Bridging Water Demand-Supply Gap :

Through Rainwater Harvesting in Public Green Spaces of Delhi, India.

by

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ADVANCED STUDIES IN LANDSCAPE ARCHITECTURE

in

THE FACULTY OF GRADUATE STUDIES

THE UNIVERSITY OF BRITISH COLUMBIA

July 2007

Abstract

"Water is likely to become one of the limiting resources of the next century, as well as one with multiple often conflicting uses."
UNCED, NY 1994

Presently, at least 1.1 billion of the world's people - about one in five - do not have access to safe water. City of Delhi in India is facing acute water crisis with a current demand supply gap of 236 million gallon per day (MGD) which is expected to widen to 564 MGD by the year 2021. In view of the growing water crisis, the main objective of the thesis is to look into ways of mitigating the water crises in Delhi by bridging the water demand-supply gap using environmental friendly and sustainable methods such as rainwater harvesting in the public green spaces of the region.

The thesis begins with a thorough investigation of the Hydrological cycle (natural and urban), contemporary and traditional methods of rainwater harvesting, methods of recharge, and geological, hydro-geological and meteorological data of Delhi region. The regional data is overlaid and analyzed to define priority action areas and a conceptual action plan is recommended for each area. To demonstrate its feasibility, specific study areas are identified in the most stressed zone and investigated across four different scenarios ranging from neighbourhood to regional scale and from minimum to maximum intervention.

It is learned through this investigation that public green spaces of Delhi hold great potential in bridging the water demand-supply gap. There are a range of modern and traditional methods available to successfully implement rainwater harvesting projects in these areas. They are technically and financially feasible and can be adopted at various levels depending on the availability of resources. It is found that public green spaces of Delhi which account for about 19% of the total urban area can bridge the water demand-supply gap by a maximum of 12.5%. Cost of the interventions can be amortized within 3 years and there are direct financial and environmental benefits to the local residents. The harvested rainwater can also be successfully used to meet the irrigation demand of the public green spaces partially, resulting in further cost savings to the government.

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List of Abbreviations

Abbreviations that are used in this project are listed below to provide a better understanding for the contents of this report:

CBO	-	Community Business Organization
CGWB	-	Central Ground Water Board
CGWA	-	Central Ground Water Authority
CPCB	-	Central Pollution Control Board, India
DDA	-	Delhi Development Authority
DJB	-	Delhi Jal (water) Board
EIA	-	Environmental Impact Assessment
ICAR	-	Indian Council of Agricultural Research
Lpcd	-	litres per capita per day
Mbgl	-	Meters below ground level
MCD	-	Municipal Corporation of Delhi
MCM	-	Million cubic meter
Mgd	-	Million gallon per day
NCT	-	National Capital Territory
NDMC	-	New Delhi Municipal Council
Rs	-	Indian currency - Rupees
RWA	-	Residents Welfare Association
RWH	-	Rainwater Harvesting

Acknowledgements

I would like to sincerely thank my committee chairperson Professor Ronald Kellett and my committee members Professor William Marsh and Professor Cynthia Girling for their valuable remarks, support and encouragement which has greatly helped me structure this research and complete it in a timely manner. Each one of them have offered me a different and deeper insight into the research helping me focus on the strengths in a very simple and clear manner. Without their feedback this research would not have been possible in its current form.

I would also like to thank Mr. Ashok Dhawan, Mr. S.G. Deolalikar, Mr. S.K. Mohiddin, Paritosh Uttarwar, staff of Central Ground Water Board, Delhi Jal Board and Delhi Development Authority, Professors and staff at University of British Columbia and School of Planning and Architecture in Delhi for supporting me with this research and providing the necessary information; and all my friends for showing their trust and faith in me and helping me with some field work in the scorching heat of Delhi.

Finally, if words could justify, my heartiest thanks to my parents, my wife Ekta, my relatives and my two little daughters Arzoo and Radha for their unconditional support and understanding.

Chapter – 1

Introduction

Water is one of the most essential natural resources needed for the growth and sustenance of all life forms, directly or indirectly. Also, it is a fundamental basic need for sustaining human economic activities. History is proof that no other natural resource has had such overwhelming influence on human civilizations. Many human civilizations started and prospered near sources of fresh water and perished in their absence. Availability of water in the desired quantity and quality, at the right time and place, has been the key to the survival of all civilizations. As the human population increases multi-fold resulting in excessive urbanization, expansion of economic activities and changing lifestyles, the demands on fresh water resources continue to grow.

While water is a renewable resource and available in abundance on earth, only 2.53 percent is fresh water.[1] Two-thirds of this is locked up in glaciers and ice caps and the remaining one-third of the fresh water supply remains - in aquifers, soil pores, lakes, swamps, rivers, plant life and the atmosphere and its availability at any specific location and time is limited by climate, geographical and physical conditions, by affordable technological solutions which permit its exploitation, and by the efficiency with which water is conserved and used.

The main and primary source of this fresh water supply is precipitation (snow, rain etc). Water precipitates from the atmosphere to the oceans or to the land surface where it is taken by plants and soils, eventually flowing overland and underground back to the oceans via streams and rivers, and to lakes and wetlands and then evaporates or transpires back to the atmosphere from the land and surface water bodies in the so called Hydrological cycle. When the precipitated water falls on the surface of earth, we have few choices. It can either be:

a. Retained on the surface for a longer period of time to allow for it to seep through the soil to the underground water system.

b. Directed to various storage areas for reuse over a period of time.

[1] "Water for people, Water for life" World Water Development Report. March 2003. The United Nations. 15 Nov. 2005 < http://www.unesco.org/water/wwap/wwdr/index.shtml>.

b. Allowed to run off from the surface directly to streams & rivers or though various conveyance systems and finally to the ocean.

While the fresh water supply is constant in the hydrological cycle of a specific location for a specific period of time, the demands for it are always increasing. To counter this imbalance of supply and demand, we must encourage choices 'a' and 'b' above, while minimizing surface run-off away from the point of use and letting it become a part of the salt water resource from where it is difficult to exploit it for human consumption without major energy and cost implications. Though this requires realization and collective efforts by the entire human civilization, it also requires improvement in planning, design and management practices. Therefore, the contribution by the professional community involved in providing technical support for areas that require utilization and management of water is of significant importance.

Although such efforts can be applied at many different scales and different parts of the world, a need for them is most felt in rapidly urbanizing cities such as Delhi in a fast developing nation such as India. The main reasons for it being the fast growing population, economic development leading to changing lifestyles, lack of awareness and prevailing design and management practices. The population of Delhi currently stands more than 15 million (13.8 million as per Census of India 2001). The city, at the moment, requires 3,324 million liters of water a day (MLD) while what it gets stands closer to 2,034 MLD. Average water consumption in Delhi is estimated at being 240 liters per capita per day (lpcd), the highest in the country.[2] The majority of population in the city today is groundwater-dependent. In spite of the municipal water supply, people use private tube wells to supplement their daily water needs in an unplanned and uncontrolled manner, resulting in Hydrological imbalance, deterioration in water quality and rise in energy requirements for pumping.

Uncontrolled disposal of industrial effluents and sewage of cities into rivers and other fresh water-bodies has also resulted in contamination of groundwater. Hence, immediate remedial actions need to be undertaken to avoid a national water crisis.

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[2] "About Delhi" Rainwater Harvesting. Centre for Science and Environment. 30 Oct. 2005. <http://www.rainwaterharvesting.org/index_files/about_delhi.htm>.

One of the ways in which the water stress can be reduced and national water crisis avoided is by rainwater harvesting. Rainwater harvesting, is an age-old system of collection of rainwater in India for future use, but systematic collection and recharging of groundwater is a recent development and is gaining importance as one of the most feasible, effective and easy to implement solutions to restore the hydrological balance. As the amount of rainwater harvested depends on the size of the surface area it becomes imperative to investigate large urban green spaces for the potential of rainwater harvesting.

1.1 The Problem Statement

The green landscapes in most locations require supplemental water to thrive. To make up the difference between a plant's water requirement and the natural precipitation in an area, additional water is usually added in the form of irrigation which is drawn from the municipal fresh water supply as a common practice in Delhi. By doing so, these areas are consuming a part of the drinking water supply for people, in a region where people are facing water crisis and sometimes go for days without getting fresh water from the city supplies. In addition, since their demands are not fully met by the local supplies, individual users and local authorities further rely on extracted groundwater (Fig. 1.1) resulting in falling groundwater levels and creating water stress in the region. In many areas of the city, groundwater level has dropped from five meters below the ground to 40 m in a span of a few years. The people and various governing bodies, however prefer to pay for a tanker of water (Fig. 1.2) when in dire straits rather than make a long term investment in a more lasting solution.[3]

Figure 1.1: Manual pumping of groundwater

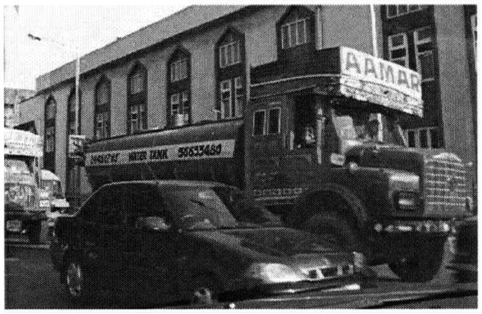

Figure 1.2: Private water tankers in streets of Delhi

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[3] Usha Rai, "Don't cloud the Issue," Hindu, magazine. Online ed. 22 Dec.2005 <http://www.thehindu.com/thehindu/mag/2002/12/22/stories/2002122200300200.htm>

In majority of man-made urban green areas in Delhi, an indifferent approach is adopted towards the water problem confronted by the whole city. Sustainable water management on site, which can be achieved through proper site grading, slopes, soil management, proper planning, design and plants selection is often neglected. On the contrary, common and easily available short term solutions are adopted, which are either preferred by the real estate developer community, the public and private owners or due to lack of knowledge, understanding and initiative by design professionals. For example, mechanical processes are preferred over natural processes and water drainage from site to city stormwater drains is preferred over water detention and retention on site for increasing surface water storage and groundwater recharge. In addition a substantial portion of fresh water is wasted by the large public green landscaped areas due to the lack of appropriate technology, adequate knowledge and commitment by the management and maintenance staff. Some indicators that can be often seen on such sites are over irrigation and broken infrastructure with overflowing water.

Delhi receives about 611 mm of rainfall every year. Flooded green spaces (Fig. 1.3) and flooded streets (Fig. 1.4) is a common site during the monsoons but due to lack of awareness, sensitivity and initiative by Delhi Government, people and the design community, a large fraction of this fresh water gets wasted. Delhi might face an even more acute water shortage in the coming days if immediate steps are not taken to utilize this perennial source of fresh water.

Figure 1.3: Flooded Green spaces

Figure 1.4: Flooded streets of Delhi during monsoons

Green landscapes in the city, owing to their large surface areas, have a vital role to play in capitalizing on the rainwater though various harvesting methods. They can help in enhancing the underground water table levels by encouraging surface water storage and reduced recharge to groundwater while minimizing their dependence on the municipal supply of water. Ironically, these areas have not been effectively considered for relieving the overall water problem in the city as they are perceived not to be directly related to the human population and their water needs for drinking and other domestic uses and therefore their role for this purpose is undefined. There have been recent efforts in the urban residential sector to promote roof water harvesting but little has been done focusing on these widely sprawled green spaces. For example, the shortage of water in Dwarka has prompted the Delhi Development Authority (DDA) to make installation of water harvesting systems mandatory in any building [to be constructed in future] with a roof area more than 100 m^2. "No design for construction of building can be approved if it is without water harvesting structures. Those building which have already been constructed will also be installed with these structures," says the Chief engineer of Dwarka project, Mr Surendrajeet Singh.[4]

A serious effort is now needed in highlighting the role of the open green spaces (developed or undeveloped) for bridging the increasing water demand-supply gap in Delhi by harvesting rainwater in these areas with a long term sustainable approach and considering them as a cohesive part of the overall problem.

1.2 Objectives, Scope and Limitations

Objectives

In light of the above arguments and reasoning, main objective of the thesis is to find out how much of this water demand-supply gap in Delhi can be bridged by capturing the rainwater in the open green spaces of Delhi through various rainwater harvesting methods. How can it be systematically achieved and at what cost?

Figure 1.5: Main Research Objective

[4] "DDA's water harvesting solution to Dwarka crisis," Statesman, New Delhi, 7 Jan. 2005, 4 <http://data.cseindia.org/news_search_main.asp>.

To achieve this goal, the research initially aims at understanding the water regime in the areas of study, prevailing monsoon patterns, terrain, water table, and the soil conditions. (Geological, hydro-geological, geomorphological, meteorological conditions) in these areas. The thesis then studies the traditional and contemporary practices and techniques of rainwater harvesting successfully used in similar climatic conditions, exploring the possibility of reviving them and/or adapting them to current design and management practices.

After careful analysis of the above conditions and techniques, the thesis then defines priority action areas at a regional scale where harvesting of rainwater can be most beneficial, highlighting the opportunities and constraints and their suitability for adopting various rainwater harvesting techniques depending on their physical structure and prevailing conditions. A conceptual action plan is then developed for each priority action area which can be adopted for each neighbourbood in these areas. As a demonstration of its applicability, the thesis finally examines a representative neighbourhood and a regional public green space in one of the most stressed priority action zone as identified by the study and assesses their potential to integrate rainwater harvesting techniques to augment local water supplies for various scenarios which can be adopted for various scales across the city.

Scope and Limitations

The issue of water is vast and needs a multi-disciplinary holistic approach with participation of all the stakeholders to bring about a meaningful change, but, the thesis solely focuses on the public green spaces of Delhi which are highly neglected and under utilized for rainwater harvesting. These areas are studied and analyzed for their technical and financial feasibility and the methodology is developed such that it can be successfully implemented in the local context across varying scales keeping in mind the local barriers and constraints.

Some of the commonly observed barriers and constraints [based on media reports and communication with local people] are - indifferent attitudes towards long term sustainable vision, bad user/resident choices, lack of awareness and experience with rainwater harvesting methods, myths surrounding people about the initial and maintenance cost of these methods, lack of available data, research and exposure to technology, lack of statutory regulations and policies, lack of political will to upgrade and improve without any biases, highly subsidized pricing policies of water by the local government, preference for reclaiming water from municipal water supply and lack of locally accepted standard for on-site rainwater harvesting.

Though research, public participation and information dissemination can address and overcome most or all of the constraints mentioned above, they are not explicitly covered in the scope of this thesis. Many of these constraints relate to user practices and policies which needs another level of actions and measures. Though it is fully acknowledged that without overcoming all these constraints a complete and long lasting success cannot be achieved, the thesis limits itself to addressing the design, planning, engineering and financial aspects as their contribution can lead to tangible and visible examples that can then spearhead changes and development in other related fields.

Another aspect of rainwater harvesting that is not addressed in detail in this thesis is roof top water harvesting which is a very important area where the water gains can be enormous through the small scale residential developments and on the larger building scales such as institutions, commercial and recreational development. A lot of local attention is already focussed in this category as the benefits are direct and immediate. To maximize the benefits of rainwater harvesting, the thesis, therefore focusses on the non-built part of the city - The Public Open Green Spaces.

1.3 Research Methodology

Considering the nature and subject of this project, following research strategies and stages are adopted:

1. **Literature Review & History Research** – This is the initial phase of the research which focusses on understanding the background, terminologies and various aspects of the subject through readings from books, articles, journals, newspapers and various electronic sources. The traditions and techniques of rainwater harvesting are explored along with the more contemporary practices prevailing in the region, and their benefits and limitations. The geological, hydro-geological, geomorphological, meteorological conditions in the region are also studied in detail for the purpose of this research.

2. Data collection and Analysis – For this stage various data sets were collected (from different sources) such as Satellite imagery (IRS 1C PAN) data, field survey, historical data and reports, old Survey of India Maps as well hydro-geological mapping carried out by the Central Ground Water Board, cadastral data from Delhi Development Authority (DDA), and the Master Plan of Delhi for 2021 prepared by DDA. The statistical data on water demand, supply and consumption was collected from the water regulatory body in Delhi - Delhi Jal Board (DJB). Data on current design and management practices and costs is collected from various local professionals such as landscape architects, planners, hydrologists, engineers, end users, governmental organizations (policy makers) and various non-government organizations.

3. Identifying stressed areas and priority action zones - Through mapping and overlaying the geological, hydro-geological, geomorphological, and meteorological data along with the statistical data on water demand-supply gap, stressed areas are highlighted and priority action zones are established. The possible opportunities and limitations in these areas are then established based on their collective characteristics through the layered data.

Based on the opportunities and limitations appropriate solution sets are then listed for maximizing rainwater harvesting benefits in different stressed zones. For the subject of the thesis the solution sets define different techniques and practices which can promote surface water storage and/or promote artificial recharge to groundwater in different conditions.

4. Working across different Scenarios - Specific study areas are then selected in one of the most stressed zone as identified by the research and analyzed for four scenarios. Working across different scenarios helps in defining a range of possible categories or levels for the study areas in which the different interventions for the given goal can happen. For the thesis, the scenario map ranges across two attributes - the physical scale and the intervention level. The physical scale of the sites ranging from the neighbourhood level to the regional level and the intervention level ranging from minimum intervention to maximum intervention. Minimum intervention at the neighbourhood scale represents the base case scenario with minimum cost, minimum alterations to the physical environment and involvement of minimum stakeholders. Maximum intervention at the regional scale represents the ultimate option within the scope, maximizing water gains through rainwater harvesting (Fig. 1.6). All four scenarios are analyzed to determine potential water gains, cost burden and cost benefits [to the government and local residents] and to assess their technical and financial feasibility. Working with a range of scenarios provides a broad spectrum in which the solutions can be adopted now and in future for all the sites in the region which may have different characteristics and might face different circumstances at different times.

