater. Currently, due to heavy urbanization, the infiltration capacity and recharge to groundwater is not more than 10 per cent.

evapo-transpiration is almost negligible. From agricultural fields around the city, 24 per cent of the total groundwater extraction is assumed to be the return flow (Basharat, 2012) whereas the rest is consumed by crops to meet evapo-transpiration requirements. Therefore total return flow is 0.41 MCM/day (150 MCM/year). For Lahore, the average water loss due to potential evapo-transpiration (ETP) for wheat is 4,000 m^3/ha; for sugarcane is 18,000 m^3/hand; for rice is 14,000 m^3/ha (Ullah et al., 2001). Therefore for any cropping pattern, the average annual ETP for Lahore can be taken as 18,000m^3/ha. This means that for 52,232 ha of Lahore's cultivable land, the annual ETP is 940 MCM/year (2.6 MCM/day). Regional groundwater outflow from the area is also an important component of groundwater budget of any area. Basharat and Rizvi (2010) have shown that excessive groundwater pumping in the city has created a reverse gradient, which means that there is no out-flow from the area or inflow to the area is taking place.

3.8 COLLECTION OF WASTEWATER

WASA is the prime body for the collection of sewage and wastewater in Lahore city. The existing service area of the sewerage system is approximately 350km^2 and the existing sewerage system is a semi-combined system. The WASA sewerage service area is further divided into six sub-catchments (Figure 8). These include Shahdara, Mehmood Booti, Khokhar Road (Siddiquepura Drain), Central Lahore, South Lahore (Sattu Katla Drain) and Southeast Lahore (Hudiara Drain).

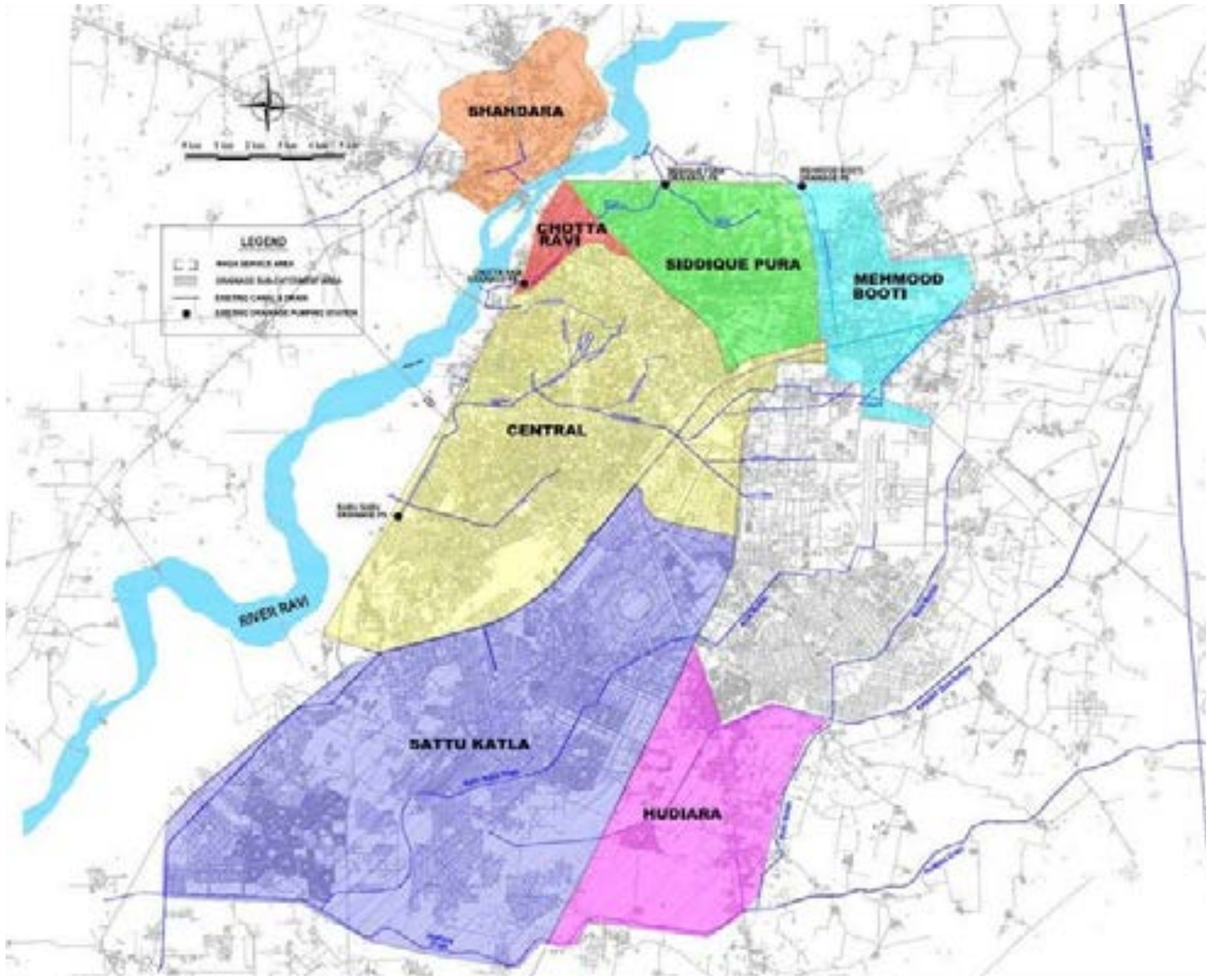


Figure 8: Sewerage Service Area of WASA in Lahore Source: WASA, 2013)

The areas included in these sewerage sub-catchments are as follows: Shahdara (only shahdara); Mehmood Booti (Mughalpura and Fatehgarh); Khokhar Road (Data Nagar, Misri Shah, Baghbanpura); Central Lahore (City, Tajpura, Mustafabad, Ravi Road, Krishannagar, Sumla Hall, Mozang, Gulberg, Allama Iqbal Town, Samnabad, and Ichhra); South Lahore (Johar Town, Green Town and the Industrial Area of Kot Lakhput)

In Figure 8, discharges of different drains are given in cusecs (ft^3/sec) (this unit is generally used by WASA). For conversion, one cusec is equal to 0.0283cumecs (m^3/sec).

Central Lahore and South Lahore are the largest sub-catchments with a service area of 100 and 138 km^2. The number of lift stations at sewerage sub-catchments of Shahdra, Mehmood Boti, Khokhar Road, Central, South and Southeast are 6, 10, 18, 27, 17 and 2, respectively. The total length of sewers in the city is about 4,000 km, out of which 700 km is trunk sewer and 3,300 km is lateral sewer (WASA Report, 2013).

The Lahore drainage system comprises of 14 major drains that collect domestic sewerage and industrial wastewater from the entire city and its surroundings through a dense network of small drains. The discharges of these 14 drains measured during 2010 are given in Figure 9.

Figure 9 shows that Hudiara Drain carries a maximum flow of 1.30MCM/day whereas Jaranwala Drain has the lowest flow of only 20,736m^3/day. Over the past 5-10 years, sewerage generation in Shadbagh, Forest Colony, Babu Sabu and Hudiara drains is increasing whereas there is a decreasing trend in Sukh Naher, Shahdara, Furakhabad, Main Outfall and Gulshan-e-Ravi drains. Sewerage from all drains is finally discharged into the River Ravi through various pumping stations without any treatment. A detailed map of the existing sewerage network of Lahore is shown in Figure 10 .

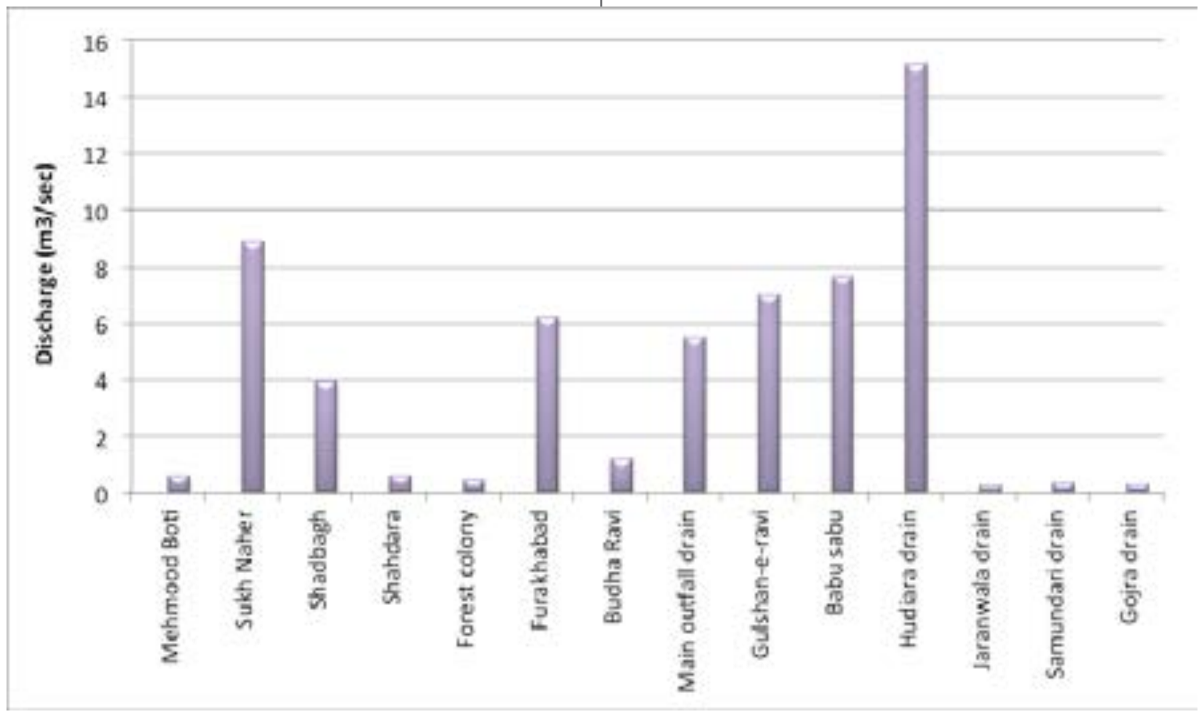


Figure 9: Discharges of Major Drains of Lahore city. Source: (WASA, 2011)

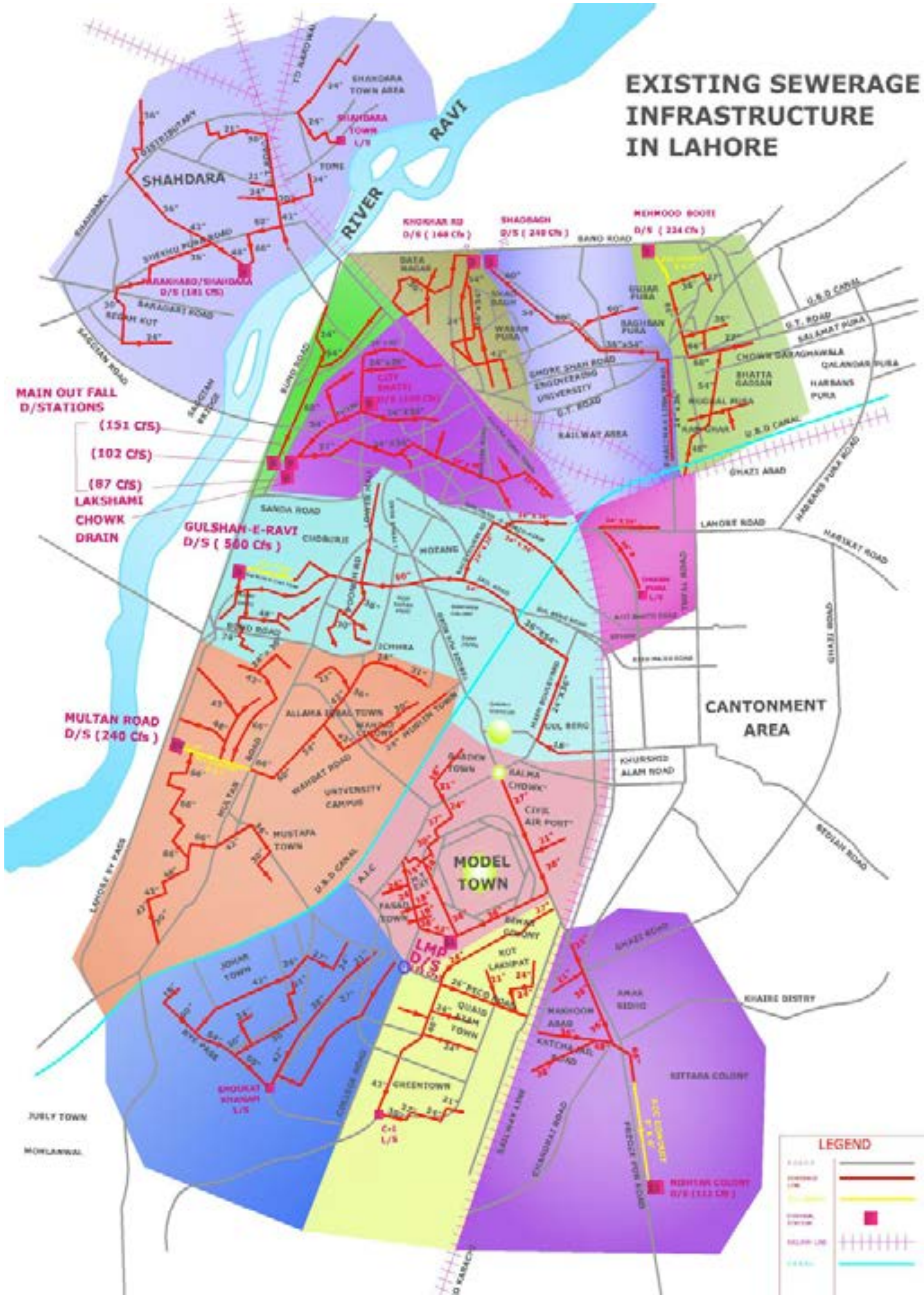


Figure 10: Existing Sewerage Infrastructure of WASA in Lahore

3.9 DISPOSAL OF WASTEWATER TO SURFACE WATER BODIES

The per capita wastewater generation in Lahore is estimated to be 231 litres (WASA report, 2013). It is estimated that 8 MCM/day of wastewater is disposed of into the River Ravi without any treatment (JICA, 2010). Some industries discharge wastewater on land or in soakage pits that results in groundwater pollution. In comparison, wastewater generation in Faisalabad is estimated to be 1,100 MCM/year, out of which approximately 20 per cent is treated before it is discharged into water bodies (Pakistan Water Operators Partnership, POWP, 2013). For the disposal of wastewater, WASA has installed 12 major disposal stations with total discharging capacity of 5.7 MCM/day. The location of these disposal stations is shown in Figure 11.

The details of these 12 pumping stations are given in Table 11 (POWP, 2013; WASA Report, 2013). There are 80 lift stations with a pumping capacity of 2.0 MCM/day and four gated drainage stations with a pumping capacity of 1.62 MCM/day to pump wastewater from the entire city. The maximum discharge is from the Gulshan-e-Ravi disposal station which is 1.37 MCM/day whereas Bhati Gate and Main Outfall– 3 has the lowest capacity of 0.24 MCM/day and 0.21 MCM/day, respectively. The wastewater pumped from these disposal stations is directly discharged into the River Ravi except for the disposal stations of LMP Block and Nishtar Colony which discharge into the Sattu Katla Drain.

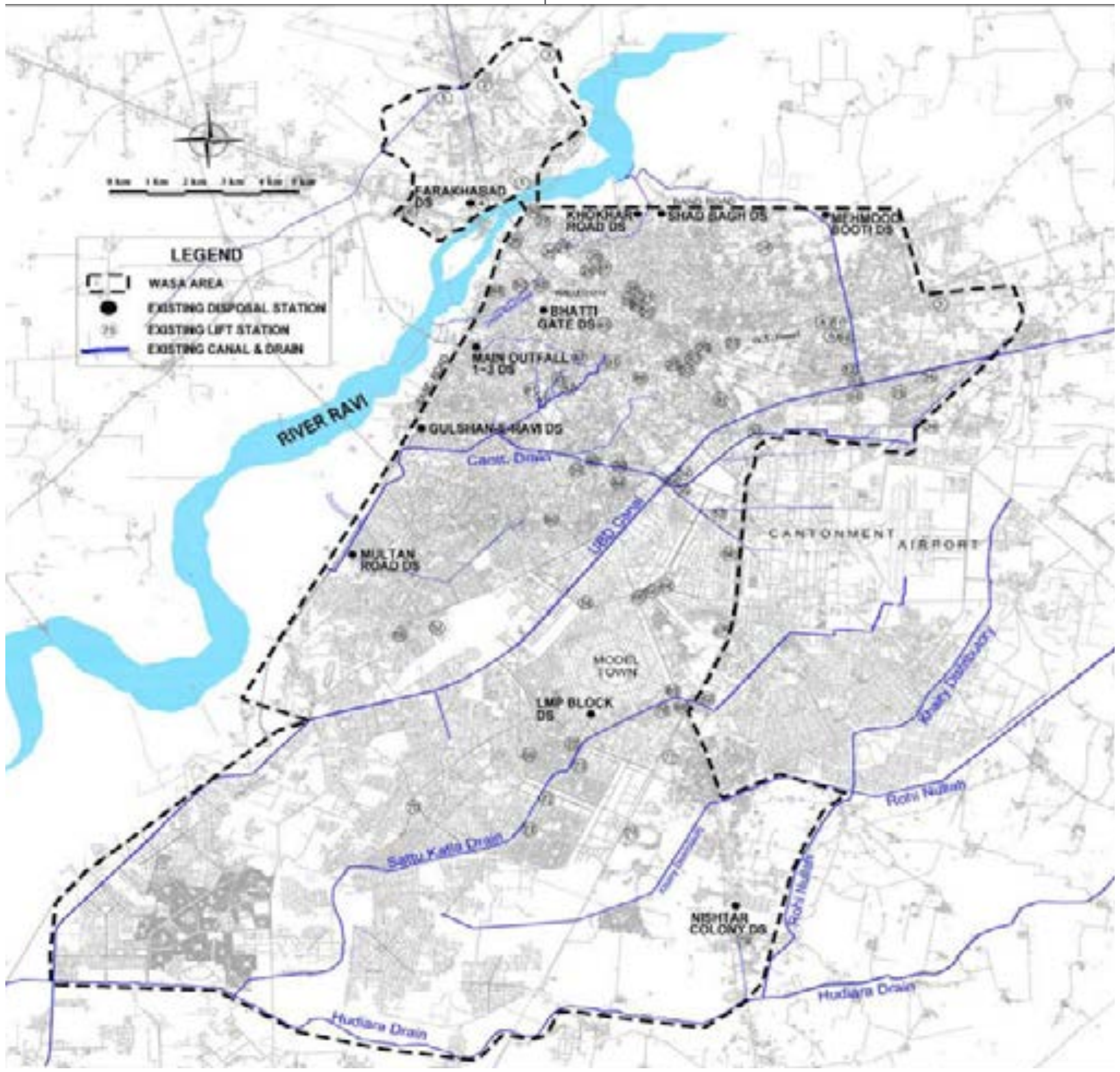


Figure 11: Location of WASA Disposal Stations in Lahore (Source: WASA, 2013)

Table 10: WASA Managed Disposal Stations and their Pumping Capacities (Source, WASA PROFILE 2013)

Sr. No.	Name of Disposal Station	No. of Pumps	Total Discharge (m3/sec)	Total Capacity (MCM/day)
1	Farrukhabad	10	5.12	0.44
2	Mehmood Booti	4	6.34	0.55
3	Shadbagh	6	6.79	0.59
4	Khokhar Road	3	4.75	0.41
5	Bhati Gate	4	2.83	0.24
6	Main Outfall - 1	10	4.27	0.37
7	Main Outfall - 2	54	2.89	0.25
8	Main Outfall - 3	5	2.46	0.21
9	Gulshan-e-Ravi	14	15.84	1.37
10	Multan Road	6	6.79	0.59
11	LMP Block	6	3.82	0.33
12	Nishtar Colony	8	3.14	0.27
	Sub-Total	130	65.04	5. 62
	Lift Stations	80	23.37	2.02
	Gated Drainage Stations	4	18.76	1.62
	Total Pumping Capacity		107.17	9.26

3.10 POLLUTION LOAD TO RIVER RAVI

The wastewater discharged into the River Ravi normally contains liquid and solid waste from domestic, industrial, and commercial premises, including but not limited to, toilet waste, grey water (household wastewater from kitchens, bathrooms and laundries), sludge, trade waste and gross solids. During the low flow season, Babu Sabu Drain is the largest contributor of organic (BOD) load to the River Ravi (154.7 tons/day) while Shahdara Drain is the lowest contributor with only 3.27 tons/day (Table 4). According to very conservative estimates, a pollution load of approximately 730 tons/day is added to the River Ravi (JICA, 2010). Sewerage from Lahore's 14 wastewater carrying drains accounts for 56 per cent of total pollutants of the river (Malik, 2012). Pollution load discharged into the River Ravi by the 14 major drains of Lahore is given in Table 12.

Table 11: Pollution Load of 14 Major Drains of Lahore City Discharged into River Ravi (Source: PCRWR, 2003-04)

Sr. No.	Name of Drains	Average DO (mg/l)	Average COD (mg/l)	Average BOD (mg/l)	Pollution Load (Tons/day)
1	Mehmood Booti	0.81	4160	1210	46.81
2	Sukh Naher	0.43	284	120	30.12
3	Shadbagh	0.79	512	192	70.72
4	Shahdara	1.6	368	124	3.27
5	Forest Colony	1.23	560	216	8.91
6	Furrakhabad	0.5	960	382	84.62
7	Bhuda Ravi	0.91	280	96	9.11
8	Main Outfall Drain	1.1	1392	412	121.1
9	Gulshan-e-Ravi	0.83	312	112	46.25
10	Babu Sabu Drain	0.86	920	312	154.21
11	Hudiara Drain	0.91	396	120	130.87
12	Jaranwala Drain	-	-	-	10.28
13	Samundari Drain	-	-	-	8.11
14	Gojra Drain	-	-	-	3.87
	Total	-	-	-	728.75

The pumping capacity of WASA disposal stations is 5.62 MCM/day against the total wastewater generation of 8.0 MCM/day. However, due to persistent power cuts and maintenance problems, these disposal stations do not work at their full capacity which greatly impacts the efficiency of WASA in timely disposal of wastewater.

3.11 WATER BALANCE OF LAHORE CITY

The results of the above analysis reveal that except for a partial reliance of the agricultural sector on surface water resources, all other sectors (i.e. domestic, industrial and institutional) are depend on groundwater to meet their demands. Total groundwater extraction in Lahore district is 7.18 MCM/day (2,619 MCM/year). The largest share (53 per cent) of this extracted water is provided to the domestic sector, 13 per cent to the industrial sector, 24 per cent to the agricultural sector and the remaining 10 per cent is provided to the commercial and institutional sector. The total recharge to Lahore's aquifer is 6.50 MCM/day or 2,372 MCM/year. Close to 73 per cent of the recharge comes from the River Ravi, 16 per cent from the canal irrigation system, 5 per cent from rainfall and the remaining 6 per cent from groundwater return flow from agricultural fields. A summary of water balance components is given in Table 13.

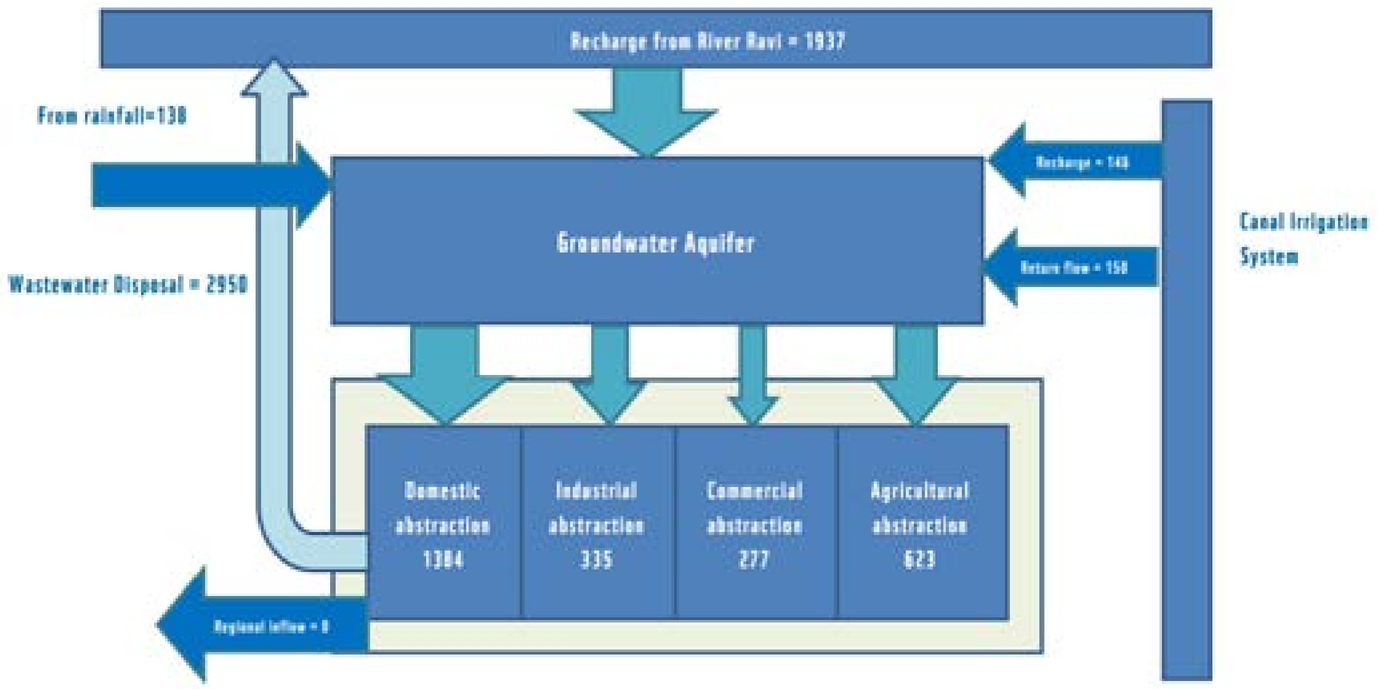
water table by about half a metre per year during the last 30 years. In 1987, depth to water table was approximately 10 m, which has decreased to 52 m in 2010. The close proximity between these results gives confidence on the approach used to calculate the water balance of Lahore in this study. In the 'business as usual' scenario, this value will increase further as the water demand will escalate owing to a rise in population. It should be noted that this water table drop is averaged over the whole area of the district of Lahore . However, in urban parts of the city, the water table drop may be higher due to excessive pumping and insignificant recharge. In rural areas, where recharge from the irrigation system and agricultural significant. A schematic presentation of the water balance of the district of Lahore is given in Figure 12.