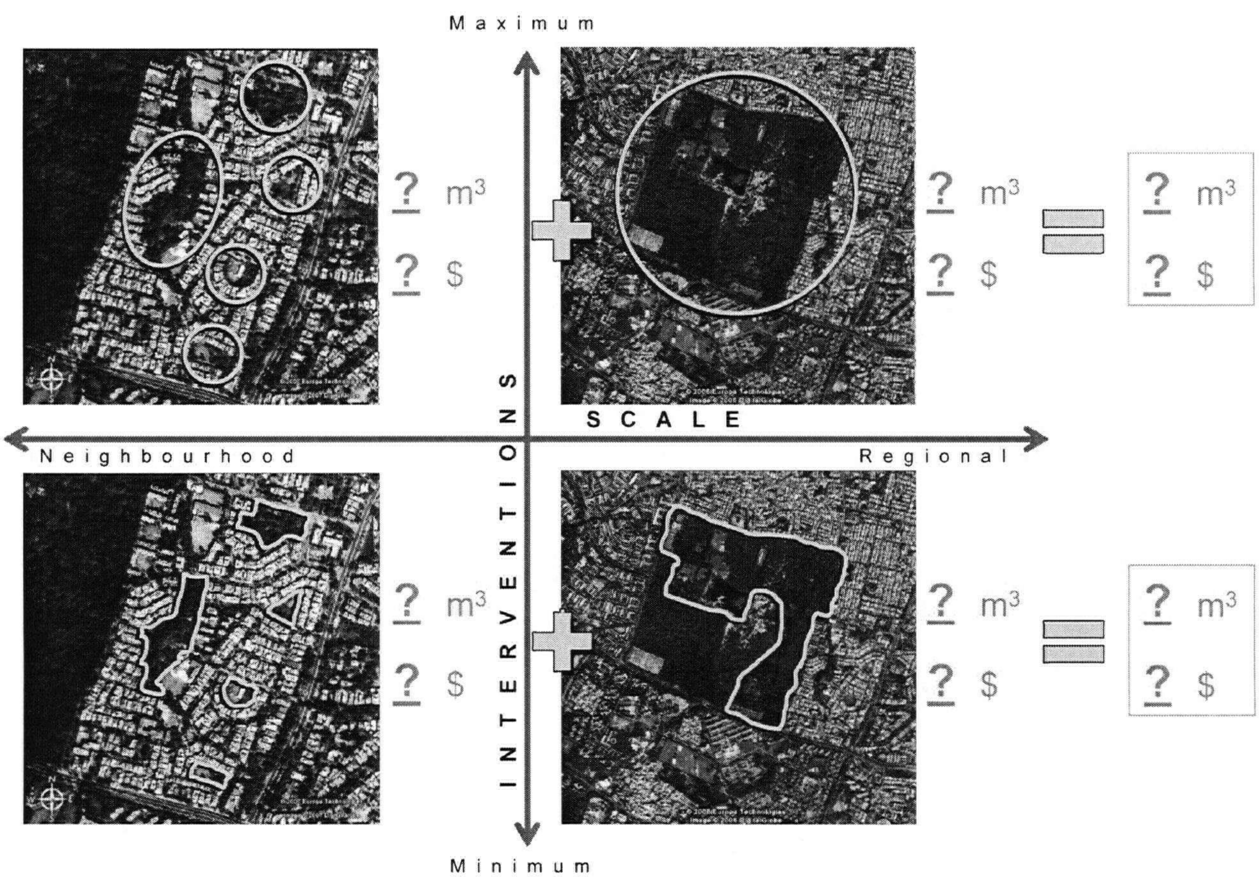

Figure 1.6: Different Scenarios for the study areas

5. **Conclusions and Recommendations** – The thesis concludes with a summary of findings from the above research and analysis. A set of recommendations are also presented in this section for successful implementation of the research findings and their integration with other methods of water harvesting and water conservation for a long term sustainable solution. Many suggestions are made for various issues relating to - Planning and design, Construction and monitoring, and Management and maintenance in the studied areas and systems.

1.4 Significance of Thesis

The people of Delhi, who have been experiencing water shortages in the recent years, continue to live in a state of self denial and resort to unsustainable short term solutions to meet their daily needs. The thesis brings the concept of rainwater harvesting in the urban green spaces into focus which will help in changing the perceptions of people from cynicism and scepticism to a realization that these alternatives are not only feasible but imperative.

While it may take some time for policy thinking to change, once adequate homework is done and claims are given a scientific basis, acceptance will gradually grow. However final lessons will be only learnt after the proposed systems have worked for a few years. The biggest point in its favour is that as compared to all other means of augmenting water supply the methods presented in the thesis are simple and inexpensive and even if optimal results are not obtained immediately it would go a long way towards mitigating the ongoing water crises and bridging the water demand-supply gap.

Chapter – 2

Water and Water Crisis

2.1 World Water Resources

Water in a free state, that's to say not chemically tied to other elements, may be solid, liquid or gaseous. Most of the earth's water (about 97.5%) is salty and can be found in the oceans. As shown in figure 2.1 only 2.5% of the world's total water supply is fresh water, which is mostly in ice or underground and only in tiny amount as surface water. The fresh water actually available for human use in lakes and rivers and the accessible groundwater amounts to only about one third of one percent of the world's total water supply. A tiny amount of water (0.001% of the total) is in the atmosphere in the form of water vapour. [5]

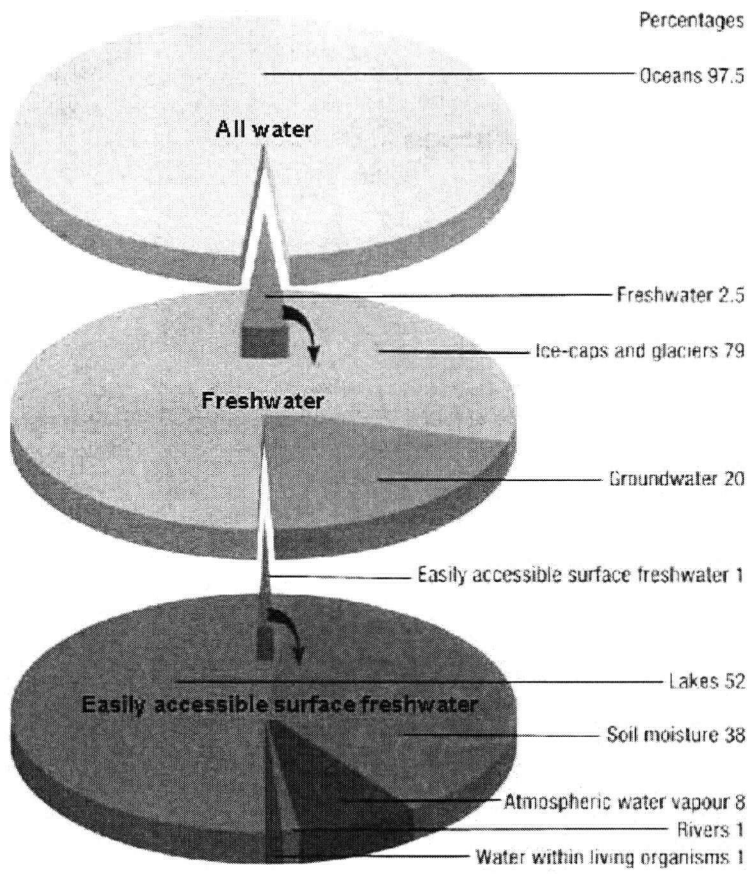

Figure 2.1: Distribution of the World's water

[5] United Nations Food and Agricultural Organization. Oct. 2006 < http://www.fao.org/docrep/U8480E/U8480E3h.jpg>

For the purpose of this study, surface water and groundwater are of great importance and will be discussed in detail in the following section.

Surface Water

Surface waters can be in the form of rivers and streams, lakes, ponds, and reservoirs, and wetlands. Rivers and streams are surface runoff outlets which drain water, in a watershed[6] to a common outlet such as a point on a larger river, lake, groundwater aquifer, or ocean. The water carried by them also carries pollutants discharged upstream which often become the problem of someone who lives downstream (or of the aquatic life that exists in-stream), and all of the activities that take place in a watershed can have a water quality impact elsewhere in the watershed. It is therefore important to remember that rivers and streams are connected by hydrology, ecology, geology, and social and economic considerations to other aquatic ecosystems.

Lakes, ponds and reservoirs are surface water storage areas formed by the natural (or man-made) depressions in the land form. The formation process, the land morphology and the input type contribute to the development of the lake environment and habitat. Lakes are sensitive to pollution inputs because they flush out their contents relatively slowly. Even under natural conditions, lakes undergo eutrophication, an aging process that slowly fills in the lake with sediment and organic matter. The eutrophication process alters basic lake characteristics such as depth, biological productivity, oxygen levels, and light transmission to the deeper water layers. It is therefore of great importance to properly manage the watershed which drains into such water bodies to minimize siltation and pollution of their waters. These surface water bodies are particularly useful for the research as they can help in storing enormous amount of harvested rainwater.

Wetlands are areas that are permanently or temporarily inundated or saturated by surface water or groundwater. Wetlands generally include swamps, marshes, bogs, and similar areas. Wetlands are some of the

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[6] All the land area and water within the confines of a drainage divide in which all surface runoff will pass through an identifiable outlet, such as a stream or river.

most unique and important natural areas on earth. They can be particularly useful areas for rainwater harvesting as they often have very close connections with the groundwater system and may serve as important groundwater recharge areas. Others, especially those in low-lying areas, may be the receptors for significant amounts of groundwater discharge and can help in storing harvested rainwater for redistribution.

Groundwater

Large volumes of water stored in the porous and fractured materials in the uppermost portion of the earth's crust is groundwater. Although only a small fraction of the precipitation reaches the saturated zone, the process has continued through geologic time resulting in large volumes of sub-surface water.

The major part (about 70%) of all fresh water available on earth (exclusive of icecaps) is groundwater. Therefore the extent of groundwater resources is enormous and usable groundwater exists almost everywhere.

According to United States Geological Survey (USGS) figures, groundwater provides an estimated:

- 22% of all freshwater withdrawals
- 37% of agricultural use (mostly for irrigation)
- 37% of the public water supply withdrawals
- 51% of all drinking water for the total population
- 99% of drinking water for the rural population

Groundwater is not confined to only a few channels or depressions in the same way that surface water is concentrated in streams and lakes. Rather, it exists almost everywhere underground, within 100 metres of the surface. It is found in the spaces between particles of rock and soil and in the interconnected cracks or spaces that are both numerous enough and large enough to allow water to move freely. In some permeable materials groundwater may move several metres in a day; in other places, such as clay and shale, it moves only a few centimeters in a century. Groundwater circulates as part of the hydrologic cycle (discussed in detail in section 2.2). As precipitation and other surface water sources recharge the groundwater it drains steadily, and sometimes very slowly, towards its discharge point.

Many terms are used to describe the nature and extent of the groundwater resource. The underground water-bearing formations which can produce useful quantities of water when tapped by a well are called **aquifers**. As shown in the figure 2.2, the level below which all the spaces are filled with water is called the **water table**. Above the water table lies the **unsaturated zone**. Here the spaces in the rock and soil contain both air and water. Water in this zone is called **soil moisture**. The unsaturated zone which is also referred to as the Vadose zone is very important for the process of water recharge. It helps in improving the water quality by removing the pollutants from the infiltrated water. If the unsaturated zone is too thick it can also result in water loss through soil moisture especially in arid and semi-arid areas. The entire region below the water table is called the **saturated zone**, and water in this saturated zone is called **groundwater**.

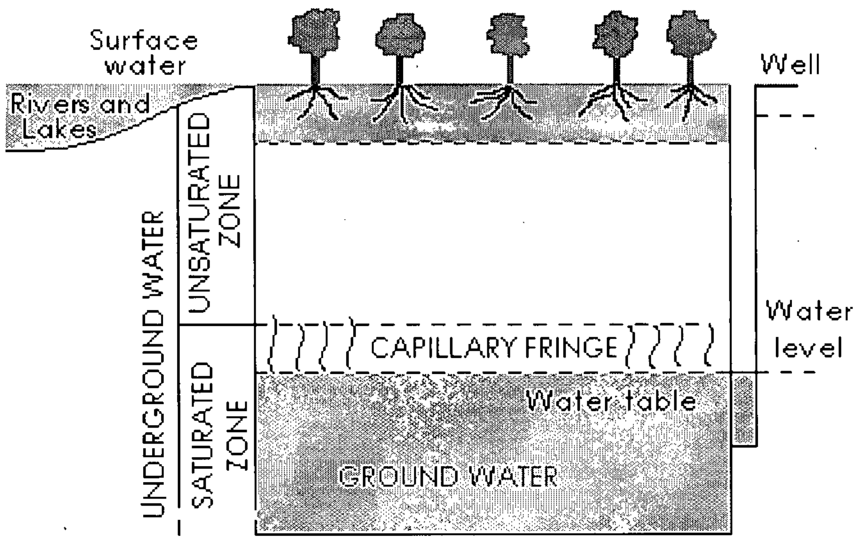

Figure 2.2: Hydro-geological section showing Groundwater

Source: < http://www.purdue.edu/dp/envirosoft/groundwater/src/gw.htm>

Groundwater is not a visible resource like lakes, rivers and glaciers. Its value, therefore, is not well understood or appreciated. Not surprisingly, concerns about water quality often focus on surface waters; and the hidden, but equally important, groundwater resources have received less public attention. In recent years, however, a number of events affecting groundwater quality have contributed to a heightened public awareness and concern about the importance and vulnerability of the resource. Even where we might not use it directly as drinking water supply, we must still protect groundwater, since it will carry contaminants and pollutants from the land into the lakes and rivers from which other people get a large percentage of their freshwater supply.

2.2 Global and Local Water Crisis

"Water is likely to become one of the limiting resources of the next century, as well as one with multiple often conflicting uses."

UNCED, NY 1994

Global Water Crisis

Rapid population growth, combined with industrialization, urbanization, agricultural intensification, and water-intensive lifestyles is resulting in a global water crisis. In 2000, at least 1.1 billion of the world's people - about one in five - did not have access to safe water. Asia contains 65 percent of the population without safe water and Africa 27 percent (Figure 2.10). During the 1990s, there were some positive developments: about 438 million people in developing countries gained access to safe water, however due to rapid population growth, the number of urban dwellers lacking access to safe water increased by nearly 62 million. [7]

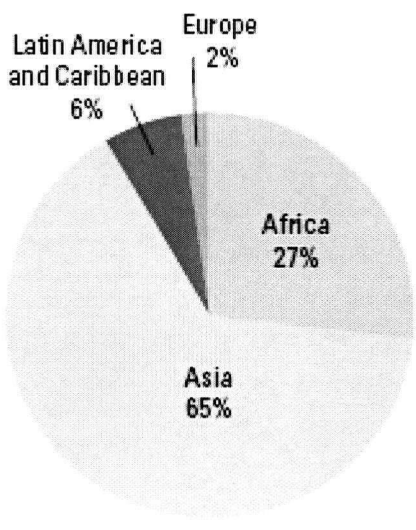

Figure 2.3: World Water Supply, distribution of unserved populations

(Source: Water for People, Water for Life. The United Nations - World Water Development Report. March 2003. <http://www.unesco.org/water/wwap/wwdr1/table_contents/index.shtml>)

[7] Rainwater Harvesting and Utilization. Blue Drop Series, Book 2: Beneficiaries and capacity builders. United Nations Human Settlements Programme (UN-HABITAT). 2005. p1-2

Falling water tables are widespread and cause serious problems, both because they lead to water shortages and , in coastal areas, to salt intrusion. Both contamination of drinking water and nitrate and heavy metal pollution of rivers, lakes and reservoirs are common problems throughout the world. The world supply of fresh water cannot be increased. More and more people are becoming dependent on limited supplies of fresh water that is becoming more polluted. Water security, like food security, is becoming a major national and regional priority in many areas of the world.

By 2025, 1.8 billion people will live in countries or regions with absolute water scarcity (Figure 2.11). Most countries in the Middle East and North Africa can be classified as having absolute water scarcity today. By 2025, these countries will be joined by Pakistan, South Africa, and large parts of India and China. This means that they will not have sufficient water resources to maintain their current level of per capita food production from irrigated agriculture—even at high levels of irrigation efficiency—and also to meet reasonable water needs for domestic, industrial, and environmental purposes. [8]

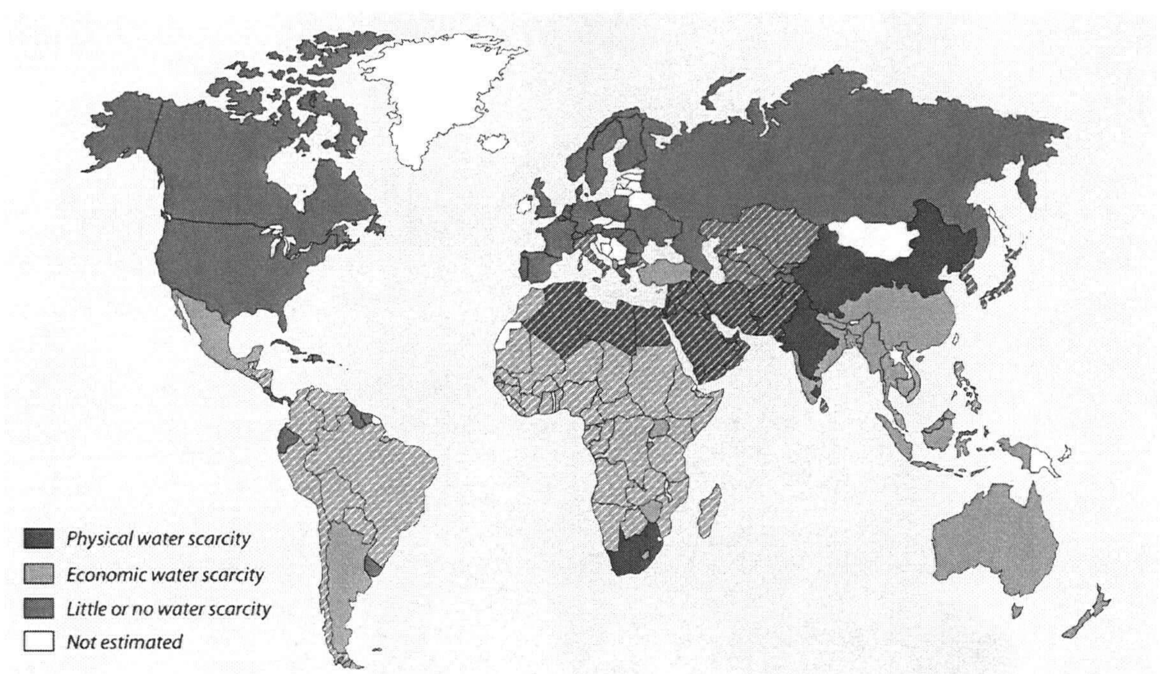

Figure 2.4: Projected Water Scarcity in 2025

(Source: International Water Management Institute. < http://www.iwmi.cgiar.org/home/wsmap.htm>)

[8] Projected Water Scarcity in 2025. International Water Management Institute. < http://www.iwmi.cgiar.org/home/wsmap.htm>

Local Water Crisis

Even though the rate of urbanization in India is among the lowest in the world, the nation has more than 250 million city-dwellers. Experts predict that this number will rise even further, and by 2020, about 50 per cent of India's population will be living in cities. This is going to put further pressure on the already strained centralised water supply systems of urban areas. The urban water supply and sanitation sector in the country is suffering from inadequate levels of service, an increasing demand-supply gap, poor sanitary conditions and deteriorating financial and technical performance.

According to Central Public Health Engineering Organization (CPHEEO) estimates, as on 31 March 2000, 88 per cent of urban population in India has access to a potable water supply. But this supply is highly erratic and unreliable. Transmission and distribution networks are old and poorly maintained, and generally of a poor quality. Consequently physical losses are typically high, ranging from 25 to over 50 per cent. Low pressures and intermittent supplies allow back siphoning, which results in contamination of water in the distribution network. Water is typically available for only 2-8 hours a day in most Indian cities.[9] The situation is even worse in summer when water is available only for a few minutes, sometimes not at all.

In India, from the 19th century onward, the paradigm of managing water has followed two interconnected routes.

1. The state took upon itself the role of sole provider of water. (It was the colonial state that centralized control over water resources. The post-independent state inherited this role, and continued with it.) Among other things, this led to communities and households being no longer the primary agents of water provision and management.
2. Historic use of stored rainwater and floodwater declined. In its place, there came a growing reliance on surface water (primarily rivers) and groundwater.

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[9] Rainwater Harvesting. Centre for Science and Environment. 19 Sept. 2006. <http://www.rainwaterharvesting.org/Crisis/Urbanwater-scenario.htm>

Today, the effects of this way of managing water are clearly visible:

- There is complete dependence on the state for any kind of water provision. It is a kind of fostered parasitism since the state, via its bureaucratic machinery, does not seem to possess the will to alter such a situation. [10]
- As a result of high level of extraction from rivers, most of India's river basins have degraded and the rivers are polluted.
- Groundwater resources have been heavily over-used.

Thus water availability, both in terms of quality and quantity, has declined to such an extent that many parts of India, rural and urban, today face a drought-like situation and serious water pollution.

"At present about 85% of water supplies for domestic use in rural areas and 50% of water for urban and industrial areas, besides 50% of irrigation water requirements, are being met from groundwater in the country."[11] Because of its wide distribution, ubiquitous presence and the extraction structures being under direct control of the user, groundwater has come to stay as a preferred source for meeting the water demand for various user sectors. It is invisible and because of over exploitation, it is depleting in many parts of India.

Water is becoming a cause for social conflicts. Protests, demonstrations, road-blockades, riots. City-dwellers against farmers. Villages against towns. Towns against cities. Citizens against the government. People against people. Increasingly, these (usually local) conflicts are taking on the general shape of a bitter war for water.[12] Water crisis may spark tensions in south east Asia and become a source of friction amongst various countries in south Asia. The per capita availability is likely to drop by 50-70 percent in the next 15 years according to the "Global Trends 2015" report, released by a wing of the Central Intelligence Agency. [13]

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[10] Rainwater Harvesting. Centre for Science and Environment. 30 Oct. 2005. <http://www.rainwaterharvesting.org/Crisis/Crisis.htm>

[11] Interview with S.S CHAUHAN, Chairman & member, Central Ground Water Board, Ministry of Water Resources, Delhi. <http://www.vigyanprasar.com/comcom/inter63.htm>

[12] Rainwater Harvesting. Centre for Science and Environment. 30 Oct. 2005. <http://www.rainwaterharvesting.org/Conflicts/Conflicts.htm>

[13] Athavale, R. N., Water harvesting and sustainable supply in India, Ahmedabad : Centre for Environment Education ; Jaipur : Rawat Publications, c2003. p 4

Delhi local Newspaper Articles highlighting the water crisis [14]

The Hindustan Times, New Delhi, 10/16/05, 2

'Groundwater at all-time low'

It was yet another parched summer for the people of Delhi. Even now many areas of the Capital - especially south and east Delhi - are reeling under an acute water shortage. And at this rate the water situation is only going to aggravate in the coming days. The fast depleting groundwater level is already giving sleepless nights to policy makers. They are predicting a water famine in the Capital in near future if immediate steps are not taken to address the issue. "If adequate steps are not taken now, the groundwater level in areas like Vasant Kunj and Tughlaqabad would completely dry up in the next ten years," said R K Srinivasan, deputy coordinator, Natural Resource management, Centre for Science and Environment.

The Statesman, New Delhi, 9/19/05, 4

'Chirag Dilli reels under acute water crisis'

It's a classic case of' water water everywhere, not a drop to drink'. It may have rained heavily during this past week but the rainwater has not improved water shortage for area that have been suffering with chronic water scarcity for the past four years. Residents have alleged that the Delhi Jal Board has not been able to augment the water supply to the area.

The Hindustan Times, New Delhi, 6/7/05, 4

'Treated water going waste'

Delhi might face an acute water shortage in the coming days if wastage of treated water is not checked properly. According a survey by the Urban Development (UD) department, a huge quantity of treated water is going down the drain despite government's initiative to check the wastage.

[14] The newspaper clippings are retrieved from the archives of Environment Resource Library, Centre for Science and Environment (CSE)

The Times of India, New Delhi, 6/1/05, 3

'Illegal boring : it's a steal that just doesn't end'

Water shortage in south Delhi is already bad. But what makes it worse is illegal extraction by builders, residents and water companies. Groundwater level I areas like Bhogal, Defence Colony, Jangpura, Vasant Vihar and Lajpat Nagar is dipping every year. In areas like Defence Colony, almost all flats constructed by builders have borewells. In some cases, the water extracted is even sold. On January 17, 2002, the Ministry of Water Resources had issued a notice in a leading daily, banning illegal boring in south and southwest Delhi.

Urban centers in India are facing an ironic situation today. On one hand, there is the acute water scarcity and on the other, the streets are often flooded during the monsoons. This has led to serious problems with quality and quantity of groundwater. Delhi is facing a similar water crisis as clearly described by a local newspaper article shown in figure 2.12. This is despite the fact that Delhi receive good rainfall. However, this rainfall occurs during short spells of high intensity. (Most of the rain falls in just 100 hours in a year). Because of such short duration of heavy rain, most of the rain falling on the surface tends to flow away rapidly leaving very little for recharge of groundwater.

2021: City parched, gap wider

CGWB Projections Say Delhi To Face Shortfall Of 564 MGD Even After Tapping All Its Resources

Maneesh Pandey | TNN

New Delhi: Even as the city eagerly waits for water from Sonia Vihar plant to finally reach households in south and east Delhi next week, experts warn that this euphoria may be short-lived.

According to a recent study by the government's Central Ground Water Board (CGWB), Delhi will face a daily shortfall of 564 million gallons a day (MGD) in 2021 even after tapping all its available resources, including water from Sonia Vihar water treatment plant.

Says the study on Water Requirements in National Capital Territory (NCT) of Delhi, whose findings are based on data collected by the NCR Planning Board, "Worst hit would be south and southwest Delhi as the groundwater resources in these areas are already in a critical state."

By 2021, the city's population is expected to soar to 22 million (approx) and its water requirement is set to rise to about 1,389 MGD. "But the critical part is that with all resources at disposal, including 140 MGD of water flowing through Sonia Vihar plant and reaching the tail-end of the distribution network in south and southwest Delhi, we would still be in the same situation as today. The loss would be over 560 MGD," says the study, basing its projections on the data supplied by the draft NCR Plan-2021 and Delhi Jal Board (DJB).

Presently, Delhi's water requirement is about 866 MGD, as against the available supply of 630 MGD, leaving a shortfall of about 236 MGD. This gap is expected to rise to about 247 MGD in 2011 and 564 MGD by 2021, as at any point of time, Delhi will not be able to generate more than 825 MGD of water.

It will be able to meet just about 50% of its water requirement then, considering the 15% loss in water distribution network.

There is hope though, says senior DJB engineers. "We have plans to build two dams — one in Himachal and the other in Uttaranchal — which together can generate over 400 MGD. But there are many road blocks, particularly for the one in Uttranchal," says a senior DJB engineer.

As for the dam in Renukaji in Himachal, the Delhi Jal Board is waiting for an environmetal clearance for the project. It hopes to source 275 MGD from the dam. But the water will pass through Haryana, which will surely ask for its share. And even if work on the dam is started this year, it will take another 8-10 years before water from it reaches Delhi.

The dam in Uttranchal is proposed at Lakhwar Byasi which can generate 135 MGD. "But the problem is that for Byasi, water sharing would raise another round of debate among Delhi, Uttar Pradesh, Haryana and Utranchal. It is still a mirage," adds a Delhi Jal Board engineer.

Prepare for a dry run

2021 Requirement 1,389 MGD
Supply | 825 MGD
Gap | 564 MGD

2011 | Requirement 1,072 MGD
Supply | 825 MGD
Gap | 247 MGD

2006 | Requirement 866 MGD
Supply | 628 MGD
Gap | 236 MGD

PROJECTIONS FOR WATER AVAILABILITY IN 2021

Total water	Source	Treatment plant
210 MGD	Yamuna	Wazirabad, Chandrawal plants
240 MGD	Bhakra, western Yamuna Canal	Haiderpur, Nangloi
100 MGD	Upper Ganga Canal, UP	Bhagirathi
140 MGD	Tehri dam	Sonia Vihar
20 MGD	Surface water	Delhi parallel branch (Canal of 102-km stretch)
125 MGD	Groundwater	Tubewells, ranney wells

EXPECTED POPULATION IN 2021: 22 MILLION

Use	2005-6	2011	2021
Drinking/domestic	808	1,014	1,355
Irrigation	44	44	44
Farmhouses	4.7	4.7	4.7
Industries	9.5	9.5	9.5
TOTAL	866	1,072	1,389

(Figures in MGD, million gallons a day)

Graphic: Ajit Bajaj

Figure 2.5: Delhi Water Crisis. Daily Newspaper, The Times of India, New Delhi. Saturday, August 5, 2006

One of the solutions to the urban water crisis is rainwater harvesting - capturing the runoff. India has a millennia tradition of rainwater harvesting. These traditions have developed over centuries in an ecologically sound manner. These were decentralized systems, where the urban and the rural communities played an active role in the water management. Rain was considered as the main source of water. Once captured, this rainfall met the demands for the rest of the year. [15] But, most of the traditional water harvesting systems in cities have been neglected and have fallen into disuse, worsening the urban water scenario. There is a need of investigating these traditional techniques and integrating them into the urban environments as there is a great deal to learn from them. They were cost-effective, clearly understood the patterns of rainfall, water and earth and applied them successfully in a most simple manner, and were easy to adopt. The types of water harvesting systems in different kinds of terrains have been intensively documented by Agarwal and Narain in their book Dying Wisdom, 1997.

There are several non-governmental organizations (NGO's) in India which are actively working in this field to research & promote rainwater harvesting at different scales and in different areas. One of the most actively involved NGO in Delhi is the Centre for Science and Environment (CSE) which has conducted intensive research in this field and continues to do so. But, it has been realized through literature review that the majority of their efforts are aimed at domestic roof-water harvesting and it is envisaged here to supplement their research through this project by looking at large urban green areas as catchments.

[15] Anil Agarwal, Sunita Narain and Indira Khurana (editors), Making Water Everybody's Business : Practice and Policy of Water Harvesting. (New Delhi: Centre for Science and Environment, 2001)

2.3 The Hydrologic Cycle and its Processes

Water moves around the world from a reservoir to another, with a continuous change of its physical states in a large, permanent cycle called the hydrologic cycle. Sun heating is the key factor that keeps the hydrologic cycle in motion. There are five main processes at work in the hydrologic cycle: **condensation, precipitation, infiltration, runoff** and **evapotranspiration**. These occur simultaneously and continuously except for precipitation.

In context of this study, the hydrologic cycle can be simply explained as consisting of inflows, outflows, and storage as shown in the flow chart in figure 2.3. Inflows add water to the different parts of the hydrologic system, while outflows remove water. Storage is the retention of water by parts of the system. Because water movement is cyclical, an inflow for one part of the system is an outflow for another. Looking at an aquifer as an example, percolation of water into the ground is an inflow to the aquifer. Discharge of groundwater from the aquifer to a stream is an outflow (also an inflow for the stream). Over time, if inflows to the aquifer are greater than its outflows, the amount of water stored in the aquifer will increase. Conversely, if the inflows to the aquifer are less than the outflows, the amount of water stored decreases. Inflows and outflows can occur naturally or result from human activity which are discussed in further detail in Section 2.4.

For the purpose of this study, it is important to understand the water losses that happen in the hydrological cycle and the processes which direct the flow of water for surface storage or sub-surface storage for a sustainable yield of fresh water for human consumption and to avoid loss of usable water to certain storage areas. The initial water losses that occur before the precipitated water can be systematically directed towards surface storage through overland flow and sub-surface storage in aquifers through seepage are - Interception loss, soil moisture loss through infiltration and depression storage loss on the surface (Fig. 2.3). In order to maximize water gains through rainwater harvesting the initial water losses must be minimized and the overland flow (surface runoff) and seepage (recharge) must be maximized.

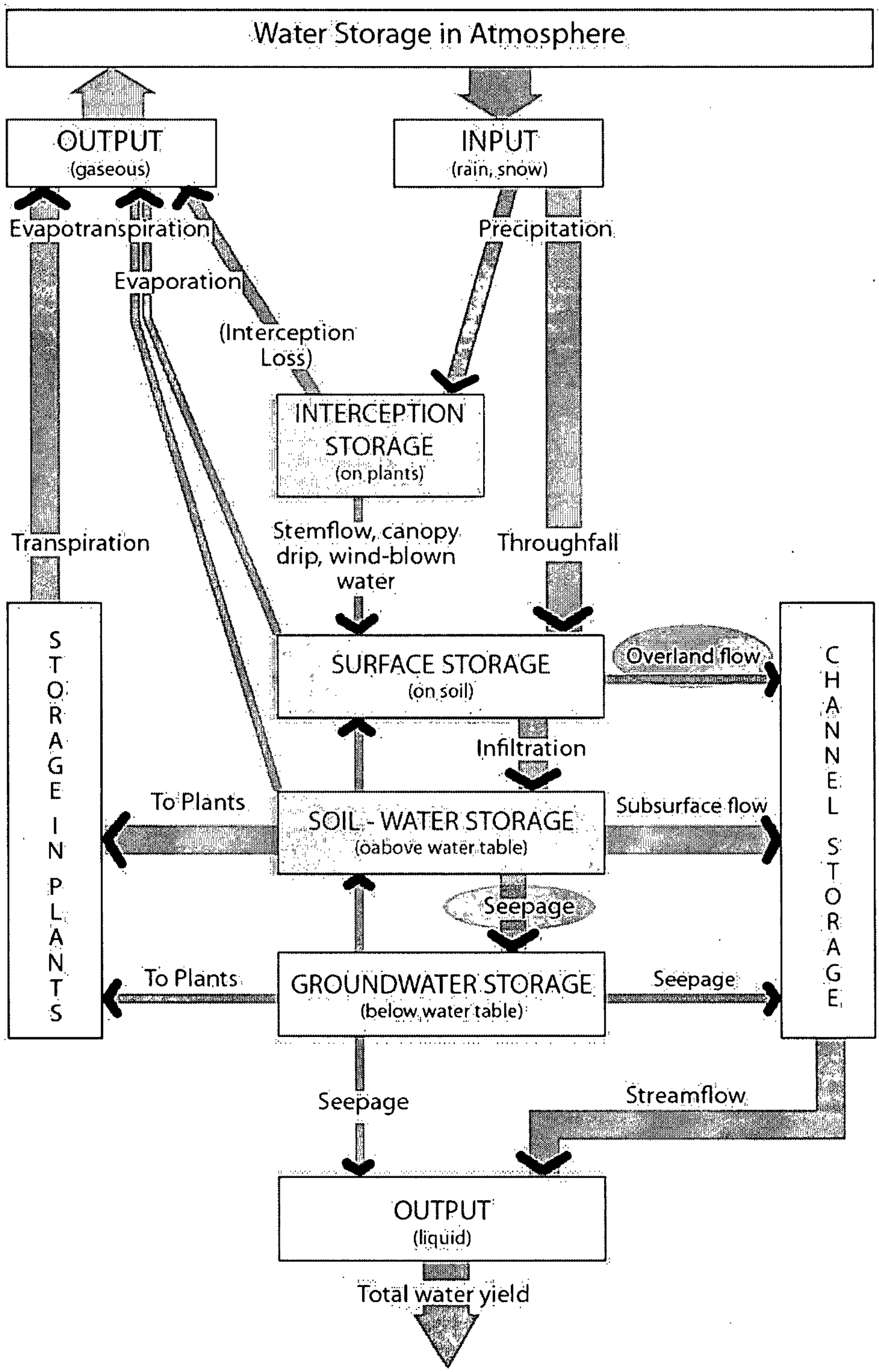

Figure 2.6: Water Storage and water flow in the Hydrological Cycle

(Adapted from Brooks, Kenneth N., Ffolliott Peter F., Gregersen, Hans M., Debano, Leonard F., Hydrology and the management of watershed, Iowa state University press, 1997, citing Anderson et al. 1976)

Initial Water Losses

1. Interception

Interception is the precipitated water retained by vegetation as leaf surface storage and returned to atmosphere through evaporation. It is solely due to evaporation and does not include transpiration (loss of internal water in the plants), throughfall (water dripping off the plant leaves) and stemflow (water running along the leaves, branches and down the stem). The amount of water intercepted in a given area depends on the species composition of vegetation, its density and also on the storm characteristics. Interception loss is larger for a small rainfall and levels off to a constant value for a larger storm as shown in figure 2.4.