Table 12: Summary of Water Balance of Lahore City

Source		(MCM/day)	(MCM/year)
Output			
	Domestic	3.79	1384
	Industrial	0.92	335
	Commercial and Institutional	0.76	277
	Agriculture	1.71	623
	Total Output	7.17	2619
Input			
	River Ravi	5.31	1937
	Irrigation system	0.40	146
	Rainfall (urban areas+ non-urban agricultural fields)	0.38	138
	Groundwater return flow from agricultural fields	0.41	150
	Total Input	6.50	2371
Output-Input		0.67	248
	Total surface water use in Lahore	3.00	1094
	Total wastewater generated in Lahore	8.0	2920

The net groundwater loss in the Lahore aquifer is 247 MCM/year which is equivalent to a 55 cm (0.55 m) per year drop in aquifer levels (assuming specific yield of 26 per cent and total area of 177,224 ha). The study conducted by WASA in collaboration with the Pakistan Institute of Nuclear Science and Technology (PINSTECH) has revealed that during the last 20 years, the groundwater table in Lahore has declined at a rate of 0.57 m per year (Niaz et al., 2010). Khalid et al. (2013) also found that extensive use of groundwater in Lahore has led to lowering of the

247 MCM of water is equivalent to 0.32MAF.



Figures 12: Water Balance of Lahore city

Table 13: Schematic presentation of the overall water balance of Lahore and aquifer

Components	Recharge	Discharge
	(MCM/yr)	(MCM/yr)
Groundwater recharge		
Recharge from rainfall	138	
Return flow from irrigation fields	150	
Recharge from River Ravi	1,937	
Contribution from irrigation system (main canals and distributaries)	146	
Total Recharge	2,371	
Groundwater abstraction for domestic water supply	1,384	
Groundwater abstraction for industries	335	
Groundwater abstraction for commercial and institutions	277	
Groundwater abstraction by for agriculture	623	
Total Discharge 2,619		
Discharge—Recharge 248 MCM/yr		

Note: In the above figure the wastewater discharge is higher than water abstracted from different sources. This is because rainwater and other surface runoff also joins the same drains (as there is no separate storm water drains) so the wastewater discharge is higher than water accounted.

4.0 IDENTIFICATION OF KEY PRESENT AND FUTURE WATER CHALLENGES

4.1 DEMOGRAPHIC AND SOCIAL CHALLENGES

Pakistan, like other developing countries in the region, has experienced a massive urban population explosion, which has resulted in severe pressure on the urban land and infrastructure of big cities. According to the 1998 survey, the population of Lahore was 6.32 million which increased to 8.5 million in 2003 and is estimated to be more than 22 million by 2025 (Siddiqi, 2004). About 16.4 per cent of Lahore's population consists of migrants from other cities.

Pakistan is one of the most urbanized countries in South Asia while the metropolitan city of Lahore is the second mostly populated city in the region. The overall populated urban area in Pakistan is 36 per cent while 84 per cent of Lahore's population resides in the metropolitan city (Government of Pakistan 2011). Lahore is expanding, growing and delivering economic incentives and amenities at the cost of productive agricultural lands. These trends may put severe strain on the country's ability to increase food production in parallel with population growth.

Urban growth in Lahore continues to grow according to the 1981-98 population census but at a slower rate on average by comparison to previous the census of 1972-81. Most of the population shift involves movement away from concentrated urban centres to vast, sprawling metropolitan regions or to small and intermediate-sized cities. With the current growth rate of 4 per cent per year, this trend is projected to continue and is expected to be 90 per cent by 2025 (Elahi, 2010). The population density (persons per km2) in Pakistan was 218 in 2010 compared to 43 in 1951 whereas the current population density of Lahore is 4,983 compared to 640 in 1951. The relative increase in density in Lahore during the period 1951-72 was 128 per cent as compared to 149 per cent during the period 1981- 2010.

This massive increase in population during the next decade will put enormous pressure on the water, sanitation, energy, transport, education and health sectors. Migration from surrounding rural areas is likely to result in the creation or expansion of informal settlements that will be overcrowded with unhygienic conditions such as no proper sanitary facility, limited access to the water supply, electricity or social services.

4.2 GROUNDWATER AVAILABILITY AND QUALITY CHALLENGES

The principal source of groundwater recharge for the Lahore aquifer is the River Ravi. Although the river is the biggest source of recharge to groundwater, the quantum of recharge has drastically decreased because the river remains mostly dry, except for the monsoon season.

In order to study the impact of excessive pumping on water table depth, groundwater table data collected from WASA and the Directorate of Land Reclamation (WAPDA) for the years 2005

and 2008 was analyzed. Assuming a similar rate of drop of the water table, groundwater table depths are projected for 2015, 2020, 2025, and 2040. It is understood that during the next 20 years, the demand for water will increase, which may accelerate the decline in the groundwater table. However, for this study it is assumed that an additional increase in water demand will be accommodated by reducing per capita water availability and thus by reducing pumping.
The water table depth maps prepared for a five year interval period starting from 2015 are presented in Figure 12. For the preparation of these maps, nine different categories of water table depth were used. These include less than 5 m, 5-10 m, 10-20 m, 20-30 m, 30-40 m, 40-70 m, 70-100 m, 100-130 m, and more than 130 m. The data for pre-monsoon conditions is used for these analyses. Due to excessive seepage, there is some recovery in the water table depth after the monsoon season. However, this recovery is usually short lived and much less than the discharge component. In addition, recovery in groundwater table depth depends on the intensity of the monsoon between different years. Therefore it is difficult to simulate at this stage.

Figure 13 shows that until 2005, water table depth in most parts of Lahore was up to 40 m. However, in the outer boundaries of the city, the water table was shallower as pumping was relatively low and recharge from rainfall and irrigation canals was significant. In 2008, the area within the depth of 30-40 m increased significantly and in some parts of the city the water table was even deeper. The projections show that areas under a range of 40-70 m will keep increasing and will cover most parts of the city by 2015. It is also projected that if persistent pumping continues, the water table depth in almost the entire central part of the city will fall to 70 m. By 2025, certain areas will witness a water table depth of even more than 70 m. The situation in 2040 will become worse when a significant part of the city experiences a water table depth of about 100 m or more. However, in the southeastern part of the city, the water table depth will remain high mainly due to seepage from canals and less pumping.