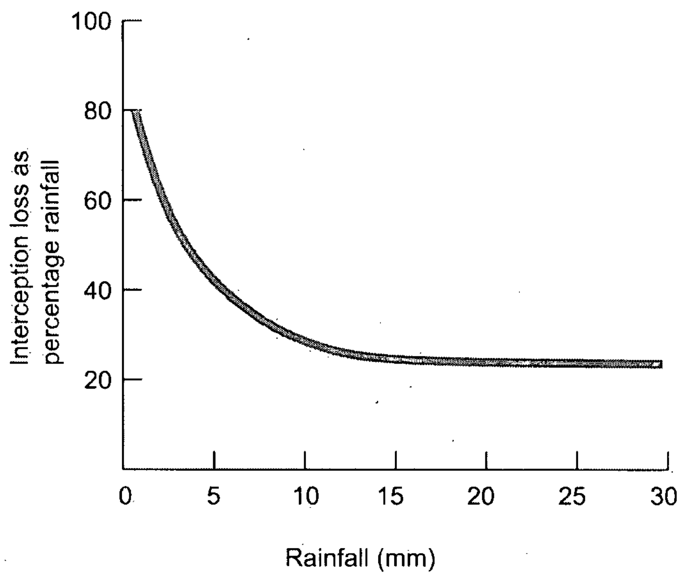

Figure 2.7: Typical Interception Loss Curve

(Source: Subramanya, K., Engineering Hydrology: Second Edition, Tata McGraw Hill publishing company limited, New Delhi, 2000. p 83)

Quantitatively, for a given storm, interception loss can be estimated as:

$Ii = Si + Ki \times E \times t$

Where, Ii = Interception loss in mm, Si = Interception storage whose value varies from 0.25 - 1.25 mm depending on the nature of vegetation, Ki = ratio of vegetal surface area to its projected area, E = evaporation rate in mm/hr during the precipitation, t = duration of rainfall in hours. [16]

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[16] Subramanya, K., Engineering Hydrology: Second Edition, Tata McGraw Hill publishing company limited, New Delhi, 2000. p 83.

Since, there are many assumptions involved in the empirical formula stated above, the common practice is to allow a lump sump value as the initial loss to be deducted from the initial period of the storm. It is found that conifereous trees have more interception loss than deciduous ones. Deciduous trees and dense grass, which account for the main vegetation in the study area, accounts for nearly 10-20% of the total rainfall in the season. [17]

2. Depression Storage

When the precipitation of a storm reaches the ground, it must first fill up all depressions on the surface before it can flow over it. The volume of water trapped in these depressions is called depression storage.

It is more qualitative than quantitative and depends on many factors, such as:

- The type of soil
- The condition of the surface, reflecting the amount and nature of depressions
- The slope of the catchment
- The antecedent precipitation, as a measure of soil moisture.

3. Infiltration

Infiltration is the downward movement of water through soil and rock until it reaches the water table where it becomes groundwater. Water percolates through the soil in the same way it fills a sponge, and moves from space to space through sand and gravel and along fractures in rock. The water stored in the soil through infiltration constitutes for the soil moisture.

The rate of infiltration is influenced by several factors, such as:

- Soil characteristics (temperature and water content of the soil)
- Surface of entry (degree of land slope and amount and type of vegetation)
- Fluid characteristics
- Rainfall intensity

[17] Subramanya. p 83

Infiltration capacity (maximum rate at which a given soil can absorb water) of a soil is high at the beginning of storm and has a exponential decay as the time elapses. [18] It is clear from figure 2.5 that the infiltration capacity for a given soil decreases with time from the start of the rainfall, it decreases with the degree of saturation and depends upon the type of soil. Infiltration capacity of a bare sandy loam soil (study area) is ~12mm/hr. [19]

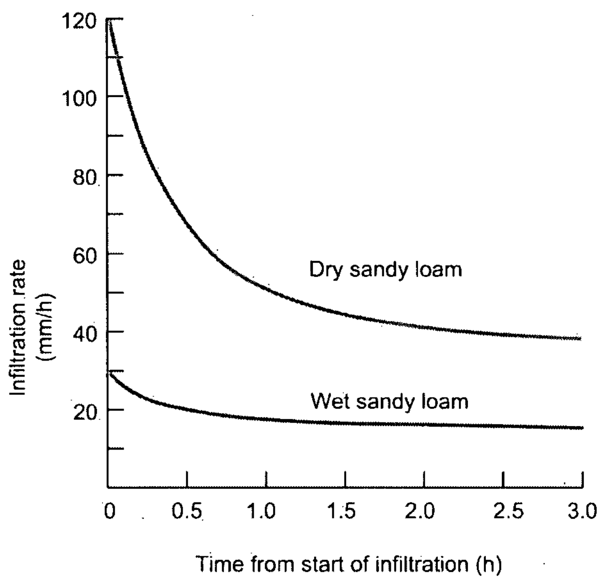

Figure 2.8: Variations of Infiltration Capacity

(Source: Subramanya, K., Engineering Hydrology: Second Edition, Tata McGraw Hill publishing company limited, New Delhi, 2000. p 88)

Water that doesn't infiltrate the soil flows on the surface as runoff. Infiltration plays a very significant role in the runoff process by affecting the timing, distribution and magnitude of the surface runoff. Further, infiltration is also the primary step in the groundwater recharge. It is therefore of great importance to-minimize these initial losses while improving the efficiency of surface runoff. Need of runoff efficiency is even higher in the study area as the rainfall is limited, evaporation rates are very high and unsaturated zones are very deep. If the water is allowed to stay on the surface longer it would be just lost to evaporation or soil moisture.

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[18] Subramanya. p 87

[19] Source: Indian Council of Agricultural Research (IACR)

For a typical 24 hr. storm in Delhi, the initial losses and possible water gains are shown in the following Hyetograph (Fig. 2.6).

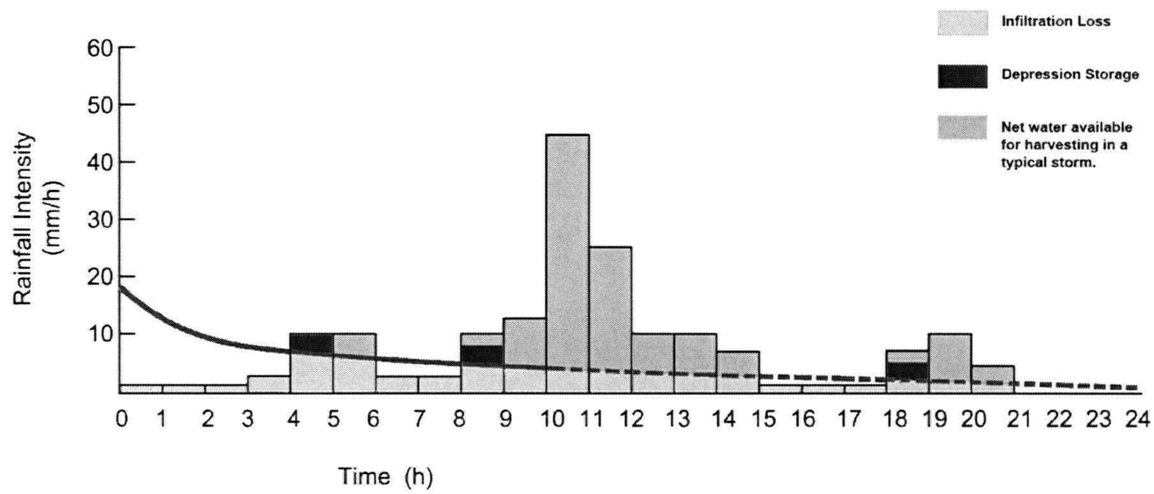


Figure 2.9: Hyetograph showing water losses and surplus for a typical 24 hr storm (10 yr return)

2.4 Effect of Human Activities on the Hydrological cycle

The earth's water supply remains constant, but man is capable of altering the cycle of that fixed supply. Water use by households, industries, and farms have increased. People demand clean water at reasonable costs, yet the amount of fresh water is limited and the easily accessible sources have been developed. As the population increases, need to withdraw more water from rivers, lakes and aquifers has risen, threatening local resources and future water supplies.

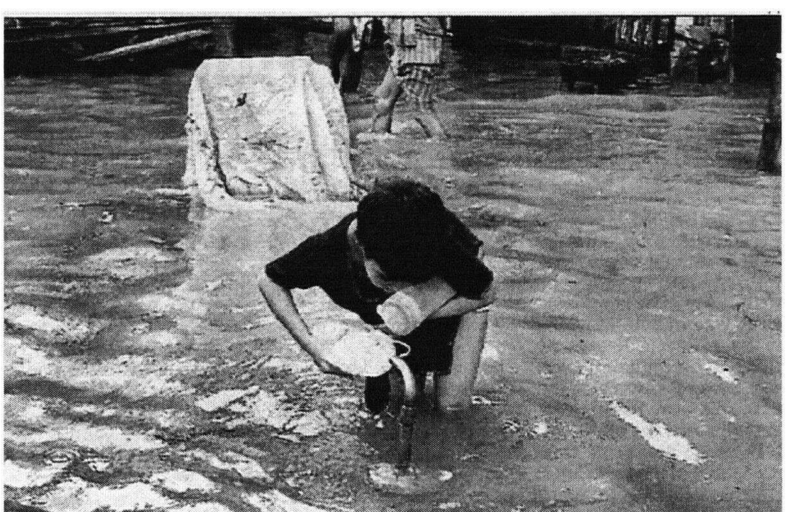
Humans in general withdraw 8 percent of the total annual renewable freshwater, and appropriate 26 percent of annual evapotranspiration and 54 percent of accessible runoff. [20] Their activities can create an imbalance in the hydrologic equation and can affect the quantity and quality of natural water resources available to current and future generations.

[20] Water for People, Water for Life. The United Nations - World Water Development Report, Executive Summary. March 2003. p9 < http://www.unesco.org/water/wwap/wwdr1/table_contents/index.shtml>

A larger population will not only use more water but will discharge more wastewater. Domestic, agricultural, and industrial wastes, including the intensive use of pesticides, herbicides and fertilizers, often overload water supplies with hazardous chemicals and bacteria. Also, poor irrigation practices raise soil salinity and evaporation rates. These factors contribute to a reduction in the availability of potable water, putting even greater pressure on existing water resources. Together with spatial and temporal variations in available water, the consequence is that water for all uses is becoming scarce and heading to a water crisis.

Large cities and urban sprawl particularly affect local climate and hydrology. Urbanization is accompanied by accelerated drainage of water through road drains and city sewer systems, which even increases the magnitude of urban flood events (Fig. 2.7). This alters the rates of infiltration, evaporation, and transpiration that would otherwise occur in a natural setting. The replenishing of groundwater aquifers does not occur or occurs at a slower rate. Together, these various effects (Fig. 2.8) determine the amount of water in the system and can result in extremely negative consequences for the water systems, and the environment as a whole.

In order to achieve a comprehensive solution to this problem, new approaches to urban development are required emphasizing sustainability and the restoration of the urban hydrological cycle. Traditionally, storm sewer facilities have been developed based on the assumption that the amount of rainwater drained away will have to be increased. From the standpoint of preserving or restoring the natural water cycle, it is important to harvest rainwater and to facilitate its permeation by preserving natural ground cover and greenery.



WATER, WATER EVERYWHERE, NOT A DROP TO DRINK: After a heavy downpour, a boy collects drinking water in Kolkata on Wednesday. Life in the city and its adjacent districts was paralysed on Wednesday as incessant overnight rain, measuring a record 180 mm, flooded vast areas and disrupted traffic.

Figure 2.10: Urban Flood in a city in India.

(Source: Newspaper clipping, Times of India, New Delhi, August 05, 2005)

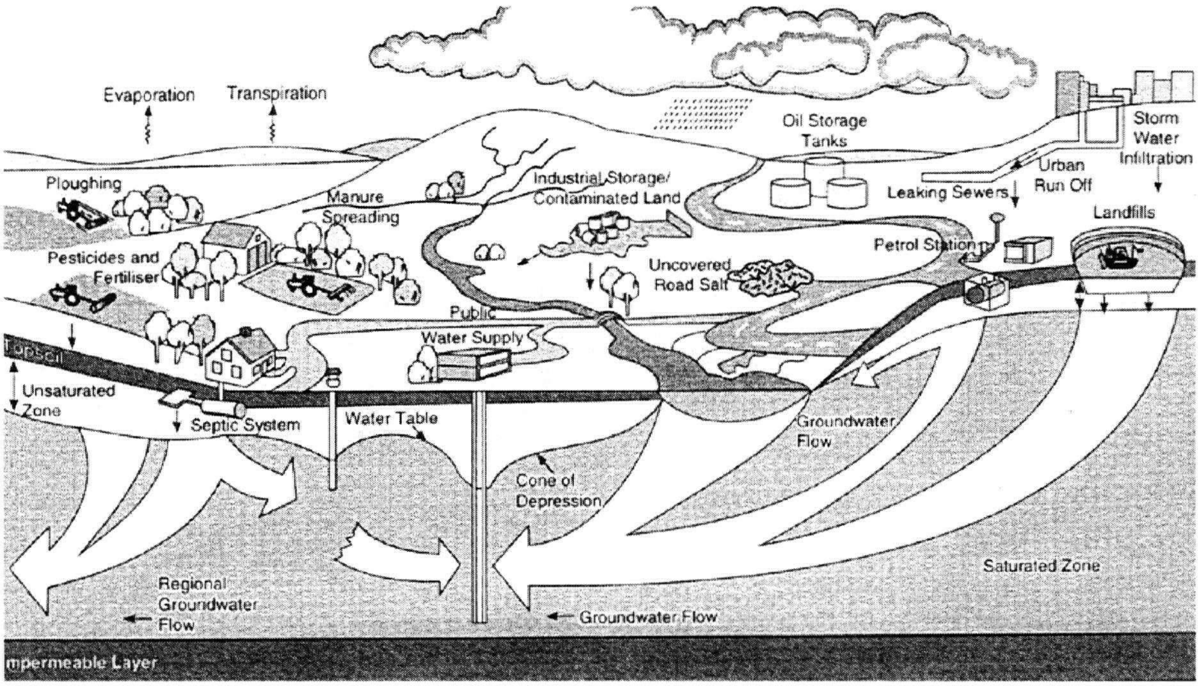


Figure 2.11: Effect of various human activities on the Hydrological Cycle.

(Source: United Nations Environment Programme < http://www.unep.or.jp/ietc/Publications/Urban/UrbanEnv-2/4.asp>)

2.5 Effect of Urban Green Spaces on the Hydrological cycle

Due to building and paving activities, urbanization tends to reduce the permeable surfaces, causing more water to rush directly into local water bodies through the city stormwater drains, rather than soaking into the soil, gradually releasing into lakes, rivers, or aquifers. The vegetation in the green spaces intercepts the falling rainwater thus reducing its velocity and quantity and helping in minimising soil erosions and surface runoffs. This intercepted water is then slowly released back to the surface through canopy drip and stem flow. Thus, the duration of water received by the surface is prolonged, its force reduced, which eventually promotes its infiltration into the soil. In the absence of green spaces the peak discharge and runoff is significantly increased in the urban areas which leads to urban flooding and also overloading of rivers, streams and lakes with stormwater carrying the non-point source pollutants from the air and surface of the urban areas.

"Runoff volumes in vegetated areas are typically between 10-20% of the average annual rainfall. In urban areas, where surfaces are highly impervious, typical runoff volumes are 60-70% of the average annual rainfall".[21] Figure 2.9 shows the relationship of impervious surface to runoff.