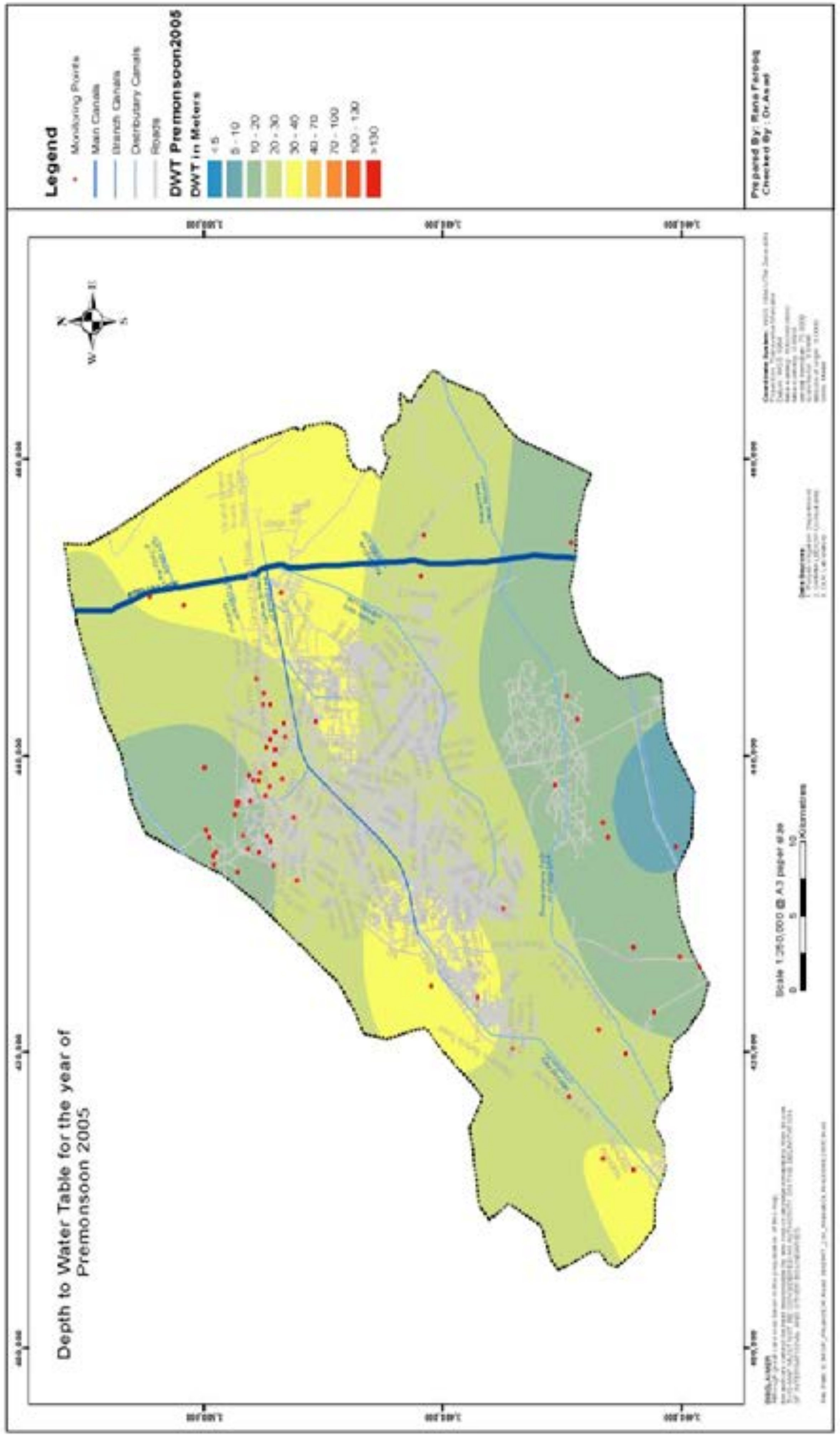


Figure 13: Depth to Water Table for the Year of Pre-monsoon 2005

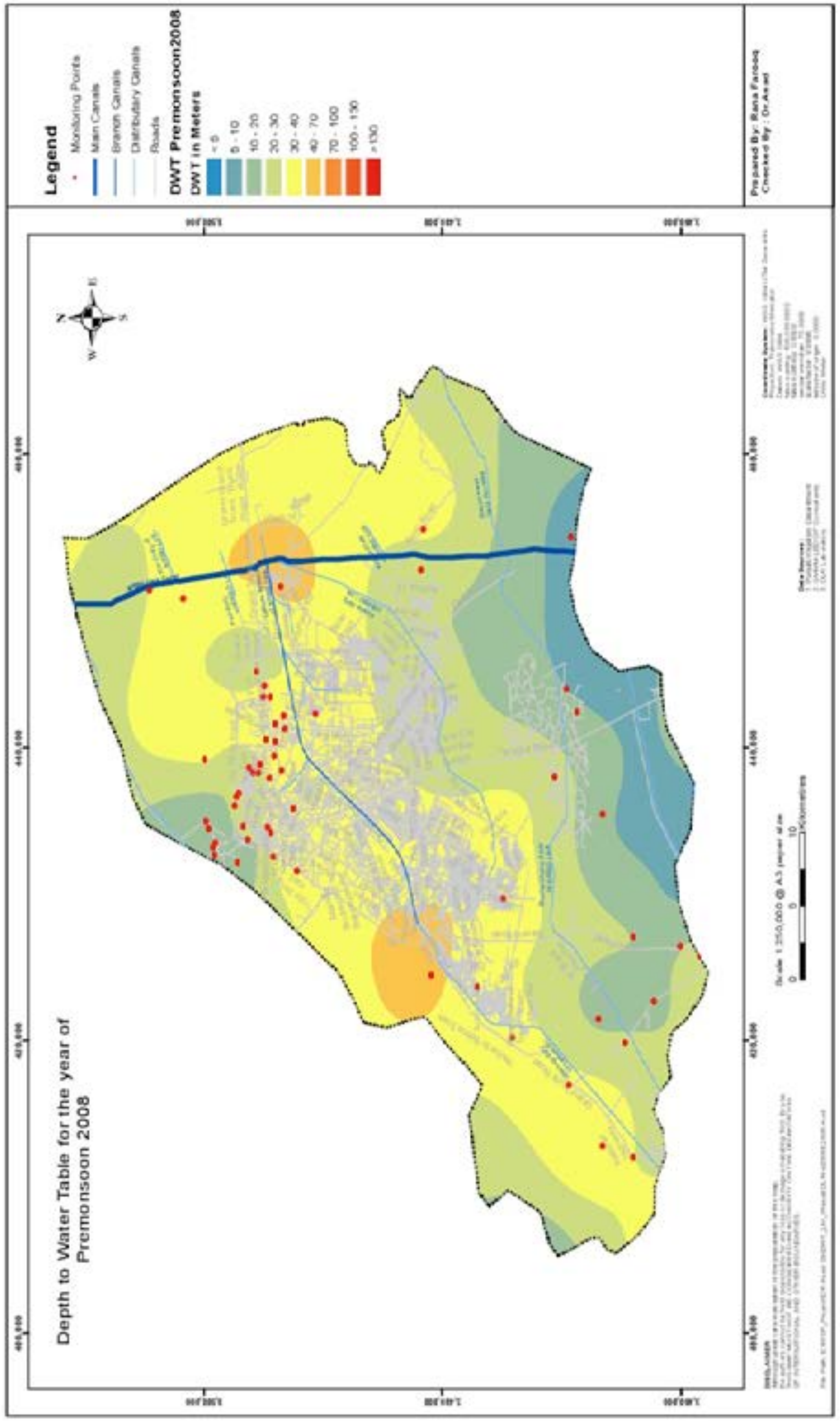


Figure 14: Depth to Water Table for the Year of Pre-monsoon 2008

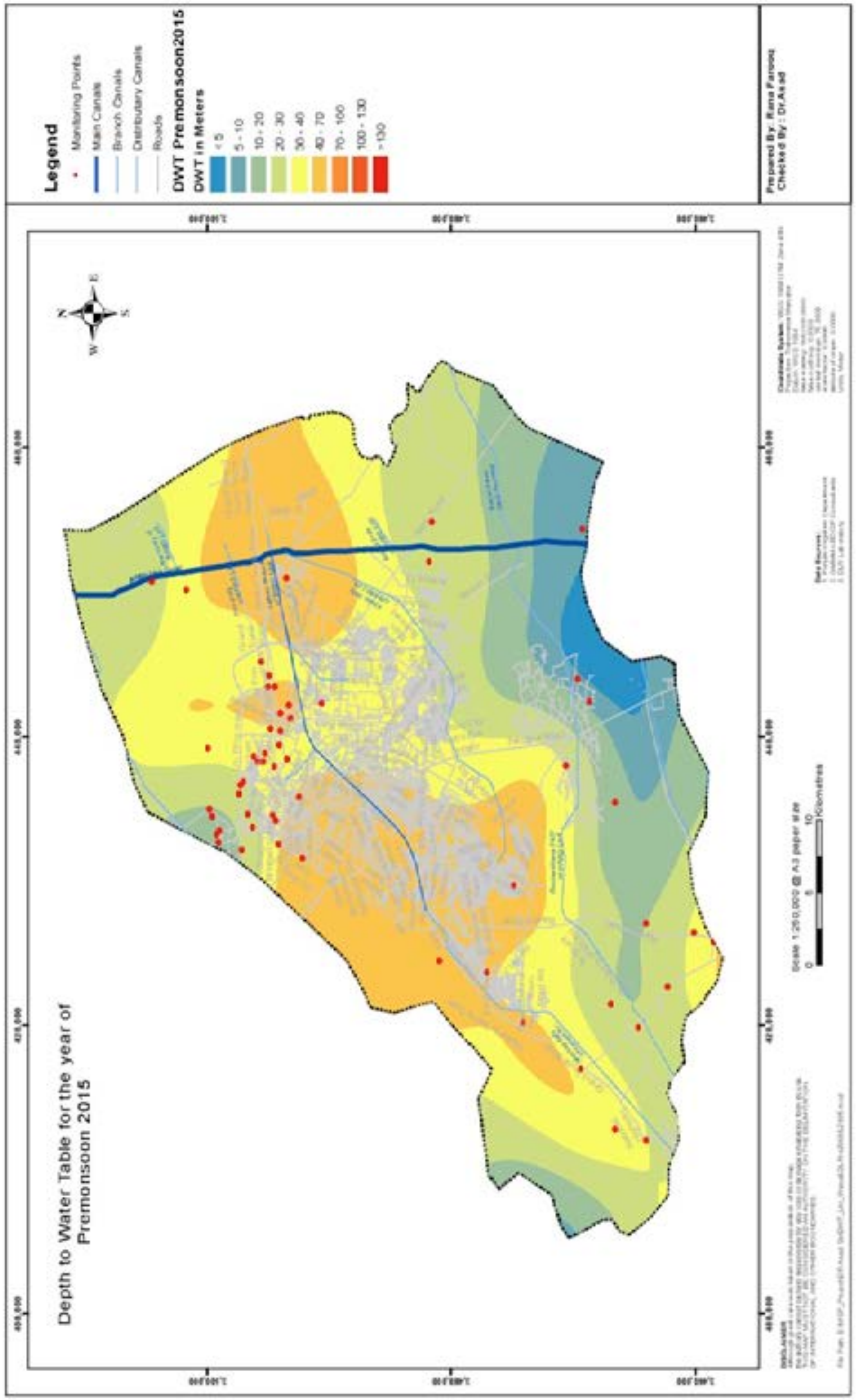


Figure 15: Depth to Water Table for the Year of Pre-monsoon 2015

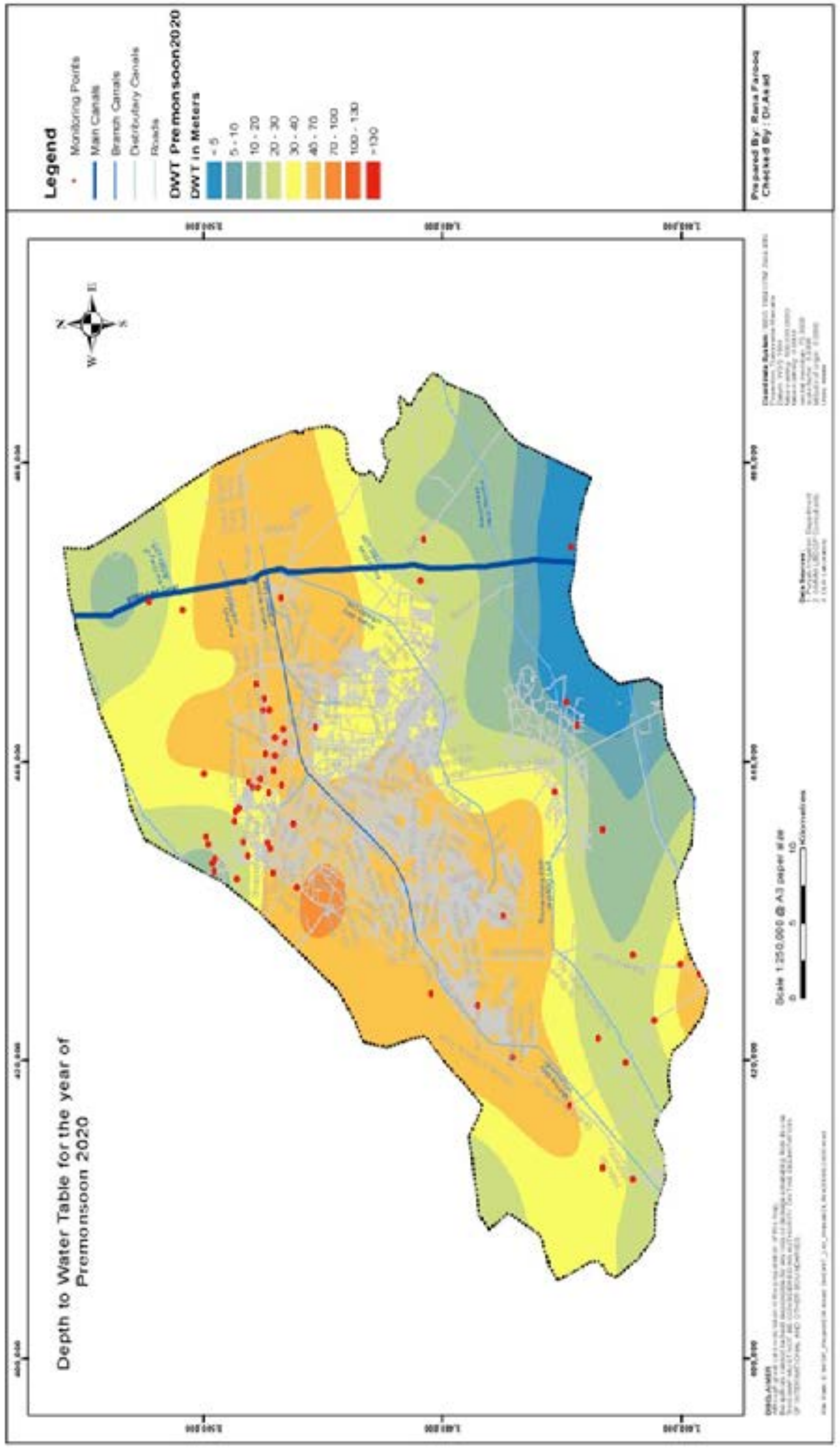


Figure 16: Current and Projected depth to Water Table for the Year of Pre-monsoon 2020

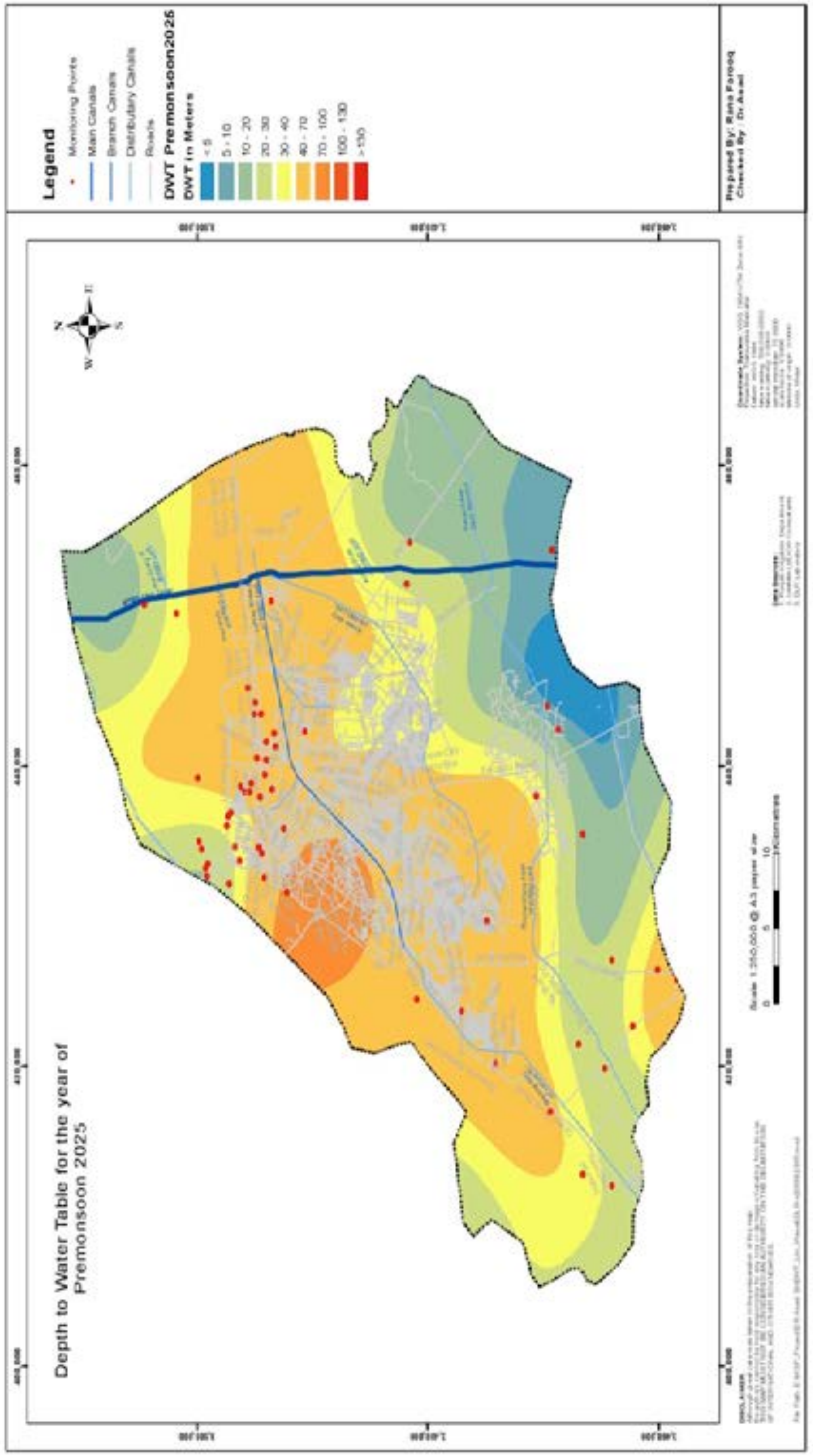


Figure 17: Current and Projected depth to Water Table for the Year of Pre-monsoon 2025

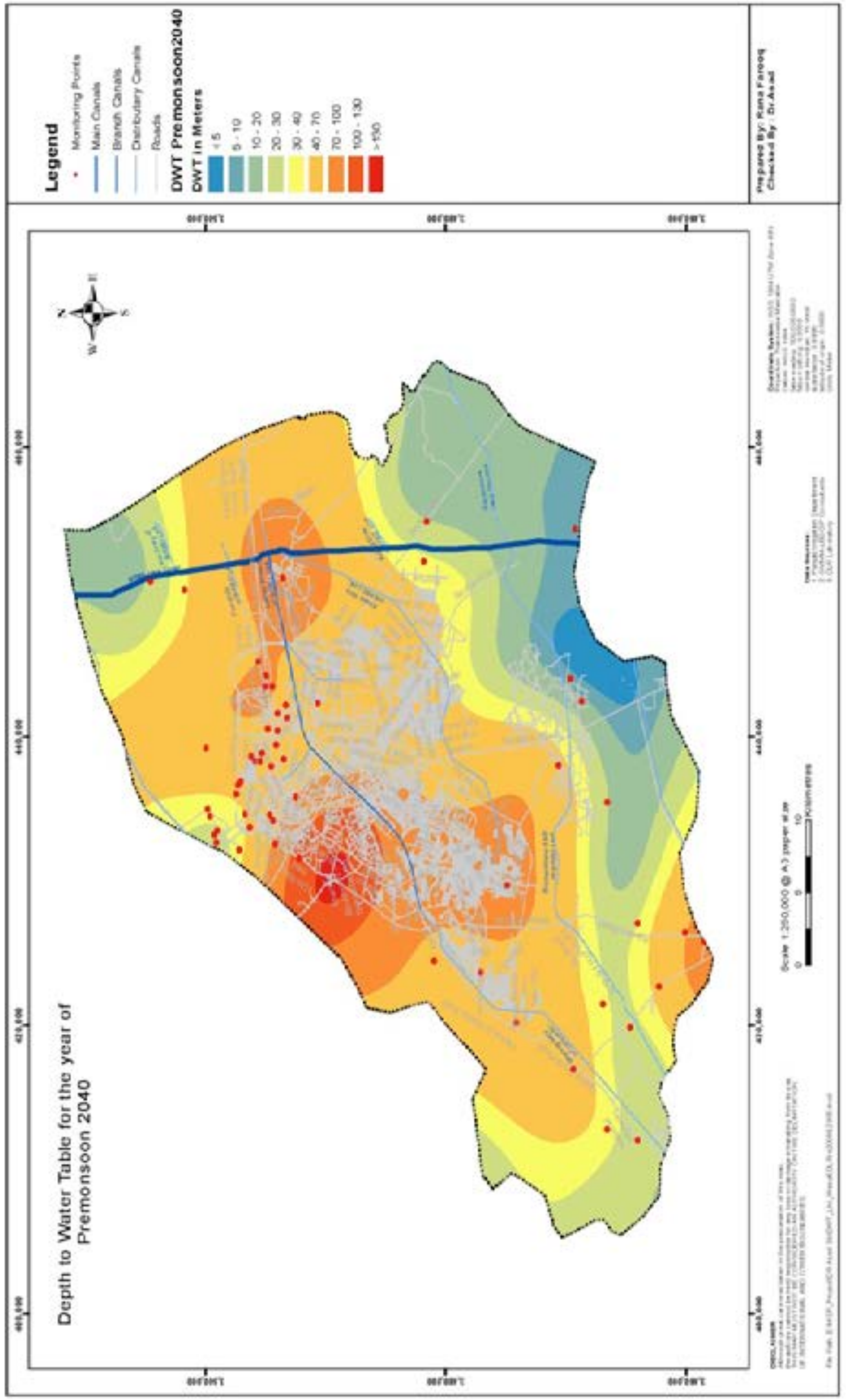


Figure 18: Current and Projected Water Table Depth for Lahore 2040

Due to over-exploitation of groundwater, there will be a clear shift towards increasing depths of the water table over time (Table 13). Until 2008, the maximum is within a depth of 40 m whereas after 2015 gradually the range 40-70 m. By 2040, an area of close to 250 km² (which will be 20 per cent of the total 1,227 km² urban area of Lahore) will have a water table depth of up to 100 m.

will experience excessive melting and flows of the Indus River will increase by 50 per cent. Thereafter flows will decrease and be reduced to 40 per cent of the year 2000 value by the end of the century (Rees and Collins, 2005). Groundwater resources are heavily used for human needs and to support agriculture. Renewable groundwater resources greatly depend

Table 14: Area (km²) under Different Ranges of Depth of the Water Table

	Different Ranges of Depth of the Water Table								
	<5	5-10	10-20	20-30	30-40	40-70	70-100	100-130	>130
2005		51	447	913	430				
2008		116	280	560	813	73			
2015	31	102	219	477	544	468			
2020	71	73	203	394	410	676	15		
2025	33	89	253	313	333	757	65		
2040	25	68	244	241	215	741	252	50	7

Extraction of water from these depths will not be technically or financially feasible. With the persistent energy crisis, groundwater pumping from excessive depths will be a huge economic burden on WASA and other organizations.
In Pakistan, the groundwater extraction cost (including both installation and energy costs) from a depth of 20 m is Rs. 2,200 (US$20) per 1,000 m³. For a water table depth up to 40 m, this cost increases to Rs. 5,000 (US$50) per 1,000 m³ and will double (US$100 per 1,000 m³) if the water table depth goes beyond 70 m (Qureshi et al., 2008).

In addition, deeper water table depths will increase the risk of saline water intrusion from neighbouring areas which will aggravate quality issues.

4.3 POTENTIAL IMPACTS OF LOCAL AND REGIONAL CLIMATE CHANGE

Pakistan is highly dependent on its water resources originating in the mountains of the upper Indus to sustain its irrigated agriculture which is the main stay of its economy. Hence, any change in the available water resources through climate change or other human interventions will lead to serious challenges of food security and livelihood of millions of poor. Although research on climate change in Pakistan is still in its infancy, evidence suggests that future changes in climate will have adverse effects on agricultural production. It is predicted that due to increasing temperatures, the Karakoram Glaciers

on recharge from river flows. Therefore, any reduction in river flows will adversely affect recharge to groundwater. The recharge to groundwater from the River Ravi has already become alarmingly low and will be exacerbated as a result of climate change in the years to come. This will have serious consequences for the population of Lahore which is solely dependent on groundwater to meet its domestic and industrial demand.

Pakistan needs to prepare itself for the possibility of future changes in climate. Current water management practices may not be robust enough to cope with the impacts of climate change on water supply reliability, flood risk, health, agriculture, energy and aquatic ecosystems. Therefore, improving water management is the best strategy to cope with projected climate changes and their impact on the agricultural economy, water supply to cities and the environment.

For this purpose, Pakistan needs to have a better understanding of global warming impacts on water, energy, and agriculture projects at the national level in order to develop risk management planning and introduce an adaptive infrastructure design criteria. To make these projections useful, uncertainties need to be reduced and spatial scale increased. Therefore, it will be of paramount importance to improve our understanding regarding uncertainties about the origins of climate trends, linkages between climate change and glacial accumulation, ablation and runoff.

4.4 MANAGEMENT OF DEGRADING WATER INFRASTRUCTURE

Water availability in the Indus Basin is highly seasonal with 85 per cent of total river flows occurring during the summer season (July-September). Storage is therefore critical for inter-seasonal transfer of water from surpluses in the summer (kharif) season to meet shortages in the winter (rabi) season to meet crop needs. Due to increased siltation, the storage capacity of Pakistan's reservoirs is expected to decrease by 57 per cent by the year 2025. Recent estimates suggest that to meet future water requirements 22 BCM more of water will be needed (World Bank, 2008a). The existing storage capacity will therefore need to double at least.

Relative to other arid countries, Pakistan has very little water storage capacity, i.e. 15 per cent of annual river flows. Pakistan can barely store 30 days of water in the Indus Basin. If no new storage is built in the near future, canal diversions will remain the same and shortfall between water availability and water demand will increase by 12 per cent by the next decade. The Pakistan Water Sector Strategy estimates that Pakistan needs to raise its storage capacity by 22 BCM by 2025 in order to meet projected requirements of 165 BCM. Therefore, it is of paramount importance that Pakistan gives serious attention to building new storage facilities.

The debate on small dams versus big dams in Pakistan has been going on for some time. Currently there are over 68 listed small dams in Pakistan which provide irrigation services to about 3000 ha. Plans to build another 300 small dams in different parts of Pakistan have hit the snags due to cost and feasibility concerns. The costs on these dams are not justified due to their limited benefits. While small dams can be used to supply drinking water for rural communities, livestock, and production of fish and provide opportunities for supplemental irrigation to rain fed areas, they have limited capacity to generate electricity (WWF, 2012). Large dams are considered feasible for the production of cheap energy but have serious social and environmental limitations. Therefore, Pakistan needs to introduce the concept of sustainable hydropower which essentially advocates integration of economic development, social development and environmental protection.

Pakistan has a large irrigation infrastructure base with an estimated replacement cost of US$60 billion (World Bank, 2005). However, due to age and neglect, much of the water infrastructure is in poor shape resulting in huge system losses and low performance in carrying water to the tail reaches of the canal commands. The cumulative effect on river barrages and head works has left these strategic structures very vulnerable to unforeseen damages with enormous consequences. Due to deferred maintenance and lack of rehabilitation, the delivery capacity of canals is 30 percent lower than designed capacity. With decreasing water availability in the future, Pakistan needs to designate more financial resources for the rehabilitation of its water infrastructure and develop a modern asset management plan for its future maintenance.

4.5 WATER-RELATED RISKS FOR INDUSTRY

The aforementioned future problems of water availability, deteriorating surface and groundwater quality, and climate changes will be major challenges for industries and businesses. It is well known that the era of cheap and easy access to freshwater is over. This will have far reaching impacts on industries as there is no substitute for water which is needed for industrial processes and human survival. For this reason, industries need to boost their scrutiny of water related risks.

In the context of Lahore where groundwater is pumped at an alarming rate, an increasing demand for water industries will increase inter-sectoral competition for water, particularly from the municipal and agricultural sectors (Alam and Bhutta, 1996). Demand for food and water has increased as a result of population growth and agriculture and municipal sectors will now claim water than their present allocations.

The increasing dependence of agriculture on groundwater, due to reduced surface water resources, is already posing a serious threat to the sustainability of irrigated agriculture in Pakistan. Similarly, the water requirements of municipal services (water supply and sanitation) will increase manifold in future. Since most of these supplies come from groundwater, it will be difficult for industries to convince civil society to be given greater access to groundwater.
In Lahore, the most prominent industries are textile, beverages, sugar, leather, food, pharmaceuticals and electronics. These industries have high water demand and therefore will have a greater water-related risk in future. They also have different water footprints depending on their water use and discharge patterns. Therefore the degree and the nature of risks will vary widely.

Cotton production is the most water intensive value chain segment for the textile sector and is also the segment most vulnerable to climate-induced physical water risks. Cotton is an immensely thirsty plant requiring 2.7 m^3 of water for each 250 grams of cotton produced – the amount needed for an average t-shirt .Textile processing is both water and energy intensive. Freshwater is an essential resource for textile processing such as dyeing or bleaching. Therefore, due to decreasing availability of freshwater, this sector is expected to suffer the most.

Portable water is the primary and most important ingredient for the majority of beverage products. Therefore, the operation of beverage companies is especially vulnerable to water availability and quality concerns. The high quality water sources required by beverage companies put them in direct competition with local populations and their drinking water needs. The virtual water use of beverage companies (water used to manufacture plastic bottles and packaging material) is also much higher than actual water use to produce beverages.

A recent study has shown that to produce one litre of bottled water in Pakistan, about 16 litres of freshwater is used. The biggest proportion of this water goes into the production of plastic bottles and the plastic packaging material (Qureshi and Nawab, 2014). For similar reasons, the use of bottled water in developed countries is decreasing . It is estimated that bottled water consumption in Pakistan will increase to 500 million litres (7.7 million m^3) by 2025. Most of the water used in this industry comes from groundwater. With declining groundwater tables and deteriorating groundwater quality, meeting this demand will be a serious challenge and the beverage industry can be at high risk. Therefore, the industry needs to find ways to reduce its water consumption.