Therefore, the area of urban green spaces should be increased and they should be strategically located and managed to recharge as much water as possible into the ground rather than a storm drain. Infiltration can be effective at treating stormwater runoff, but soil properties must be appropriate to achieve effective treatment while not adversely impacting groundwater resources. Therefore a thorough knowledge of surface geology, hydro-geology and surrounding areas and functions is important to know before promoting on-site infiltration as it might effect the water quality of groundwater in the long run.

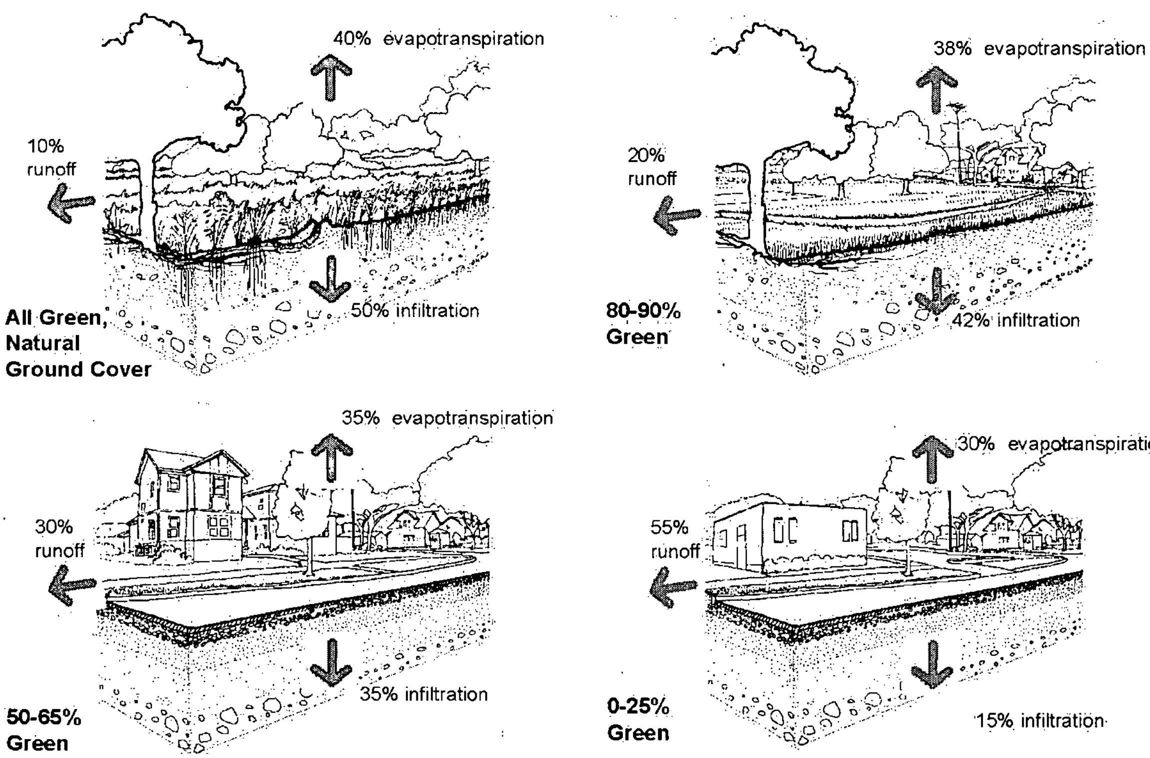


Figure 2.12: Runoff diagrams in different green cover conditions.

(Source: Bonsignore, R; < www.designcenter.umn.edu/reference_ctr/publications/pdfs/db3.pdf> p 4

[21] Bonsignore, R; Urban Green Space: Effects on Water and Climate, Design Brief, Number 3. Design Center for American Urban Landscape. University of Minnesota. August 2003. < www.designcenter.umn.edu/reference_ctr/publications/pdfs/db3.pdf> p 3

Shallow infiltration may be an important source of base flow to streams and lakes, cooled and filtered through the soil. Deep infiltration recharges aquifers, particularly important to communities relying on wells that draw from aquifers nearer the surface.

Enhancing or protecting water quality

Rainwater in urban areas can be a significant source of pollution. It concentrates atmospheric pollutants as well as oil residues, hydro-carbons and suspended solids carried by runoff from roads and other impervious surfaces. The pollutants in urban runoff can be dissolved in the water column or can be attached to solid particles that settle in streambeds, lakes, or wetlands. All of these contaminants can impair the beneficial uses of the receiving waters (both ground and surface waters). Pesticides and poly-nuclear aromatic hydrocarbons (PAHs) are of particular importance to discharges to groundwater. [22]

Vegetation can moderate urban effects on water bodies in several ways. Plants intercept and hold a portion of water on leaves and stems and can also act as a sediment trap, preventing transport of soil particles into water bodies. This effect is enhanced in natural areas such as forests where fallen trees and leaf litter are allowed to accumulate and more water can be retained, absorbed, and infiltrated in the spongy layers of humus.

The organic matter in the soil helps in removing the pollutants such as total suspended solids (TSS), heavy metals, phosphates, and organics from stormwater. The microorganisms (bacteria and fungi) present in the soil organic matter either partially or completely metabolize (break down) various pollutants. Most microorganisms inhabiting the soil profile where oxygen is plentiful degrade pesticides via aerobic metabolism. As pollutants undergo aerobic metabolism, they are normally transformed into carbon dioxide and water. Soils must contain sufficient organic matter and/or clays to sorb[23], decompose, and/or filter stormwater pollutants. Pollutant/soil contact time, soil sorptive capacity, and soil aerobic conditions are also important considerations.

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[22] Stormwater Management Manual for Eastern Washington. Washington State Department of Ecology, Water Quality Program. Publication Number 04-10-076. September 2004.

[23] Sorption is the action of soaking up or attracting substances; process used in many pollution control systems. It refers to the total action of both absorption and adsorption.

Urban green spaces can be further enhanced by designing them as stormwater infiltration treatment facilities such as a ponds, trenches, or bio-infiltration swales whose underlying soil and layers can remove pollutants from stormwater more effectively. These facilities can serve the dual purpose of removing pollutants (Table 2.1) and recharging aquifers. Infiltration treatment facilities should be preceded by a pre-treatment facility, such as a pre-settling basin or vault, to reduce the occurrence of plugging (blocking voids in the soil). Any of the basic treatment facilities designed to meet flow control requirements, can also be used for pretreatment.

Table 2.1: Ability of various Stormwater Treatment Facilities to Remove Key Pollutant. [24]

Treatment Facility	Total Suspended Soilds	Dissolved Metals	Total Phosphorus	Pesticided/ Fungicides	Hydrocarbons
Wet Pond	++	+	+	_	+
Bio-Filtration	++	+	+	+	+
Constructed Wetland	++	++	+	++	++
Leaf Compost Filters	++	+	_	++	++
Bio-infiltration	++	++	+	++	++

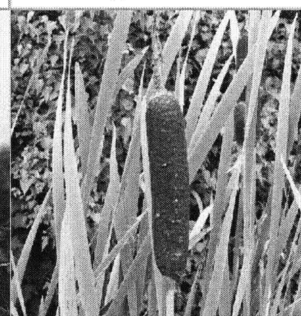
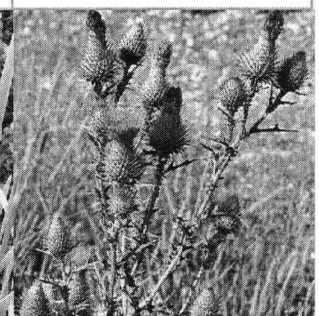
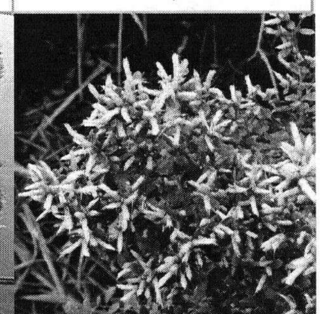
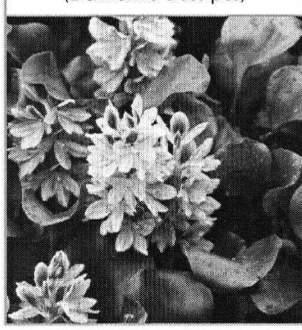
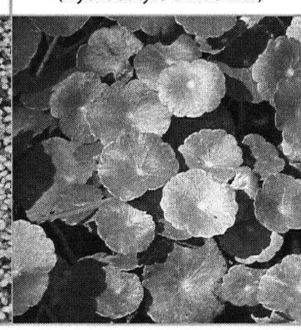
++ Significant Process, + Lesser Process, _ Not particularly effective at treating the identified pollutant

There are several natural plants and plant systems that are used worldwide for treating water through natural processes. The plants slow down the water flow, favour the settling of suspended solids and keep the deposits partially oxygenated by providing oxygen at the level of the roots. The vegetation also plays a role by providing a little oxygen and a few organic acids to the roots, thus favouring the development of bacteria. The stem also provide support for the bacteriological cultures. If such vegetation is introduced in the urban green spaces through careful planning and design, the green spaces can be much more effective in improving the quality of the stormwater. They also promote biodiversity and help in preserving and enhancing the ecosystem.

[24] Adopted from Stormwater Management Manual for Eastern Washington. Washington State Department of Ecology, Water Quality Program. Publication Number 04-10-076. September 2004. There are several other types of facilities which are not included in the table above as they deal with more non-natural processes and therefore beyond the scope of this study.

Some of these plants are listed in table 2.2 below with their common and scientific names. Some may require monitoring and maintenance as they tend to be invasive such as the Water Hyacinth, therefore, care must be taken while introducing them in the urban green areas.

Table 2.2: Plants suitable for water treatment through natural processes.

bulrush (Scirpus lacustris)	common reed (Phragmites communis)	broadleaf cattail (Typha latifolia)	common thistle (Cirsium vulgare)
			
paleyellow iris (Iris pseudacorus)	barnyard millet (Echinochloa crusgalli)	purple loosestrife (Lythrum salicaria)	cayotebrush (Baccharis pilularis)
			
water hyacinth (Eichhornia crassipes)	duckweed (Lemna minor)	manyflower marshpennywort (Hydrocotyle umbellata)	alkali seaheath (Frankenia salina)
			

Chapter – 3

Rainwater Harvesting

Water is a mobile substance and it is always on the move. Water harvesting is basically the practice of holding it in place in its desired phase for some period of time for human utilization. In some of the earliest definitions of the term, it is described as the process of collecting natural precipitation from prepared watersheds for beneficial use or the process of collecting and storing water form an area that has been treated to increase precipitation runoff. A "Water harvesting system" can be described as the complete facility for collecting and storing precipitation runoff. [25] It is composed of a catchment or water collecting area, a water storage structure and/or a water recharge structure and other components such as piping, evaporation control and fencing.

As we notice that most definitions refer to the precipitated water for harvesting, and rainfall being the most common and readily available source of nearly pure fresh water in Delhi, water harvesting is also commonly referred to as rainwater harvesting in Delhi, which specifically refers to collecting and storing rainwater for eventual human use. Rainwater which falls from the sky, free of any costs and unhindered by government regulations, can splendidly augment domestic water resources, if harvested.

The Rainwater collection system is known to have existed for over 4000 years. The rainwater that falls on any surface is guided to borewells or pits through small diameter pipes to recharge the underground water which can be used later whenever required. It can also be also directed to storage cisterns for direct re-use.

3.1 The Potential for Rainwater Harvesting

The total amount of water that is received in the form of rainfall over an area is called the **rainwater endowment** of that area. Out of this, the amount that can be effectively harvested is called the **water harvesting potential.** Among the several factors that influence the rainwater harvesting potential of a site, climatic conditions specially rainfall and the catchment characteristics are considered to be the most important.

[25] Athavale, R. N., Water harvesting and sustainable supply in India, Ahmedabad : Centre for Environment Education ; Jaipur : Rawat Publications, c2003. p 36

1. Rainfall

- **Quantity**: Rainfall is the most unpredictable variable in the calculation and hence, to determine the potential rainwater supply for a given catchment, reliable rainfall data are required, preferably for a period of at least 10 years. Also, it would be far better to use rainfall data from the nearest station with comparable conditions.
- **Pattern**: The number of annual rainy days also influences the need and design for rainwater harvesting. The fewer the annual rainy days or longer the dry period, the more the need for rainwater collection in a region. However, if the dry period is too long, big storage tanks would be needed to store rainwater. Hence in such regions, it is more feasible to use rainwater to recharge groundwater aquifers rather than for storage.

2. Catchment area characteristics

Runoff depends upon the area and type of the catchment over which it falls as well as surface features. All calculations relating to the performance of rainwater catchment systems involve the use of runoff coefficient to account for losses due to spillage, leakage, infiltration, catchment surface wetting and evaporation, which will all contribute to reducing the amount of runoff. (Runoff coefficient for any catchment is the ratio of the volume of water that runs off a surface to the volume of rainfall that falls on the surface. Runoff coefficients for various catchment surfaces are provided below in Table 3.1, for undeveloped areas and Table 3.2, for developed areas.

Based on the above factors the water harvesting potential of a site could be simply estimated using the formula given below.

Water harvesting potential = Rainfall x Area of catchment x Runoff coefficient

Size of the catchment areas have a great impact on the runoff efficiency, especially in arid and semi-arid climatic conditions such as that of the study area. Several studies done around the world show that rainwater harvested from smaller catchments is much more in quantity than that collected from large catchments as shown in Table 3.3, based on studies done in Negev desert in Israel and Table 3.4, based on Walnut Gulch experimental area in USA. The studies showed that every 10-fold increase in catchment area reduces average annual runoff by about 36 percent. [26]

Table 3.1: Runoff Coefficients for Undeveloped areas. Watershed types [27]

	Extreme	High	Normal	Low
Relief	**.28 -.35**	**.20 -.28**	**.14 -.20**	**.08 -.14**
	Steep, rugged terrain with average slopes above 30%	Hilly, with average slopes of 10 to 30%	Rolling, with average slopes of 5 to 10%	Relatively flat land, with average slopes of 0 to 5%
Soil Infiltration	**.12 -.16**	**.08 -.12**	**.06 -.08**	**.04 -.06**
	No effective soil cover, either rock or thin soil mantle of negligible infiltration capacity	Slow to take up water, clay or shallow loam soils of low infiltration capacity, imperfectly or poorly drained	Normal; well drained light or medium textured soils, sandy loams, silt and silt loams	High; deep sand or other soil that takes up water readily, very light well drained soils
Vegetal Cover	**.12 -.16**	**.08 -.12**	**.06 -.08**	**.04 -.06**
	No effective plant cover, bare or very sparse cover	Poor to fair; clean cultivation crops, or poor natural cover, less than 20% of drainage area over good cover	Fair to good; about 50% of area in good grassland or wood-land, not more than 50% of area in cultivated crops	Good to excellent; about 90% of drainage area in good grassland, woodland or equivalent cover.
Surface Storage	**.10 -.12**	**.08 -.10**	**.06 -.08**	**.04 -.06**
	Negligible surface depression few and shallow; drainageways steep and small, no marshes	Low; well defined system of small drainageways; no ponds or marshes	Normal; considerable surface depression storage; lakes and pond marshes	High; surface stor-age, high; drainage system not sharply defined; large flood plain storage or large number of ponds or marshes.