In the food industry, the most significant water-related exposure is in raw material production (i.e. precipitation and irrigation is needed to grow food and maintain pastures for grazing). Water availability also impacts food commodity prices. Increasing temperatures and dry weather as a result of climate change is expected to increase the water requirement for livestock whose numbers are growing as global demand for meat increases. Consumption of red meat in Pakistan and India has increased by 33 per cent in the last decade and is expected to double globally between 2000 and 2050 . Increasing awareness among consumers that meat is a very water-intensive food with a large carbon footprint, may affect demand for meat production in the future.

Water is also an important source for the pharmaceutical and electric industry, with the most significant portion of the industry's water footprint associated with semi-conductor manufacturing.

The water-related risks for industries can be divided into three categories; i) physical risks, ii) reputational risks and iii) regulatory risks (Morrison, et al., 2009). These risks are briefly discussed below:

PHYSICAL RISKS

Water scarcity directly impacts business activities, raw material supply, intermediate supply chain, and product use in a variety of ways. Decline or disruptions in the water supply can undermine industrial and manufacturing operations where water is needed for production, irrigation, material processing, cooling and/or washing and cleaning. A decreasing water supply of acceptable quality can seriously damage production potentials. The quality of water is critical in many industrial production systems and a contaminated water supply may require additional investment and operational costs for pre-treatment. In cases where the current high quality water source does not require pre-treatment, a degraded supply can necessitate costly capital expenditures for treatment technology. When alternative sources of water or treatment options are not physically or financially feasible, industries will have to shut down operations or relocate to areas where water of acceptable quality and quantity is available.

REPUTATIONAL RISKS

Reputational risks are related to socio-cultural problems. Decline in water availability and quality increases competition for clean water, which is likely to develop tensions between businesses

Water footprints are geographically explicit, indicating the location of water withdrawal or discharge, and includes both direct (e.g. water withdrawals) and indirect water use (e.g. the water used to produce inputs). A water footprint measures three primary components: blue, green and gray water footprints. Blue water is freshwater from surface water and groundwater sources. Green water is rainwater stored in the soil as soil moisture, and gray water is polluted water. The methodology for calculating water
footprints has been developed by the Water Footprint Network (WFN). Source: "Water Footprints, "Water Footprint Network, 2008'. See: http://www.waterfootprint.org/?page=files/DefinationWaterFootPrint

Valeries Stevens, 2007. "Fresh Water, "Optimum Population Trust, Manchester, United Kingdom. See: http://www.optimumpopulation.org/opt.more.water.html

Public concern about clean water access is impacting bottled water sales, worth $91 billion globally in 2007. Public demand is soaring in developing countries, but falling in large developed countries such as United States. PepsiCo sustained lower quarterly earnings and major job losses in 2008, largely due to falling sales of its non-carbonated beverages and bottled water. A 2008 Morgan Stanley study showed that 16 percent of consumers are cutting back on bottled beverages and drinking more tap water for environmental reasons. Andrew Martin, "Tap water's popularity forces PepsiCo to cut jobs," International herald tribune, October 15, 2008.
See: http://www.iht.com/articles/2008/10/15/bussiness/15pepsi.php

Elizabeth Rosenthal, "As more eat meat, bid to reduce emissions," The New York Times, December 3, 2009. See: http://www.nytimes.com/2008/12/04/science/earth/04meat.html and local communities, particularly in areas where the local population is still struggling to have access to a safe and reliable drinking source. Local conflicts can damage brand image or, in rare instances, even lead to loss of operating licenses. Due to increasing pressure from civil society, companies may lose their licenses to use groundwater. These risks will increase as people become more aware of their right to access water. Healthy aquatic ecosystems are an essential part of local communities and livelihoods, not as a source of clean drinking water, but also by providing cultural, social, aesthetic and economic value. Therefore, significant water withdrawal or wastewater discharge will inevitably increase the risk of potential conflict with local communities. Due to declining groundwater table conditions in Lahore, communities may also raise their voices in future to limit extraction of groundwater by industries. Further, reputational risks occur when corporate activities are seen as inconsistent with responsible stewardship.

REGULATORY RISKS

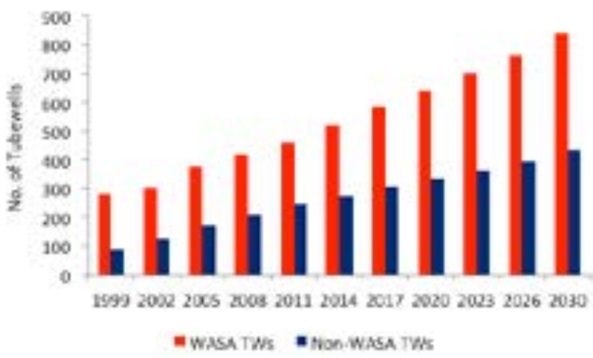


Figure 19: Current and Projected Tube Wells for WASA and non-WASA Areas (Source: Farhan, 2009)

Physical and reputational pressures affecting water availability and wastewater discharge can result in more stringent water policies. Water scarcity, coupled with increased concern of local communities about water withdrawals, will put pressure on local authorities and policymaker may consider water reallocations, regulations, and development of water markets that can usage, suspend permits to draw water and lead to stricter water quality standards. Concerns over water pollution and its impacts on the ecosystem and local water resources may lead to new and costly requirements on companies' wastewater discharge. Some national governments already impose strict water quality standards on water supply and wastewater discharge. Such standards can lead to costly litigation, civil penalties or criminal fines. Other governments, especially in emerging markets, have yet to develop and/or enforce water quality standards.

In summary, the industrial sector is expected to have the following water-related risks in future.

- Reduced access to water;
- Increasing pressures from communities to reduce groundwater withdrawal and look for other options to meet their water requirements;
- Increasing costs to treat water as per regulations;
- Regulatory restrictions for specific industrial activities and investments;
- Increased health costs for employees;
- Reputational risks in the back drop of increasing trade with international brands;
- Future water availability (physical risk) in case of increased demand of the products/ services

Taken together, this means that industries will face increased uncertainties about the availability of quality water supply. Therefore, it is increasingly crucial for the industrial sector to think of collective actions to avoid water risk. A critical driver of success in the 21st century economy will be how companies and investors balance competing demands for water and energy. Companies should be prepared to provide details on the risks they face from water challenges and to be transparent about energy trade-offs.

4.6 WATER-RELATED RISKS FOR COMMUNITIES

It is anticipated that by 2030, WASA will need to extend its services to 9.0 million people compared to 6.0 million in 2013 (WASA Report, 2013). The projected water demand in 2030 will increase to about 3,200 MCM/year from 1,985 MCM/year in 2013. To meet this demand, WASA will have to install 358 more tube wells by 2030 (Farhan, 2009). This will increase the total number of WASA tube wells to 842 from the existing 484 (Figure 9). Similarly, the number of non-WASA tube wells will increase to 435 from the existing number of 240. This study further reveals that with the continuation of existing abstraction patterns, water table depth in Lahore will drop to 48 m in 2015, 54 m in 2020 and more than 60 m in 2025.In addition to the installation of extra tube wells, WASA will have to reduce the average water demand to reduce the gap between future demand and supply of water. The current unaccounted for water is 33 per cent, which needs to be reduced to 23 per cent (JICA Report, 2010; WASA Report, 2013).

Groundwater in densely populated urban areas of Lahore is falling rapidly, which is replete with serious consequences. Unless managed properly, there is a growing danger that it will become contaminated due to intrusion of saline groundwater from neighbouring areas. Although the Lahore aquifer is a part of the huge groundwater reservoir lying under the Indus Plain, extensive groundwater withdrawal has formed a groundwater depression zone in the central part of the city, which is gradually expanding (Figure 15). In the depression zone, the water table was 5 m deep in 1960, and has now declined to 40 m. As a result, groundwater from surrounding areas has started moving into the depression zone. The area of the depression zone, which was 52 km² in 2007, swelled to 150 km² by 2011 (Khalid et al., 2013). The area of this depression zone keeps varying as a result of rainfall and its impact on recharge to groundwater. The maximum expansion in the depression zone occurred during the period 2008-09 (64 km²) whereas the minimum was in 2010-11 (8 km²).

In the surrounding areas of Lahore, a strip of about 10km wide between Pattoki and Chunian starting from Raiwind and ending at about the middle of Okara and Sahiwal, contains highly saline groundwater (up to 10,000 parts per million) (Basharat and Rizvi, 2011). Continuous groundwater pumping from this depression zone is likely to induce a negative hydraulic gradient, which can accelerate the intrusion of saline groundwater from this strip to the fresh groundwater zone of Lahore. If this were to occur it would have disastrous consequences as there is no quick and simple way available to clean the polluted aquifer. Therefore, it is imperative to control pumping in the most vulnerable areas to save safe clean drinking water for the next generations.

4.7 WATER-RELATED HEALTH AND ENVIRONMENTAL RISKS

Due to lack of appropriate drainage and treatment facilities, most untreated municipal and industrial waste is discharged into water bodies such as irrigation canals and the River Ravi. This polluted surface water in turn contaminates groundwater, which is the main source of drinking water. Recent water quality monitoring results (JICA, 2010) have shown that most drinking waters are biologically contaminated. The presence of faecal coliforms in drinking water has been found to be much higher than WHO standards. Khan et al. (2013), based on the analysis of industrial wastewater samples collected from 25 different localities of Lahore district, has found higher concentrations of Copper, Manganese, Nickel and Cadmium above WHO limits whereas Zinc, Iron and Lead concentrations were below these safe limits. Elevated levels of heavy metals in sewage water

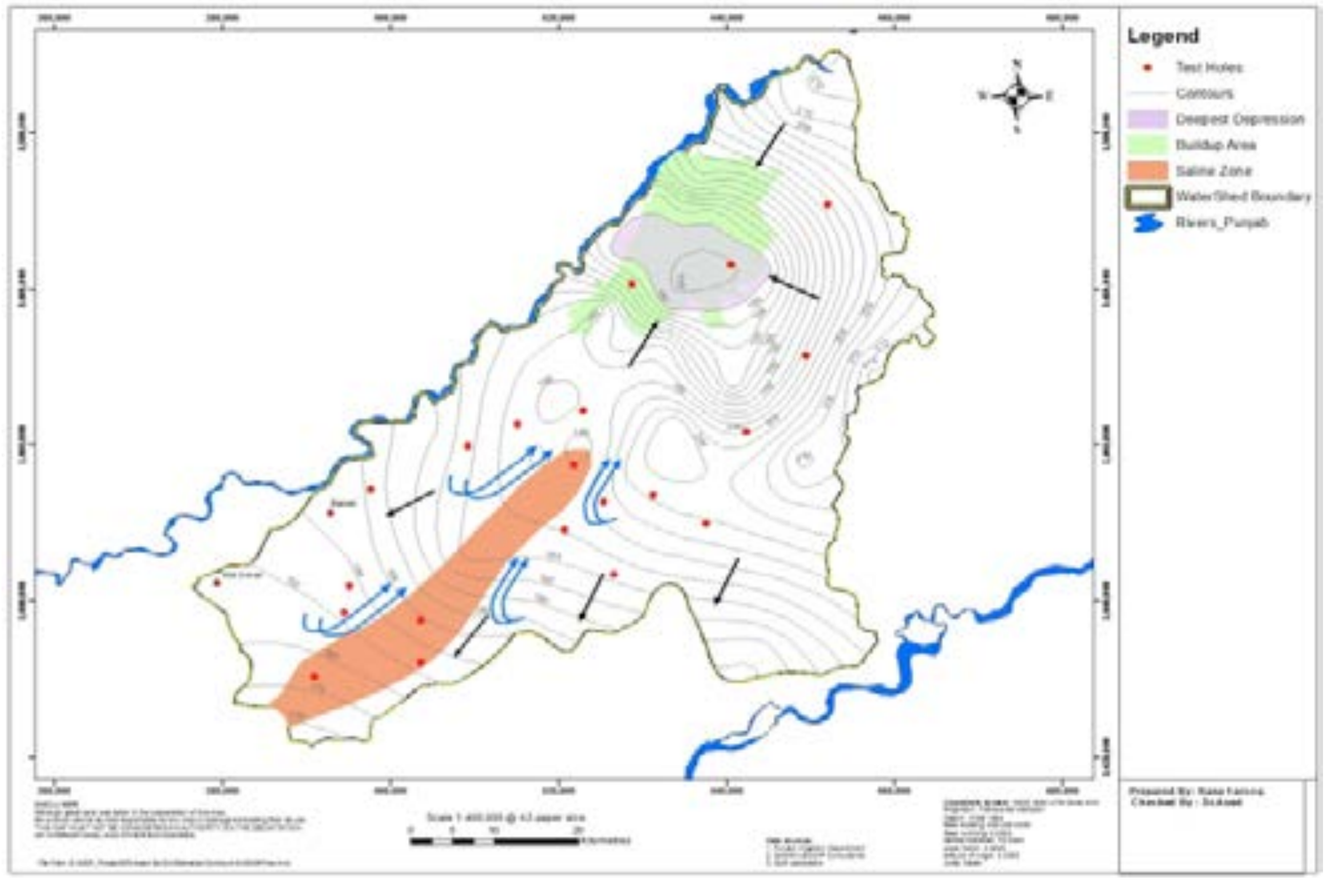


Figure 20: Groundwater Elevation Contours and Extent of Depression Zone.

were also found in Faisalabad (Ensink et al. 2007). The River Ravi is considered as the most polluted river among the main rivers in Punjab. Over time, a significant reduction in the Dissolved Oxygen (DO) level has occurred over a reach of 62 km between Lahore and Baloki because of excessive wastewater flows in the river (Basharat and Rizvi, 2011). This can have serious consequences for groundwater as the Ravi is the main source of recharge to groundwater, which is a potential source of drinking water for the population of Lahore (Ejaz et al., 2011).