[26] Agarwal, A.; Narain, S.; Khurana, I. (Eds.), Making Water Everybody's Business : Practice and Policy of Water Harvesting. Centre for Science and Environment, New Delhi, 2001. p xxii

[27] California Department of Transportation. February 2007
< www.dot.ca.gov/hq/construc/stormwater/sw_attachments/attachment_d.doc>

Table 3.2: Runoff Coefficients for Developed areas [28]

Type of Drainage Area	Runoff Coefficient	Type of Drainage Area	Runoff Coefficient
Commercial:		Playgrounds:	0.10 - 0.25
Downtown area	0.70 - 0.95	Parks, cemeteries:	0.20 - 0.40
Neighbourhood areas	0.50 - 0.70	Lawns:	
Residential:		sandy soil, flat, <2%	0.05 - 0.10
Single-family areas	0.30 - 0.50	Sandy soil, average, 2-7%	0.10 - 0.15
Multi-units, detached	0.40 - 0.60	Sandy soil, steep, >7%	0.15 - 0.20
multi-units, attached	0.60 - 0.75	Heavy soil, flat, <2%	0.13 - 0.17
Suburban	0.25 - 0.40	Heavy soil, average, 2-7%	0.18 - 0.25
Apartment dwelling units	0.50 - 0.70	Heavy soil, steep, >7%	0.25 - 0.35
Industrial:		Streets:	
Light areas	0.50 - 0.80	Asphaltic	0.70 - 0.95
heavy areas	0.60 - 0.90	Concrete	0.80 - 0.95
Railroad yard areas:	0.20 - 0.40	Brick	0.70 - 0.85
Unimproved areas:	0.10 - 0.30	Roofs:	0.75 - 0.95

Table 3.3: Effect of catchment size on quantity of water harvested [29]

S.no	Size of Catchment (hectares)	Quantitiy of water harvested (Cubic metres/hectare)	Percentage of annual rainfall collected
1	Microcatchment [30]	160	15.21%
2	20	100	9.52%
3	300	50	3.33%

[28] California Department of Transportation

[29] Agarwal. p xix

[30] A microcatchment is a very small catchment of size upto 1000 sqaure metres or 0.1 hectares

Table 3.4: Mean annual runoff from 12 catchments in the Walnut Gulch area, USA [31]

Size of Catchment (hectares)	No. of years for which the record was maintained	Mean annual runoff (mm/year)
1.30	13	27.6
151	15	12.7
1,550	12	8.2
9,510	13	5.7
14,900	18	4.7

Harvesting Potential of Delhi

The average annual rainfall in Delhi is 611 mm. However, recharge of groundwater is limited due to decreased availability of permeable surfaces owing to urbanization, and the runoff getting diverted into the sewers or stormwater drains that convey the water into the river Yamuna. The annual rainwater harvesting potential has been assessed at 2500 million litres per day (mld). If even 25 percent of this could be harvested it would imply availability of 625 mld, which would be nearly equivalent to the presently estimated deficiency. This is in addition to the potential for roof water harvesting assessed at around 27 mld. [32]

3.2 Benefits of Rainwater harvesting

Rainwater harvesting has proven to be a beneficial way of procuring water for local communities since historical times (refer Section 3.3). Rainwater is relatively clean and the quality is usually acceptable for many purposes with little or even no treatment. Some of the benefits of rainwater harvesting systems include:

1. Rainwater harvesting has few negative environmental impacts compared to other technologies for water resource development. [33]

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[31] Agarwal. p xxii

[32] Delhi Development Authority. Draft Master Plan for Delhi 2021. 24 Sept. 2006 < http://ddadelhi.com/greens/greens_default.htm>

[33] United Nations Environment Programme < http://www.unep.or.jp/ietc/Publications/Urban/UrbanEnv-2/2>

3. Rainwater Harvesting is neither energy-intensive nor labour-intensive. It can be a cost-effective alternative to other water-accruing methods, such as desalination plants and dams. [34]
4. Rainwater harvesting systems can provide water at or near the point where water is needed or used. The systems can be both owner and utility operated and managed.
5. Rainwater harvesting provides a water supply buffer for use in times of emergency or breakdown of the public water supply systems, particularly during natural disasters.
6. Helps in utilizing the primary source of water and prevent the runoff from going into sewer or storm drains, thereby reducing soil erosions and the load on treatment plants.
7. Reduces urban flooding, decreasing choking of stormwater drains and flooding of roads.
8. Harvesting rainwater for recharging it into the aquifers helps in improving the quality of existing groundwater through dilution. It also prevents intrusion of seawater into coastal regions.
9. Storing harvested rainwater for immediate or future use helps in saving energy as it requires 0.40 kilo watt hour of electricity to lift one cubic metre of groundwater, by one metre. [35]

Apart from increasing water availability, local water harvesting systems developed by local communities and households can reduce the pressure on the state to provide all the financial resources needed for water supply. As governments in developing countries are often short of funds, this approach will greatly reduce constraints posed by financial considerations. Involving people will also give them greater ownership over water projects and will go a long way towards reducing misuse of government funds.

Moreover, when communities and households develop their own water supply systems, they are more likely to look after them as demonstrated in various parts of India where rainwater systems are still in active use. Water will also be used more efficiently instead of being squandered as is often visible in the urban centers with centralized services.

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[34] Gopinath, K.R; "Rainwater Harvesting and Educational Awareness", Session at the 3rd World Water Forum, Japan , March 2003. < http://www.krg-rainwater.com/WaterForum.html>

[35] Delhi Jal Board. 25 Sept. 2006 <http://www.delhijalboard.nic.in/djbdocs/r_w_harvesting/harvesting2.htm>

3.3 History and Traditional Practices

Rainwater harvesting and utilisation systems have been used since ancient times and evidence of roof catchment system date back to early Roman times. Roman villas and even whole cities were designed to take advantage of rainwater as the principal water source for drinking and domestic purposes since at Least 2080 B.C.[36] In the Negev desert in Israel, tank for storing runoff from hillside for both domestic and agricultural purposes have allowed habitation and cultivation in areas with as little as 100 mm of rain per year.

According to an Archaeological Encyclopedia "The first cisterns were dug in the Middle and Late Bronze Age [2200-1200 B.C.]. The rainwater that collected in them during the short rainy season would be enough for at least one dry season. In some parts of Palestine cisterns were the main (sometimes even the only) source of drinking water in peace time as well as in war time. In the early Iron Age [1200-1000 B.C.] the sides of cisterns began to be covered with watertight plaster, which considerably prolonged the time for which water could be stored. It was this important innovation that made it possible to extend the areas of settlement into the mountainous parts of the country".[37] The rainwater was generally collected from the roof and the courtyard of the house, in cities as well as in the countryside. A simple example or such system is shown in figure 3.1 below.

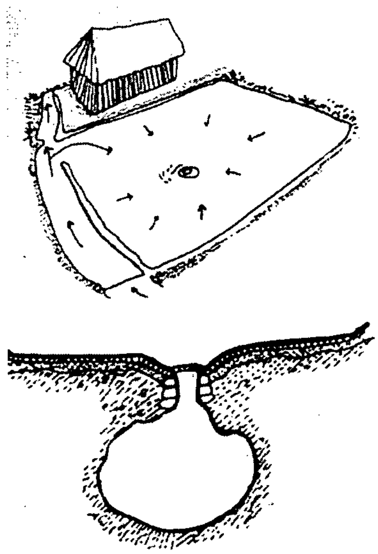

Figure 3.1:

Ancient practice of collecting rainwater from the roof and courtyards by sloping the surface towards center with a storage cistern dug in the ground.

[36] Rainwater Harvesting and Utilization. Blue Drop Series, Book 2: Beneficiaries and capacity builders. United Nations Human Settlements Programme (UN-HABITAT). 2005. p10

[37] Wåhlin, Lars; The family cistern: 3,000 years of household water collection in Jordan. Papers from the Third Nordic Conference on Middle Eastern Studies, Joensuu June 1995. C. Hurst & Co. Ltd. London. 1997

The earliest known evidence of the use of the technology in Africa comes from northern Egypt, where tanks ranging from 260-2000 m^3 have been used for at least 2000 years - many are still operational today. The technology also has a long history in Asia, where rainwater collection practices have been traced back almost 2000 years in Thailand. [38] The small scale collection of rainwater from the eaves of roofs or via simple gutters into traditional jars and pots has been practiced in Africa and Asia for thousands of years. In many remote rural area, this is still the method used today.

In India tradition of water harvesting are more than two millennia old. Evidence of this tradition can be found in ancient texts, inscriptions, local traditions and archaeological remains. There is some evidence of the existence of advanced water harvesting systems even from pre-historic times. Hindu texts like the Puranas, Mahabharata and Ramayana and various Vedic, Buddhist and Jain works contain several references to canals, tanks, embankments and wells.

Water harvesting and integrated land-water management are not new to India or to many other parts of the developing world. The art and science of 'collecting water where it falls' is an ancient but dying wisdom which needs to be revived to meet modern freshwater needs adequately, equitably and sustainably, and modernized with inputs from science and technology. [39]

India's traditional water harvesting structures demonstrate people's ingenuity at its best. Using unique modes and basic engineering skills, people living in ecosystems across the country have developed a wide array of techniques for satisfying their thirst. Some of these tractional practices which are more relevant for the context of this study are summarized below with their main principle, their features and forms, the functions that they served and/or promoted and their suitability in current urban environments at the regional and neighbourhood scales.

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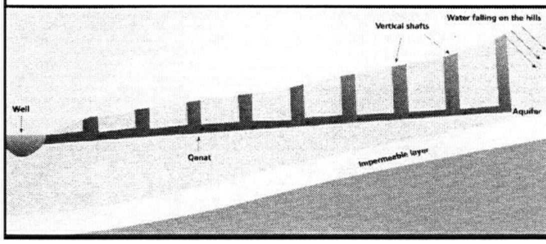
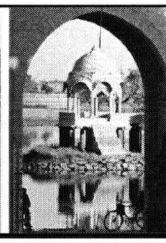
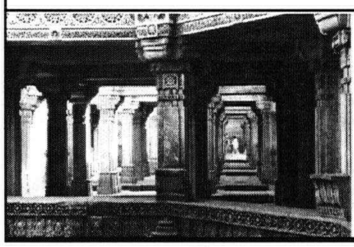
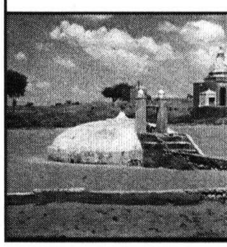
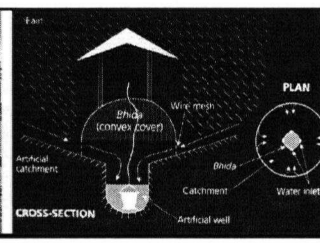
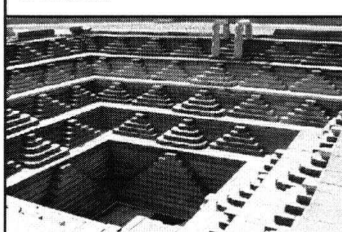
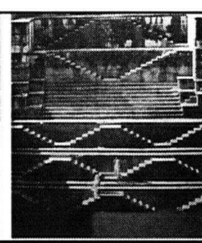
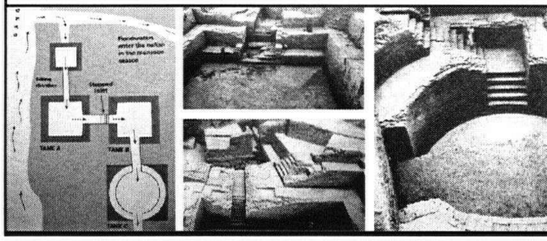
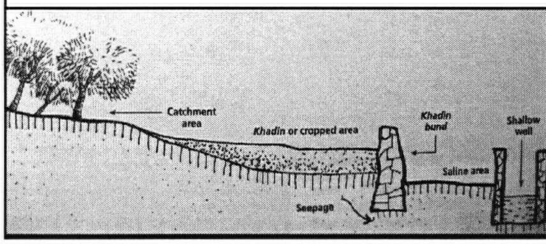
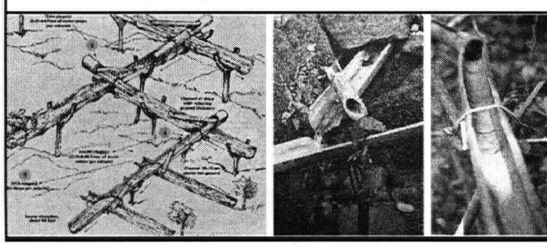
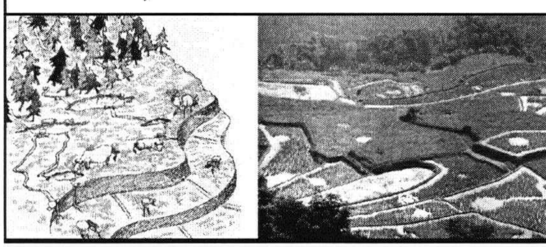
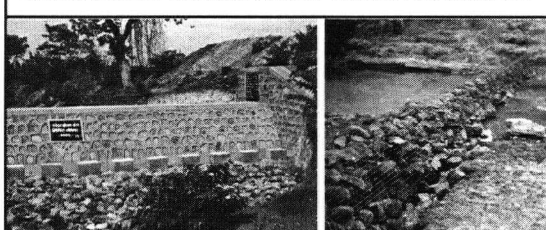
[38] Rainwater Harvesting and Utilization. Blue Drop Series. p 11

[39] Aggarwal, Anil and Sunita Narain (ed): Dying Wisdom: Rise, Fall and Potential of India's Traditional Water Harvesting Systems: A Citizens' Report. Centre for Science and Environment, Delhi, edition 2005.

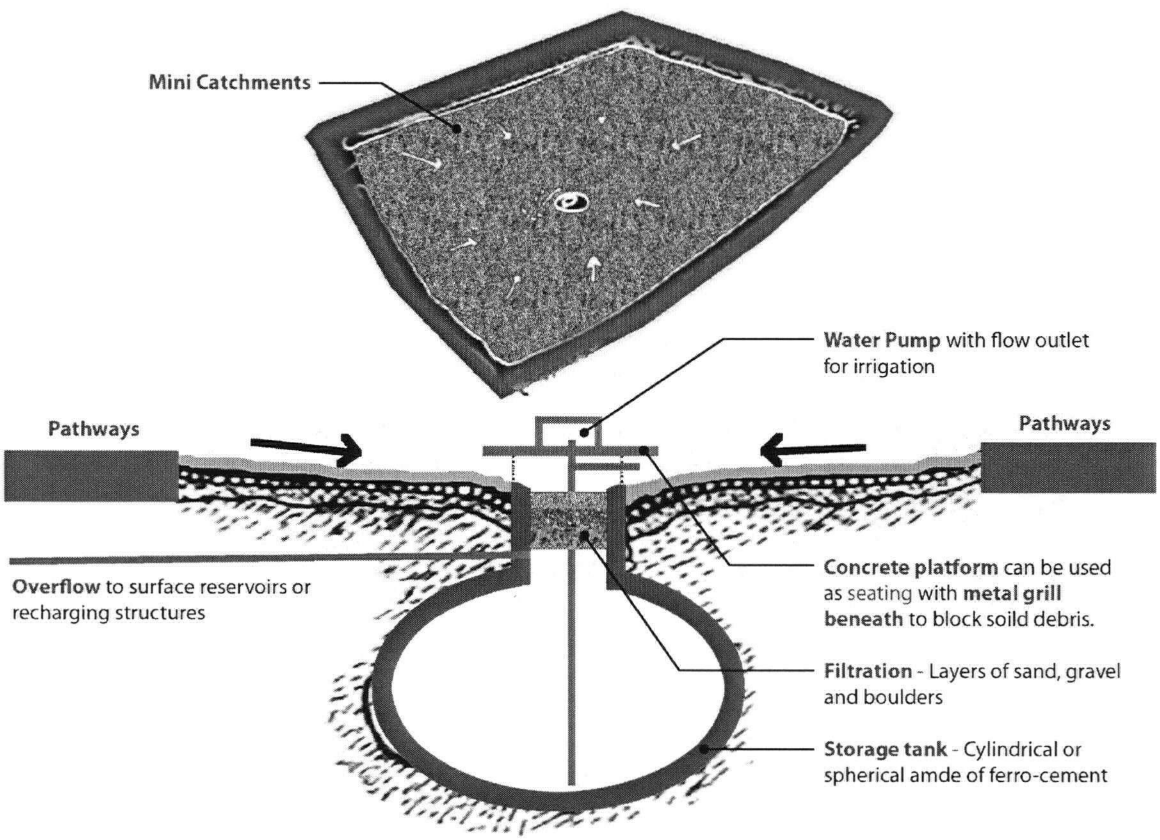
Traditional Rainwater Harvesting practice	Principles	Features/Forms	Functions
Qanats / Surangam: 	Capturing ground-water from alluvial fan on mountain slopes. Using force of Gravity. Minimizing seepage and evaporation losses	Sub-terranean tunnels Vertical shafts for maintaining atmospheric pressure and maintenance. Storage ponds	Village domestic use such as drinking, bathing, washing. Irrigating fields. Feeding livestock
	▒ ■		
Artificial Lakes / Johads / Rapats: 	Watershed management. Understanding and utilizing topography. Capturing rainwater	Natural depression, further excavated to increase storage capacity. Enhanced edge for communal use.	Domestic use-bathing, washing, drinking. Religious and communal ceremonies Groundwater Recharge
	▒	▒	▒
Baolis / Step wells: 	Tapping groundwater. Making it easily accessible at all levels and all times. Community participation.	Large dug well Series of steps leading down to the groundwater. Communal gathering space around water.	Drinking water for village/town and caravans. Religious ceremonies. Recreation space.
	▒ ■		▒ ■
Kunds / Kundis: 	Mini catchments. Increasing runoff efficiency. Ensuring water quality Avoiding evaporation.	Saucer shaped smooth catchment area. Circular well with hemi-spherical cover. A wire mesh across water-inlets.	Mainly Drinking water in desert areas. Universal design easily identifiable across the desert landscape. Gathering space.
	▒ ■	▒ ■	▒ ■
Jhalaras: 	Capturing sub-terranean seepage. Community participation	Central water tank often rectangular. Network of steps all around the water tank at multiple levels.	Community use, mostly bathing. Religious ceremonies.
	▒ ■	▒	▒

▒ - Adaptable at the regional Scale ■ - Adaptable at the neighbourhood Scale

Tank Systems: 	Capturing flood waters Water quality improvement through siltation . Water division for long term use.	De-silting chamber. Series of tanks with stairs. Spill and exit channels Series of wells.	Storing water for periods of drought. Used for all domestic purposes including drinking.
Khadin: 	Harvesting surface runoff from gravelly hill slopes. Using water-saturated land for cultivation. Collecting seepage	Very long (100-300 m) earthen embankment Sluices and spillways allowing excess water to drain off. Shallow well.	Crop production. Drinking water.
Bamboo Drip irrigation: 	Capturing natural springs water. Use of gravity flow Diversion and controlled distribution	Bamboos of varying diameters Intricate network of bamboo pipelines Jute ropes and wooden props.	Drip irrigation of black pepper and betel leaf plantations.
The 'Zabo' System of cultivation: 	Capturing upland surface runoff with a conservation base Soil erosion control Water resource development.	Artificial ponds for storing runoff Cattle yard to provide organic manure Terraced paddy fields	Forestry Agriculture Animal care
Check Dams / Stream Weirs / Gabion Structures: 	Capturing stream flow Stream channel storage. Enhancing recharge and reducing erosion	Dam across stream width in local material such as bricks, stones. The height is normally less than 2m and lower in the middle to allow water flow.	Irrigation Livestock and domestic needs Replenishment of nearby groundwater reserves and wells

- Adaptable at the regional Scale - Adaptable at the neighbourhood Scale

Most of the traditional practices described above are often associated with rural or remote areas where centralized water supply is not available. They are generally associated with sufficient areas, human resources and human involvement and dependence. In current urban context, that is often not the case as the areas available for such practices is limited, availability of centralized water supply makes the local residents less or not dependent on them and moreover the changing lifestyles don't support such systems in the urban context in their totality. However, after careful analysis of the traditional rainwater harvesting practices it is found that many of them can still be adapted at the regional and neighbourhood scale in the urban areas. Some of the practices can be adapted in their totality such as the Kunds/kundis and the one showed in figure 3.1, while others can be adapted in parts, either in their principle, or their features and forms, or their functions. A simple demonstration of how these can be used in green open spaces in urban environments is shown in figure 3.2 below.