Polluted water has become a threat to various water usages including drinking, irrigation, and sustenance of aquatic life. Lahore city is in constant danger of health and environmental risks and ecosystem challenges. The extensive use of Ravi water for irrigation not only leads to harmful effects on soil and crop quality but has become a serious threat to the groundwater aquifer, which is the only source of drinking water for Lahore as well as hundreds of villages downstream of the River Ravi (Soomro et al., 2011). Individuals who come in direct contact with wastewater are vulnerable to water-related diseases such as typhoid, cholera, dysentery and hepatitis, which are responsible for one third of all deaths (WHO, 2010; World Bank, 2006) .

The use of the River Ravi's contaminated surface water for irrigation and recreational purposes is also replete with serious consequences as this will have direct impacts on the ecosystem and human health. Moreover, it is detrimental to the habitat of birds such as the cattle egret, bank mynas and black drongos (Sadia and Zahid, 2011). In the peri-urban areas of Lahore, farmers use untreated sewage/industrial water for vegetable production. Evidences exist that, in Pakistan, vegetables and fruits grown with wastewater are prone to contamination with heavy metals. Khan et al. (2013) found that vegetables grown with wastewater in the peri-urban areas of Lahore, such as spinach and cauliflower, have heavy metal concentration higher than the permissible limits of WHO (1996). Spinach, bitter gourd, okra, pumpkin, turnip, and eggplant samples collected from Lahore's markets were also found to be contaminated with heavy metals (Faridet al.2003; Ronaqet al. 2005).The studies conducted by Ahsanet al. (2011) also confirmed the presence of Zicn, Copper, Lead, Nickel, Cadmium and Chromium contents in edible portion of vegetables.

The presence of toxic heavy metals in irrigation water, especially downstream of the River Ravi is also causing serious damage to aquatic life and wildlife in the surrounding areas (Ayesha, 2011). A direct economic impact of untreated wastewater is the loss of fishery catches, which affects incomes and has nutritional and health impacts on consumers. Constant use of such sewage/industrial water for irrigation over longer periods can cause build-up of heavy metals up to toxic levels for plant and animal health (Kirkhan, 1983).

The use of polluted water for irrigation is also dangerous for human health as crops with green leaves absorb a significant amount of heavy metals from the polluted water (Yasar et al. (2010). Traces of heavy metals in vegetables and fruits have been found in many parts of the world (Arora et al. 2008; Liu et al., 2006; Barman et al., 2000). The inflow of sewer and toxic industrial waste has increased the level of pollution in the Lahore Canal to an alarming level. The Biological Oxygen Demand (BOD) level of wastewater released by 12 housing societies into the Lahore Canal is 400 parts per million (ppm), according to a report by the Pakistan Council of Scientific and Industrial Research (PCSIR, 2011). This level is exhaustively higher than the maximum permissible level of 10 ppm. The Punjab Environmental Protection Agency (PEPA) has also shown great concern on the rising pollution levels in the canal and has recently issued notices to the Water and Sanitation Agency, Town Municipal Administration of concerned towns and many housing societies. The Irrigation Department had also sent legal notices to the administration of polluting housing schemes numerous times, but so far no action has been taken in this regard.

4.8 INSTITUTIONAL AND ORGANIZATIONAL CHALLENGES

The use of groundwater, other than for irrigation, is managed by WASA for urban areas and the Public Health Engineering Department (PHED) for rural areas. The Lahore Development Authority (LDA), established by the statutory Law, holds the authority to issue permits for the installation of tube wells. The LDA act states that:

1. The Authority shall have the exclusive right to use groundwater resources within the area.

2. No person shall, without the permission of the Authority, install a tube well at such places within the Area as may be notified from time to time in the official Gazette by the Authority.

However, despite these strict laws, excessive pumping of groundwater is taking place in the city. LDA has not notified any areas where groundwater should be restricted and, even if it is notified, the decision is not followed due to lack of accountability. Keeping in view the growing crisis of groundwater and its consequences on the future water supply of Lahore, WASA needs to play an active role in monitoring groundwater abstraction and identify critical areas where groundwater extraction should be restricted.

WASA is financially not a sustainable organization as its financial deficit during 2011-12 was 2,196 million (WASA Report, 2013). With the increasing price of electricity, 48 per cent of WASA's total funds are consumed to pay for electricity charges. A lion's share of 35per cent is spent on staff salaries whereas less than 20 per cent is used for the maintenance of the water supply and drainage systems. Considering the extensive role of WASA in supplying drinking water and providing drainage facilities to the large population of Lahore, the agency needs to revise its tariffs to generate more resources and bring innovations in operations to cut down administrative costs. The assessment of surface and groundwater quality is not carried out regularly despite water quality laws and regulations present in Pakistan. The Pakistan Environmental Protection Act (PEPA) 1997 focuses on the protection, conservation, rehabilitation and improvement of the environment, prevention and control of pollution, and promotion of sustainable development. The National Water Policy (draft), National Environment Policy and National Environmental Quality Standards (NEQS) also exist in Pakistan, but the implementation of laws and regulations is weak (Hashmi, 2011). The EPA has so far failed to enforce regulatory laws on industries which is the primary reason why industrial effluent is discharged into drains and canals without any treatment. This negligence is costing water consumer heavily in terms of pollution of precious water resources.

Pakistan ranks number 80 among 122 nations in quality of drinking water. The use of poor quality water causes many health related problems in the country. According to a study by UNICEF, about 20-40 per cent patients suffer from water-borne diseases, which causes one-third of all deaths (World Bank, 2006). About 25 per cent adults and 40 per cent children suffer from water-borne diseases (Bhatti and Mustafa, 2009). It has been reported by the World Bank that Pakistan spends 1.8 per cent GDP on health costs related to water-borne diseases (Benjamin, 2011).

5.0 STRATEGIES FOR FUTURE MANAGEMENT AND MITIGATION

5.1 MANAGING AQUIFER RECHARGE

Increasing demand and decreasing availability of surface water resources suggests that, in future, dependence on groundwater will increase. It is further projected that quantities of surface water supplies will vary significantly because of increased drought and flood events due to climate change (Kundzewicz et al. 2007). This is highly unlikely that current water management practices will be adequate in reducing the impacts of climate change on the reliability of water supplies.

Despite the construction of more than 800,000 dams around the world, only 20 per cent of surface runoff is stored. In many Asian countries, more than 70 per cent of rainwater still runs into the sea (INCID, 1999). Groundwater supplies can be increased significantly if a small portion of this rainwater is stored underground which requires sound aquifer management with planned decline of the water table in the pre-monsoon dry months. Partially empty aquifers enhance recharge from both monsoon rains and return flows from irrigation water. Many developed nations have practiced aquifer management similar to this. For example, artificial groundwater recharge contributes to total groundwater use by 30 per cent in Germany, 25 per cent in Switzerland, 22 per cent in the USA, 22 per cent in Holland, 15 per cent in Sweden and 12 per cent in England (Li, 2001).

To protect the quantity and quality of groundwater, groundwater protection zones need to be identified according to the safe yield of the aquifer. If groundwater extraction volumes exceed the recharge rate several negative consequences will occur such as water level decline, land subsidence, and increased salinity (Sharma and Smakhtin, 2006). Introduction of groundwater protection zones can help implement policy instruments such as a ban on boreholes and dug wells, defining limits of withdrawal, imposing groundwater extraction fees, etc.

GROUNDWATER PROTECTION

Depression zones can be classified according to the level of vulnerability to groundwater extraction and should be protected from potentially polluting activities, viz. urbanization, solid waste dumping, chemical disposal, mining and quarrying. In Lahore, for example, central parts of the city where a groundwater depression zone has developed should be defined as a "groundwater protection zone" and pumping should be restricted or at least regulated. Once groundwater protection zones are defined, more complementary approaches can be initiated such as public information campaigns and groundwater user groups.

Since groundwater plays an important role in economic development, prohibiting or limiting access to groundwater is tantamount to stopping development. Agriculture and industry depend heavily on groundwater, so policies dealing with agriculture and industrial development must try to incorporate the impacts of climate change on groundwater resources. In many countries such as Japan, industries have been given access to surface water resources to reduce their dependence on groundwater. In Pakistan, industries can also be given surface water rights to cut down pumping. In addition, industries should also be required to facilitate groundwater recharge and improve efficiency of water use.

Government agencies are less interested in explaining the importance of groundwater resources and potential impacts of climate change on groundwater to communities and industries. This is perhaps the reason that people usually consider groundwater an unlimited resource and uses it generously. Therefore, all water users and stakeholders, including government staff, need to be educated about the importance of groundwater to ensure sustainable management of groundwater resources. Providing education and training to local communities about rainwater and runoff water harvesting for domestic use, agricultural use and for groundwater recharge will also enhance the adaptation options to cope with current and anticipated future problems.

5.2 BALANCING DISCHARGE AND RECHARGE

The existing technical and institutional capacity of WASA and LDA has so far been unsuccessful in developing a tangible mechanism to regulate groundwater use in the city. This has created a huge imbalance between discharge and recharge, which has resulted in the rapid depletion of groundwater resources threatening the drinking water supply of approximately 10 million people in the city. Similarly, non- compliance of environmental laws by industries has polluted surface and groundwater resources to the extent that their use has become unsafe for humans, animals, soil and aquatic life. Therefore, there is an urgent need to take necessary measures for the protection of the quality and quantity of groundwater resources. The following suggestions may be helpful in this regard:

- WASA should educate households to reduce water usage especially in the central parts of the city where the depletion rate is much higher than other parts of the city. Under its long-term plan, WASA has proposed to reduce the per capita allocation from 335 lpcd to 227 lpcd in an attempt to minimize the gap between demand and supply. This reduction in demand must be taken seriously and steps should be taken to implement it.
- For long-term sustainability of drinking water supplies, groundwater supplies should be supplemented by surface water supplies. The possible surface water sources that can be tapped for this purpose include the River Ravi and BRBD canals, once quality concerns are addressed. However, there is a need to strike a balance between recharge and usage by implementing laws and regulations at all levels.
- New housing societies should also be made aware of the problem and their groundwater extraction quota should be fixed, based on specified per capita demand.
- To increase recharge to groundwater, rainwater harvesting should be encouraged in all new schemes and in WASA jurisdiction areas. Special recharge zones need to be developed where rainwater can be collected and then used to recharge groundwater using different recharge technologies. However, while doing so the rights of downstream users must be protected.
- Water should be treated as an economic good and its exploitation rights should be given through a proper permit system and competitive pricing especially to the industrial sector. Well defined groundwater usage rights should entitle individual users or user groups to an abstraction allocation at a certain point in time or during a specified time period in certain aquifer conditions.
- The majority of WASA customers are provided water on a flat rate equivalent to the area of the house which results in water wastage. To promote the culture of water conservation, a metering system should be introduced to levy a charge on water usage on a volumetric basis. This will help in promoting economically usage of water in the same way as electricity, gas and other utilities.
- WASA, LDA and EPA should enforce environmental laws to restrict industries from disposing of waste in drains, canals or other water bodies without treatment.
- Monitoring of waste disposal at key points should be introduced to act as a guiding tool to find sources of major pollution in surface drains.
- Quantity and quality of wastewater disposed of by the government as well as private entrepreneurs should be monitored regularly. All polluters should be required to treat waste at source before throwing it into water channels. Existing laws and their implementation needs to be stricter. The National Water Quality Standards also need to be revised so that they are relevant to Pakistan's situation.
- Sewerage should be treated before disposal into the River Ravi. A lined channel alongside the

River Ravi to transmit treated waste can help reduce pollution loads to the aquifer.