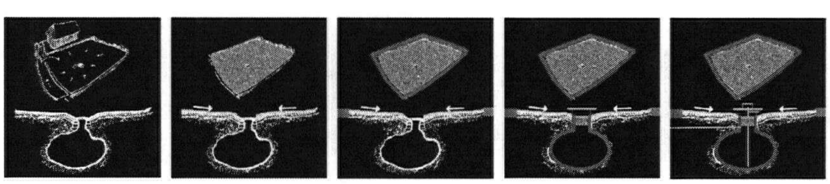


Figure 3.2:

Demonstration of a Traditional Rainwater Harvesting Practice adapted for urban context.

3.4 Types of Rainwater Harvesting Systems

Typically, a rainwater harvesting (RWH) system consists of three basic elements: the collection system, the conveyance system, and the storage system. Collection systems can vary from simple types within a household to bigger systems where a large catchment area contributes to an impounding reservoir from which water is either gravitated or pumped to water treatment plants. The categorisation of rainwater harvesting systems depends on factors like the size and nature of the catchment areas and whether the systems are in urban or rural settings. Some of the urban RWH systems are described below.

1. Simple roof water collection systems

While the collection of rainwater by a single household may not be significant, the impact of thousands or even millions of household rainwater storage tanks can potentially be enormous. The main components in a simple roof water collection system are the cistern itself, the piping that leads to the cistern and the appurtenances within the cistern. The materials and the degree of sophistication of the whole system largely depend on the initial capital investment. Some cost effective systems involve cisterns made with ferro-cement, etc. In some cases, the harvested rainwater may be filtered. In other cases, the rainwater may be disinfected.

The water collected from the roof of a house can be re-used after storing in a cistern or can be recharged to the ground (Figure 3.3) through various techniques described in the next chapter.

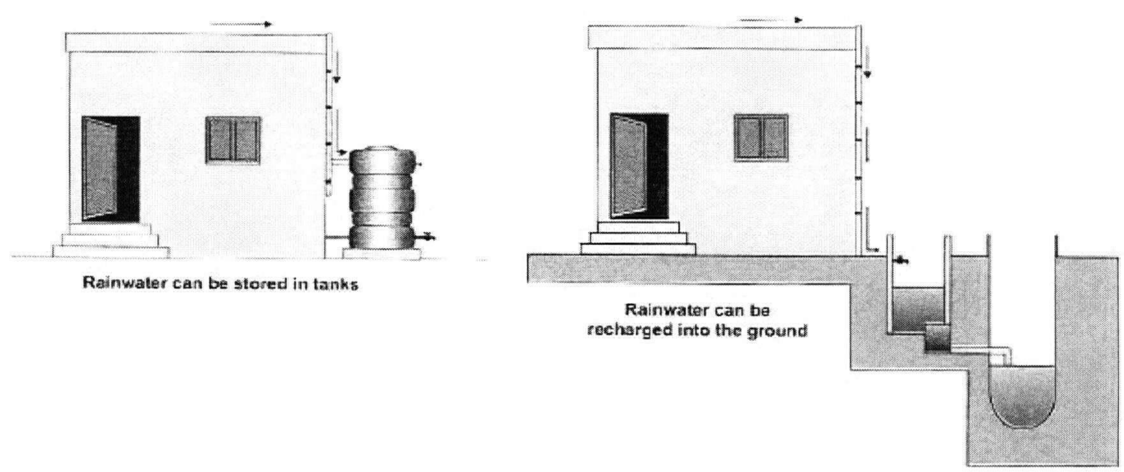


Figure 3.3: A simple Domestic Rainwater Harvesting system

(Source: UN-HABITAT, Blue Drop Series, Book 2: Beneficiaries and capacity builders. 2005. p 11)

2. **Larger systems for educational institutions, stadiums, airports, and other facilities**

Larger land uses such as mentioned above hold great potential for rainwater harvesting and becoming self sustainable for their water needs owing to their large surface areas. They generally need a combination of roof top harvesting and surface water harvesting and after identifying their water needs the water can be either stored in above ground or under ground tanks. This water can be used for potable use after minor filtration or non-potable use directly. The surplus water is also useful in maintaining open green spaces of these large land uses and/or recharging the aquifers from where it can be withdrawn in times of emergency. When the systems are larger, the overall system can become a bit more complicated, and need proper planning and detailed geological and hydro-geological study of the catchment areas.

3. **Land surface catchments**

Rainwater harvesting using ground or land surface catchment areas can be a simple way of collecting rainwater. Compared to rooftop catchment techniques, ground catchment techniques provide more opportunity for collecting water from a larger surface area. By retaining the flows (including flood flows) of small creeks and streams in small storage reservoirs (on surface or underground) created by low cost (e.g., earthen) dams, this technology can meet water demands during dry periods. The stored water also allows for infiltration into the ground for charging the aquifers. The surface runoff collected in stormwater ponds/reservoirs from urban areas is subject to a wide variety of contaminants. Keeping these catchments clean is of primary importance, and hence the cost of water pollution control can be considerable.

3.5 Quality Considerations in Utilizing Rainwater

It is generally believed that rainwater can provide clean, safe and reliable water which can be consumed without pre-treatment. This however may be used in some areas that are relatively unpolluted. Rainwater collected in many locations contains impurities. Therefore, in order to ensure quality of water, the collection systems will have to be properly built and maintained and the water shall also have to be treated appropriately for intended uses. Once rain comes in contact with a roof or collection surface, it can wash many types of bacteria, molds, algae, protozoa and other contaminants into the cistern or storage tank. Indeed, some samples of harvested rainwater have shown detectable levels of these contaminants.

Health concerns related to bacteria, such as salmonella, e-coli and legion Ella, and to physical contaminants, such as pesticides, lead and arsenic, are the primary criteria for drinking water quality analysis. Falling rain is generally free of most of these hazards. But, if the rainwater is intended for potable use inside the household, appropriate filtration and disinfection practices should be employed. If the rainwater is to be used outside for landscape irrigation, where human consumption of the untreated water is less likely, the presence of contaminants may not be of major concern and thus treatment requirement can be less stringent or not required at all. Depending on where the system is located, the quality of rainwater itself can vary, reflecting exposure to air pollution caused by industries such as cement kilns, gravel quarries, crop dusting and a high concentration of automobile emissions. Hence air quality standards also need to be reviewed and enforced (not included in the scope of this study).

In terms of physical-chemical parameters, collected rainwater tends to exhibit quality levels that are generally comparable to the World Health Organization (WHO) guidelines for drinking water. Low pH [40] rainwater can occur as a result of sulphur dioxide, nitrous oxide and other industrial emissions. However, for irrigation purposes in the context of the study a broad range of pH is acceptable according to the criteria specified by the Central Pollution Control Board in Delhi which allows a range of pH from 6.0 to 8.5. [41]

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[40] The determination of whether water is acidic, neutral, or basic. is referred to as pH, which is a measure of the hydrogen ion concentration in water. In a scale from 0 to 14, 7 is neutral, values less than 7 represent more acid conditions, values greater than I represent more basic or alkaline conditions. The desired pH of potable water is pH 7.

[41] Central Pollution Control Board. Delhi, India. 07 Oct. 2006 <http://www.cpcb.nic.in/classi.htm>

Chapter – 4

Groundwater Recharge

In public green spaces, the potential of storing harvested rainwater for their direct use is only limited to irrigation purposes, but the potential of recharging the harvested rainwater to groundwater is tremendous, which improves the availability of groundwater in the region for drinking or other domestic purposes, thereby relieving to some extent the conventional water supply system from demand pressures. Groundwater recharge is therefore studied in detail in this chapter.

4.1 Concept of Groundwater Recharge

Groundwater recharge may be defined in a general sense as the downward flow of water reaching the water table, forming an addition to the groundwater reservoir. Recharge of groundwater may occur naturally from precipitation, rivers, canals, drains and lakes and as man-induced phenomenon via such activities as irrigation and pumping regulations.

Groundwater recharge can be divided into three basic categories - direct, indirect, and artificial (man-induced) as mentioned below:

1. Direct recharge is defined as water added to the groundwater reservoir in excess of soil moisture deficit and evapotranspiration, by direct vertical percolation of precipitation through the unsaturated zone.
2. Indirect recharge results from percolation to the water table following runoff, flood out and localization in ponding in low lying areas or through the beds of water courses.
3. Artificial Recharge is the process by which the groundwater reservoir is augmented at a rate exceeding that under natural conditions of replenishment. Any man made scheme or facility that adds water to an aquifer may be considered to be an artificial recharge system. A simple water flow diagram in an artificial recharge cycle is shown below in figure 4.1.

The artificial recharge to groundwater aims at augmentation of groundwater reservoir by modifying the natural movement of surface water utilizing suitable civil construction techniques. It is most suitable in urban areas where natural filtration is generally reduced drastically due to over development. It is also suitable for areas where the groundwater levels have gone down tremendously, thus, increasing the depth of unsaturated zone, in order to prevent excessive water loss to soil moisture. It is therefore of great importance for the study area.

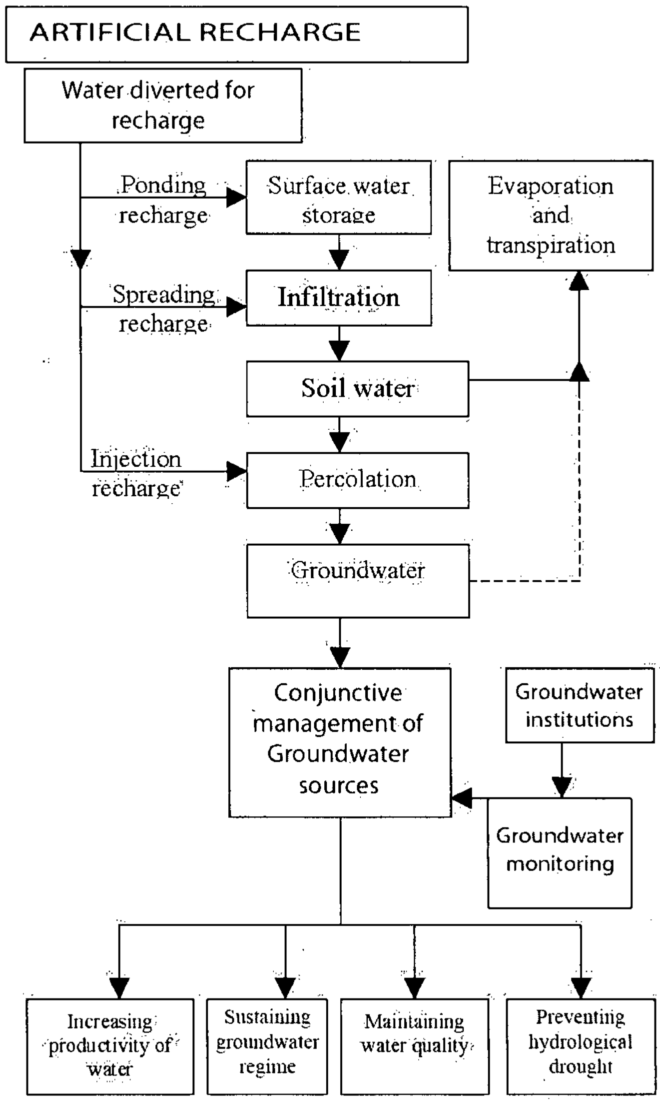

Figure 4.1: Schematic Diagram of the hydrological Processes involved in artificial recharges and its conjunctive management.

(Source: Adapted from Sakthivadivel, R.; Artificial Recharging of Groundwater Aquifers and Groundwater Modelling in the Context of Basin Water Management; Modelling in Hydrogeology, Eds: L. Elango and R. Jayakumar, UNESCO-IHP, Allied Publishers, 2001)

4.2 Need for Artificial Recharge to Groundwater

Natural replenishment of the groundwater reservoir is slow and is unable to keep pace with the excessive continued exploitation of groundwater resources in various parts of the country. This has resulted in declining groundwater levels and depleted groundwater resources in some areas of the country. In order to augment the natural supply of groundwater, artificial recharge of groundwater has become an important and frontal management strategy in the country.

The annual groundwater resources in India have been assessed as 432 Billion cubic metres (BCM) out of which 361 BCM is available for irrigation. Besides this the in-storage fresh groundwater resources up to the depth of 450 m in alluvium & 100 m in hard rock terrain, have been estimated as 10,812 BCM.[42] Groundwater development is not uniform throughout the country and some of the areas have been excessively exploited due to liberal subsidies, easy credit facilities and advanced drilling and pumping techniques leading to groundwater scarcity. At present about 85% of water supplies for domestic use in rural areas and 50% of water for urban and industrial areas, besides 50% of irrigation water requirements are being met from groundwater in India. [43]

Other factors attributing to the problem with the groundwater are seawater intrusion and pollution due to human activities. Most of the urban areas face water scarcity due to urbanization, construction of buildings and paved area. To alleviate the problems of declining groundwater levels and deterioration of groundwater quality, adoption of large scale artificial recharge of the surplus monsoon runoff is a pivotal solution. Augmentation of groundwater resources through artificial recharge can be intensified through individual and community efforts. Specific emphasis needs to be given in the areas where groundwater levels are declining and water scarcity is being felt.

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[42] Excerpt from an interview with S.S CHAUHAN, Chairman & member, Central Ground Water Board, Ministry of Water Resources, Delhi. Dec. 2005<http://www.vigyanprasar.com/comcom/inter63.htm>

[43] ibid

In hilly areas, even though the rainfall is high the scarcity of water is felt in the post monsoon season. Due to the steep gradients, major quantity of water flows to the low lying areas as surface run-off. Springs which are the major source of water in hilly areas are also depleted during the post monsoon period. Therefore, artificial recharging is needed for providing sustainable yield to springs. This can done by increasing the recharge period during and after the rainy season. Small surface storages above the spring level would provide additional recharge and would result in sustainable yield to springs.

In arid and semi-arid areas of the country (study area) rainfall varies between 150 and 600 mm/ year with less than 10 rainy days. Majority of the rain occurs in 3 to 5 major storms lasting only a few hours. The rates of potential evapo-transpiration (PET) are exceptionally high in these areas which range from 300 to 1300mm.[44] The average annual PET is much higher than the rainfall and at times as high as ten times the rainfall. The entire annual water resource planning has to be done by conserving the rainfall by either storing on surface or in sub-surface reservoir. The climatic features are not favourable for creating surface storage. Artificial recharge techniques have to be adopted which help in diverting most of the surface storage to groundwater storage within shortest possible time. The artificial recharge techniques aim at increasing the recharge period in the post-monsoon season for about 3 more months providing additional recharge. This results in providing sustainability to groundwater development during the lean season.

4.3 Benefits of Artificial Recharge to Groundwater

Artificial recharge has several benefits, most important of those are listed below:

1. It enhances availability of groundwater at specific place and time and utilizes rainwater for sustainable development restoring supplies from aquifers depleted due to excessive groundwater development
2. The structures required for recharging groundwater reservoirs are of small dimensions and cost effective, such as percolation tanks, surface spreading basins, pits, check dams, subsurface dykes etc. (Appendix A)

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[44] Master Plan for Artificial Recharge to Groundwater in India, Central Ground Water Board, Ministry of Water Resources. Delhi. India. 2002

3. Sub-surface storage has advantages of being free from the adverse effects like inundation of large surface area, loss of cultivable/open land and displacement of local population
4. Groundwater is not directly exposed to evaporation and pollution.
5. It improves the quality of existing groundwater through dilution in areas where it is brackish or saline.
6. The underground storage of water would also have beneficial influence on the existing groundwater regime. It increases the productivity of aquifer. The aquifer also serves as distribution system thereby reducing the cost intensive surface water conveyance system at the regional level. [45]
7. It leads to rise in groundwater levels resulting in reduction in pumping costs and energy saving.
8. The effluence resulting from such sub-surface storage at various surface intersection points in the form of spring line, or stream emergence, would enhance the river flows and improve the presently degraded ecosystem of riverine tracts, particularly in the outfall areas. [46]

4.4 Basic Requirement for Artificial Recharge Projects

The basic requirements or pre-requisites for recharging the groundwater reservoir are:

1. Source water availability.
   - Area contributing run off like residential, green belt, paved areas etc.
   - Hydro-meteorological characters like rainfall duration, pattern and intensity.
2. Suitable hydro-geological environment (developed aquifers) and sites for creating subsurface reservoir through cost effective artificial recharge techniques.
3. Groundwater dependent community.

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[45] Guide on Artificial Recharge to Groundwater, Central Ground Water Board, Ministry of Water Resources. New Delhi. May 2000

46 ibid

Source Water Availability

The availability of source water, one of the prime requisites for groundwater recharge, is assessed in terms of non committed surplus monsoon run off, which as per present water resource development scenario is going unused. This component can be assessed by analyzing the monsoon rainfall pattern, its frequency, number of rainy days, and maximum rainfall in a day. The variations in rainfall pattern in space and time, and its relevance in relation to the scope for artificial recharge to sub-surface reservoirs must also be considered for assessing the surplus surface water availability.