5.3 PROTECTING SURFACE WATER AND GROUNDWATER QUALITY

Water quality challenges need to be addressed in an integrated manner and by adopting pollution prevention strategies. Water pollution can be reduced by eliminating contaminants at source, which is the most effective way to protect water quality. Pollution prevention involves reducing or eliminating the use of hazardous substances, pollutants, and contaminants; process modification techniques so that less waste is generated; reducing leaks and fugitive releases; and reducing energy and water consumption (Ayesha, 2012). The prevention of pollution at source is a cost-effective solution as less money is required on waste handling, storage, treatment, remediation, and regulatory monitoring. Industrial units can recycle wastewater generated from one process into another process if it satisfies water quality standards.

There are effective technologies and approaches for the improvement of water quality and wastewater treatment. Industrial units and municipal institutions should be legally bound to set up treatment plants and local technology should be used to establish treatment plants rather than importing costly equipment. WWF-Pakistan's project City wide partnership for sustainable water use and water stewardship in SME's of Lahore-Pakistan has selected the four most water intensive SMEs (textile processing, leather, sugar, and paper and pulp). The project has engaged intensively on ground with a group of select SMEs to practice local and easy-to-implement solutions that do not require big investments to save water. These techniques are focused on good housekeeping and management services pertaining to reuse and recycling practices Such as:

- Leaks and spills control
- Monitoring and measurement of water carrying lines by installing water meters
- Workers training
- Identifying unnecessary washing of both raw material and equipment and simply turning off water when machines are not operating
- Reuse of water for other processes such as cooling, cleaning etc.

The increased investment on existing water quality systems and research to improve water treatment methods can help in reducing the cost of treatment, and increasing the reliability of existing methods.

Water quality solutions include:

- Regular monitoring of water quality. For this purpose, capacity of institutions (staff, laboratories, technologies, finances) should be enhanced.
- Water quality rules and regulations should be enforced in order to prevent the discharge of untreated effluents from industrial units and municipalities.
- Appropriate solid waste management system should be introduced to prevent the dumping of solid waste into water bodies and leachate generation.
- Proper sanitary landfill sites should be constructed and the open dumping of human excreta and animal waste should be prohibited.
- A sustainable pollution control strategy should be devised in order to reduce wastewater volumes. This approach may include segregation of wastewater streams, process modification techniques and recycling and reuse of wastewater.
- Epidemiological studies should be conducted in areas close to contaminated water bodies in order to assess the effect of polluted water on the health of consumers.
- Mass awareness campaigns about the importance of water quality should to be launched. Media and non-governmental organizations (NGOs) can play a vital role in this aspect.
- An integrated water resource management approach should be adopted by involving all stakeholders for the protection of water quality. The linkage between research and development needs to be strengthened.

5.4 MANAGEMENT STRATEGIES FOR INDUSTRIES

Water is crucial for the economy. Virtually every sector and industry from agriculture, electric power generation and industrial manufacturing to beverages, apparel, and tourism rely on it to grow and ultimately sustain their business. It is now a well established fact that water is becoming scarcer and there is every indication that its availability will be further reduced in the future. Increasing demand, degrading quality, and growing competition for water by various sectors is already putting enormous pressure on businesses to reduce their consumption of clean water. Until recently, industries used reliable and inexpensive water without any problem. However, during the last few years, the use of water by industries and the discharge of untreated wastewater in to freshwater bodies have come under great scrutiny. As a result, there is growing pressure to reduce water allotments to industries, pricing water more realistically and developing stringent quality regulations to dispose of industrial wastes.

Lately water stewardship is promoted as a practical approach for businesses and industries to address their common and shared responsibilities with other stakeholders in order to reduce their footprint of water usage and to work towards sustainable water resources. Increasing demand and increasing water usage by the corporate sector suggests that supply chains dependent on the Indus Basin would be at risk of continued future operations.

Water presents real and prevalent obstacles for companies now and in the near future, and company risk at a river basin level implies that other users are at risk too – namely ecosystems, other businesses, communities and governments. Identifying government and company shared risk around water enables all parties to find common ground in the urgent need to manage water effectively, equitably and sustainably. Water stewardship involves guiding key companies, both water users and investors, on a journey toward better river basin governance at national level where water is allocated appropriately, taking all stakeholders into account. Companies must first focus on how the water footprint of their operations and supply chains can improve but crucially also understand the context of where they directly and indirectly operate.

Climate change is also expected to alter all components of freshwater which means that access to water of acceptable quality will be the biggest issue for societies and the environment. Nestlé's Chairman Peter-Letmathe puts it more bluntly, calling water availability a bigger challenge than energy security by stating, 'I am convinced that, under present conditions and with the way water is being managed, we will run out of water long before we run out of fuel.'

Despite these challenges, businesses and investors are largely unaware of water-related risks and do little to develop strategies to cope with this challenge in future both at the personal and collective level. Investors are mostly unaware of these risks due to poor information therefore the corporate sector needs to have full disclosure of these risks and their economic implications. In this section, a number of actions are proposed which can help in the management and mitigation of water-related industrial risks.

- Companies should become conscious of their water footprints (i.e. water use and waste water discharge) throughout their entire value chain, including suppliers and product use.
- Companies should assess their physical, reputational and regulatory risks and seek to align the evaluation with the company's energy and climate risk assessment.
- In the context of Lahore, all industries should resolve to monitor their water resources and develop strategies to maintain their water reserves.
- Industries should invest in treating their wastewater at source and reuse it. This will build up their reputation in society and will help them in avoiding future water risks.
- Industries should install wastewater treatment plants. Technologies need to be scaled up rapidly to deal with the tremendous amount of untreated waste entering water bodies daily; and water and wastewater utilities need financial, administrative, and technical assistance to implement these approaches.

To promote water conservation as a collective action in the industrial sector, developing compelling arguments for why businesses should engage in collective action to address water management challenges will be critical to the success of any endeavour that is taken at the industrial level. In fact, what is required is a 'business approach' at the city level to highlight the importance of sustainable water resources for the economic activity of the city and for the concerned business. In other contexts, demonstrating the economic value of water has proved to be a catalyst for water management authorities and businesses to take action to place water resources on a more sustainable consumption footing. A step towards achieving the said objective could be to develop a common understanding amongst all stakeholders (business, government, and civil society) of the water risks to Lahore and to businesses, communities and the government. This report is a resolve in this direction. Ultimately it can lead to a consortium of NGOs, multinational companies, SMEs, trade associations, chambers of commerce and government agencies that can sit together under the umbrella of stewardship and make decisions to:

- Agree on the key priority water risks for the city of Lahore
- Develop projects and actions (e.g. lobbying) to address those risks
- Access funding (e.g. international donors or businesses) to implement projects

"A water warning: Peter Brabeck-Letmathe, chairman of Nestlé, argues that water shortage is an even more urgent problem than climate change,' The Economist, November 19, 2008. See: http://www.economist.com/theworldin/PrinterFriendly.cfm?story id=12494630

• Act as a collective voice for the key changes that all stakeholders want to see on water management for Lahore.

Promoting the concept, ideas, and elements of water stewardship in the private sector and the government institutions of the country will:

- Enhance the willingness, capability and capacity of the industrial sector to effectively contribute to water policy making, planning, and programmes;
- Convince and mobilize the industry and government institutions of Lahore, international bilateral and multilateral institutions and multinationals to make investments in water stewardship of Pakistan under public-private partnerships on issues identified by the consortium;
- Persuade industries to invest in wastewater treatment, cleaner production, and water stewardship; and
- Conduct research on water stewardship concepts and elements for Lahore with academia.

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ANNEXURES

PROCEEDINGS OF CONSULTATIVE CONFERENCE

A consultative workshop on the study "Situation Analysis of Water Resources of Lahore: Establishing a Case for Water Stewardship" was organized by WWF-Pakistan on April 8 2014 in Lahore. The study is a part of WWF-Pakistan's on-going project "City-wide partnership for sustainable water use and water stewardship in SMEs in Lahore-Pakistan" funded by the European Union. The objective of the workshop was to share the findings of the study with a panel consisting of officials from the Environment Protection Agency (EPA), Land Reclamation and Irrigation Department, Lahore Development Authority (LDA), Pakistan Council of Research in Water Resources (PCRWR), NESPAK, WASA, Nestle, Cleaner Production Institute (CPI), International Water Management Institute (IWMI), Government College University (GCU), Lahore and Associated Consulting Engineers Consultancy Participants were invited to give their feedback on the study.

On the occasion, Dr Asad , (Water Management Specialist, Mott Macdonald) highlighted that conspicuous gaps exist in data generation and coalition on the water resources of Lahore. He further added that since the domestic sector is the major water consumer in Lahore, there is a need to reduce per capita water consumption in order to achieve water conservation. He requested government officials to step-up and shoulder the responsibility of conserving the water resources of Lahore. The consultative workshop was followed by a vigorous discussion session among the participants.

The following points were thoroughly discussed in this meeting:

- Water conservation measures should be adopted at all levels. WASA should introduce a metering system to make people aware about water issues.
- WASA and LDA need to implement laws for the installation of private tube wells in the city and in private housing schemes to control the fast declining water tables.
- A large amount of domestic waste is thrown into the River Ravi without any treatment. As the domestic waste is less polluted compared to industrial effluent, it may be re-used to irrigate city parks to reduce its volume for disposal into the River Ravi.
- The city government should install treatment plants at disposal points so that wastewater can be treated before being thrown into the River Ravi.
- Polluting the River Ravi would be catastrophic as this is the biggest source of drinking water for the population of Lahore.
- Water should be treated as an economic good and its availability to industrial and other commercial sectors should at a proper cost with the promise that they will not pollute the water for downstream users.
- Industries should be made responsible for treating their waste and should restrict discharge into water bodies. Industries stress that treatment is very expensive and the government should cooperate with the private sector to facilitate treatment of waste.
- WASA and other organizations should increase their capacity to collect wastewater from the city and treat it. The government should provide them with enough financial and technical resources to fulfil these tasks.
- Relevant data collection and its accessibility to relevant organizations were also discussed and the need to increase cooperation between different organizations was emphasized.
- Mass awareness campaign should be initiated to make people, the industrial sector and policymakers aware of increasing surface and groundwater problems in the city, both in terms of quantity and quality.
- To address water management and governance problems, some type of forum should be formulated including technical advisers, policy makers, representatives of media and civil society. WWF may take the lead in setting up such a forum with the help of other government and non-government organizations and relevant industries.
- Participants expressed a keen interest in future collaboration with WWF-Pakistan on water-related issues. They emphasized the need of a city-wide partnership for successful movement on water conservation in Lahore, which was appreciated and exemplified by all stakeholders.
- Re-using Lahore's wastewater for landscaping purposes was discussed as well as the scope of constructed wetlands to promote biological water treatment and groundwater recharge.

LIST OF ATTENDEES

Sr. No	Name of attendee	Organization
1	Dr. Asad Sarwar Qureshi, Senior Environmental Consultant	Water Expert, Mott Macdonalds
2	Zamil Ali	Pakistan Council of Research in Water Resources
3	Muhammad Dilshad Arshad	Pakistan Council of Research in Water Resources
4	Arif Anwar	International Water Management Institute
5	M. Tariq Yamin	Directorate of Land Reclamation, Irrigation Dept., Lahore
6	Dr. Abdullah Hanan	Directorate of Land Reclamation, Irrigation Dept., Lahore
7	Faisal Nadeem	NESTLE, Pakistan
8	Zeeshan Suhail	NESTLE, Pakistan
9	Riaz Hussain	Lahore Development Authority
10	Zeeshan Yasin	National Engineering Services Pakistan
11	Ajmal Nadeem	Environment Protection Agency Punjab, Lahore
12	Wasim I. Rabbani	National Environmental Consultant
13	Shakeel Ahmad Kashmiri	WASA, Lahore
14	Dr. Javed Iqbal	WASA, Lahore
15	Dr. Engr. Abdullah Yasar	Sustainable Development Study Centre, GCU Lahore
16	Akram Khan	World Health Organization
17	S. Nihal Asghar	Solution Environmental Analytical Laboratory
18	Dr. Inayatullah	Bee Well Hospital
19	Sameen Khokhar	Associated Consulting Engineers (Pvt) Ltd.
20	Husnain Yasin Malhi	Associated Consulting Engineers (Pvt) Ltd.
21	Dr. Ejaz Ahmad	WWF-Pakistan
22	Ali Hasnain Sayed	WWF-Pakistan
23	Sohail Ali Naqvi	WWF-Pakistan
24	Durre Shahwar	WWF-Pakistan
25	Saba Dar	WWF-Pakistan
26	Saima Mian	WWF-Pakistan
27	Sarah Ephraim	WWF-Pakistan

WWF-Pakistan's Water Stewardship Project will contribute to improving environmental sustainability and livelihoods and supporting sustainable economic growth in Pakistan.

WWF-Pakistan was formed in 1970 to address the growing environmental and conservation issues in Pakistan.

WWF-Pakistan is part of the global WWF Network, one of the world's largest and most experienced conservation organizations, with almost five million supporters in more than 100 countries.

The Water Stewardship Project aims to create broad awareness through enhanced understanding and sharing knowledge of the impacts of unsustainable water use.

Design: Hassan Zaki

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Why we are here:

To stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature.

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