Hydro-geological Aspects

Detailed knowledge of geological and hydrological features of the area is necessary for adequately selecting the site and the type of recharge structure. In particular, the main features and data to be considered are: geological boundaries, hydraulic boundaries, inflow and outflow of waters, storage capacity, soil hydraulic conductivity, water resources available for recharge, and depth of the aquifer. The aquifers best suited for artificial recharge are those aquifers which absorb large quantities of water and do not release them too quickly. Theoretically this will imply that the vertical hydraulic conductivity is high, while the horizontal hydraulic conductivity is moderate. The availability of sub-surface storage space and its replenishment capacity further govern the extent of recharge. The unsaturated thickness of rock formations, occurring beyond three meters below ground level should be considered to assess the requirement of water to build up the sub-surface storage by saturating the entire thickness of the vadose up to 3 m. below ground level. [47]

The upper 3 m of the vadose zone[48] is not considered for recharging, since it may cause adverse environmental impact e.g. water logging, soil salinity, etc. The post monsoon depth to water level represents a situation of minimum thickness of vadose zone available for recharge which can be considered vis-a-vis surplus monsoon run off in the area.

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[47] Guide on Artificial Recharge to Groundwater, Central Ground Water Board, Ministry of Water Resources. New Delhi. May 2000

[48] The unsaturated geologic material between the bottom of the infiltration facility and the top of an unconfined aquifer is called the vadose zone. It usually provides some level of treatment by removing contaminants by filtration, adsorption, and/or degradation. In some cases, the treatment provided by the vadose zone is suitable for protecting groundwater quality from contamination by stormwater runoff; in other cases, additional pre-treatment may be required to protect groundwater quality.

4.5 Techniques and Designs

Groundwater recharge techniques have been developed world over through large number of experimental projects implemented with diverse objectives. Whereas the aim of majority of the projects is to augment groundwater storage by utilizing surplus rainy season flows or the waste waters; projects for benefaction of water quality, conserving surface waters for subsequent use and stopping land subsidence are quite common. In India, the applicability of technologies to tropical conditions has been evaluated through a number of studies conducted by Central Ground Water Board and the State Groundwater Organizations.

Similar to the variations in hydro-geological framework, the artificial recharge techniques vary widely too. The artificial recharge techniques can be broadly categorized as follows:

1. Direct surface techniques
   - Flooding
   - Basins or percolation tanks
   - Stream augmentation
   - Ditch and furrow system
   - Over irrigation
2. Direct sub surface techniques
   - Injection wells or recharge wells
   - Recharge pits and shafts
   - Dug well recharge
   - Bore hole flooding
   - Natural openings, cavity fillings.
4. Combination of surface – sub-surface techniques
   - Basin or percolation tanks with pit shaft or wells.
5. Indirect Techniques
   - Induced recharge from surface water source.
   - Aquifer modification

General Suitability of various recharge methods mentioned above for different lithological and topographical conditions is given below in table 4.1.

Table 4.1: General Suitability of Recharge methods

Lithology	Topography	Type of Structures Feasible.
Alluvial or hard Rock upto 40 m depth.	Plain area or gently Undulating area.	Spreading pond, Groundwater dams, irrigation tanks, check dams, percolation tanks, unlined canal systems.
Hard rock down to 40 m depth	Valley slopes	Contour bunds, trenches
Hard rocks	Plateau Regions	Recharge ponds
Alluvial or Hard rock with confined Aquifer (40m depth)	Plain area or gently undulating area. Flood plain deposits	Injection wells, connector wells.
Hard rock	Foot hill Zones	Farm ponds, recharge trenches.
Hard rocks or Alluvium	Forested area	Groundwater Dams.

(Source: Guide on Artificial Recharge to Groundwater, Central Ground Water Board, Ministry of Water Resources. New Delhi. May 2000)

Details of various recharge structures mentioned in this chapter are given in Appendix A but some, which can be particularly useful for the purpose of this study in the urban context and large open spaces are shown below in figure 4.2, 4.3 and 4.4.

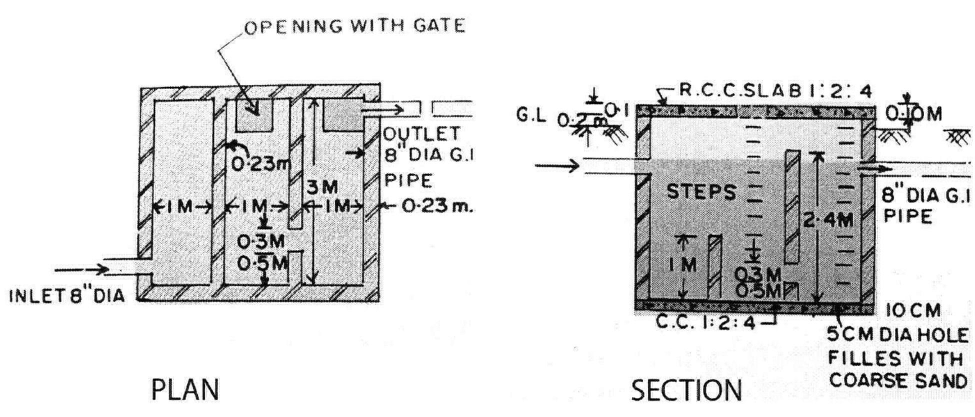


Figure 4.2: Typical Desilting Chamber

(Source: Rainwater Harvesting and Artificial Recharge to Groundwater - A Guide to Follow, Central Ground Water Board, UNESCO, International Hydrological Programme. Delhi, November 2000.

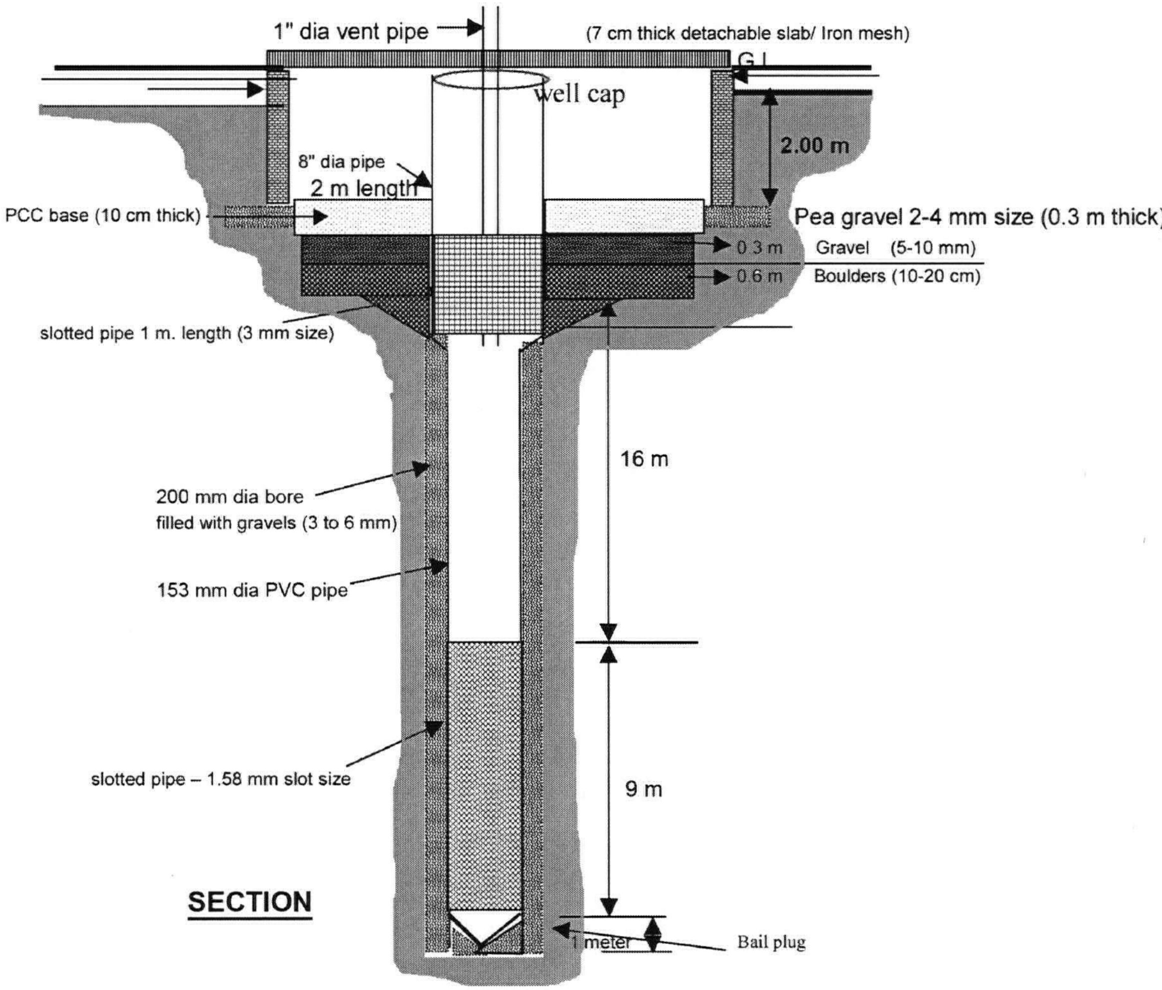


Figure 4.3: Recharge Pit with single Borewell (Source: Central Ground Water Board)

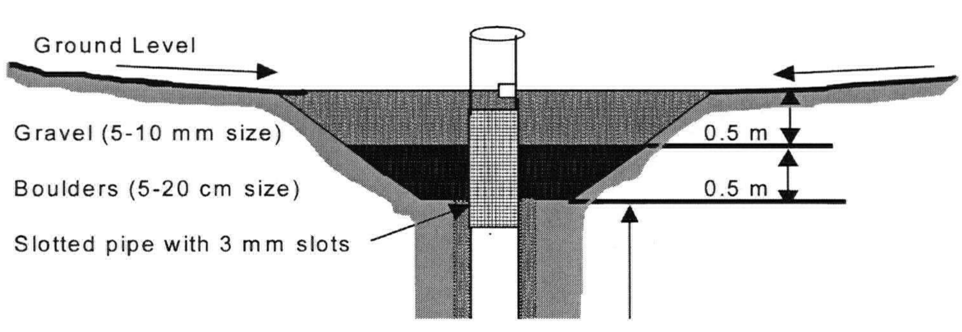


Figure 4.4: Alternative Design for Recharge Pit with single Borewell (Source: Central Ground Water Board)

(more suitable for natural conditions such as stream channels, lake beds and parks where water accumulation on the surface does not pose any problems while the water gets recharged)

Chapter – 5

Delhi: Regional Background

The National Capital Territory of Delhi occupies an area of 1483 sq.km, and lies between 28°25 W and 28°53'00" north latitude and 76°50'24"and 77°20'30" east longitudes. It is bounded on the north, west and south by Haryana, on the east by Uttar Pradesh with the river Yamuna flowing on its eastern side in a north-south direction, its greatest length and breadth are 51.9 km and 48.48 km, respectively.

5.1 History and Facts

Delhi has been the seat of one empire after another since the 11th century, it has always been a prosperous and populous city.

The Tomar king Anangpal's city of Dilli was founded around 1020 AD, near the present Surajkund (meaning Sun reservoir) (Fig. 5.1). Having a semi-circular shape, the tank has a stepped stone embankment and called Surajkund because it had a sun temple . Its purpose was to capture and store the rainwaters of the Aravalli hills. During the Sultanate period that followed, several cities were built in the terrain of the Aravalli hills. All these cities had extensive water harvesting systems, which enabled the people to meet their daily needs.

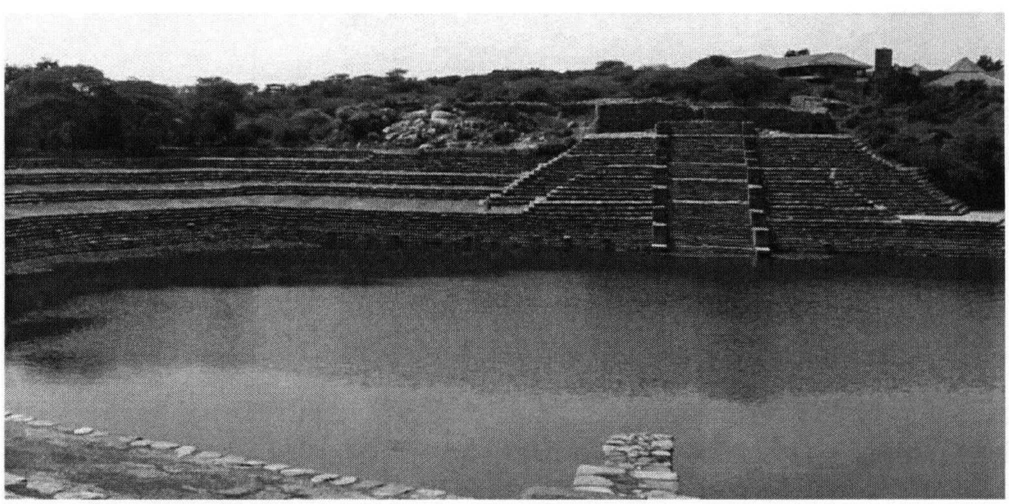


Figure 5.1: Surajkund near Delhi

Sultan Iltutmish (1210-1236 AD) built a large tank known as Hauz-e-Sultani or Hauz-e-Iltumish. Alauddin Khilji and Feroz Shah Tughlaq later had the tank repaired. This tank, measuring 200 m x 125 m, is still used by pilgrims visiting the Dargah of Kaki Saheb. The tank has recently silted up and its catchment area has been encroached upon by private builders and the Delhi Development Authority (DDA)

Besides tanks, sultans and their nobles built and maintained many baolis (stepwells, Fig. 5.2). These baolis were secular structures from which everyone could draw water. The Satpula (meaning seven spans) was built to regulate water supply for irrigating the area falling outside the city. It is a dam towering 64.96 m above ground level. Its seven principal spans were sluices that controlled the water in an artificial lake.

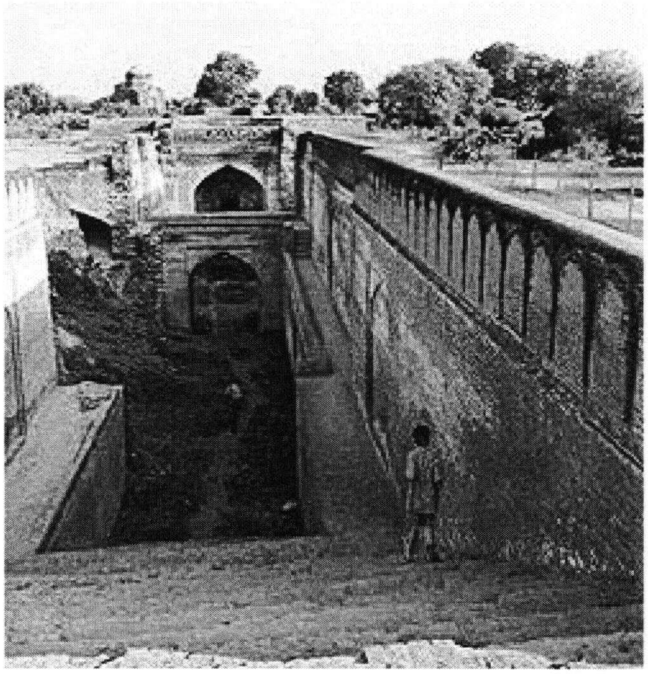


Figure 5.2: A typical Baoli (Stepwell) (Source: www.tribuneindia.com)

Emperor Shahjahan (1627-58 AD) first shifted the city from the Aravalli hills towards the plains of the Yamuna. He made sufficient arrangements to meet the water needs of the new city. His system of Shahjahani canals and dighis was probably the best creation of the time. He brought the waters of the Yamuna to the city and to his palace through canals. In the main city, the canal charged dighis and wells. A dighi was a square or circular reservoir of about 0.38 m x 0.38 m with steps to enter. Each dighi had its own sluice gates. People were not allowed to bathe or wash clothes on the steps of the dighi. However, one was free to take water for personal use. Most of the houses had either their own wells or had smaller dighis on their premises. In the event of canal waters not reaching the town and the dighis consequently running dry, wells were the main source of water. In 1843, Shahjahanabad had 607 wells. Today 80 per cent of the wells are closed because the water is contaminated by the sewer system. [49]

The present day Delhi is been divided into 15 Zones from A to P (Table 5.1), of which 8 Zones are in the urban area, one in River bed and remaining 6 in the rural area according to Master Plan 2021 (Fig. 5.3). The total area of National Capital Territory (NCT) of Delhi is 1,48,639 ha., with 44,777 ha. under urban cover.

Table 5.1: Zone Wise Area in NCT of Delhi [50]

Zone	Name of Zone Area	Area (Ha.)
A	Old City	1159
B	City Extn. (Karol Bagh)	2304
C	Civil Line	3959
D	New Delhi	6855
E	Trans Yamuna	8798
F	South Delhi-I	11958
G	West Delhi-I	11865
H	North West Delhi-I	5677
J	South Delhi-II	15178
K	K-I West Delhi-II K-II Dwarka	5782 6408
L	West Delhi-III	22840
M	North West Delhi-II	5073
N	North West Delhi-III	13975
O	River Yamuna / River Front	8070
P	P-I Narela P-II North Delhi	9866 8534

[49] Aggarwal, Anil and Sunita Narain (ed): Dying Wisdom; Rise, Fall and Potential of India's Traditional Water Harvesting Systems: A Citizens' Report. Centre for Science and Environment, Delhi, 1997.

[50] Delhi Development Authority. Draft Master Plan for Delhi 2021

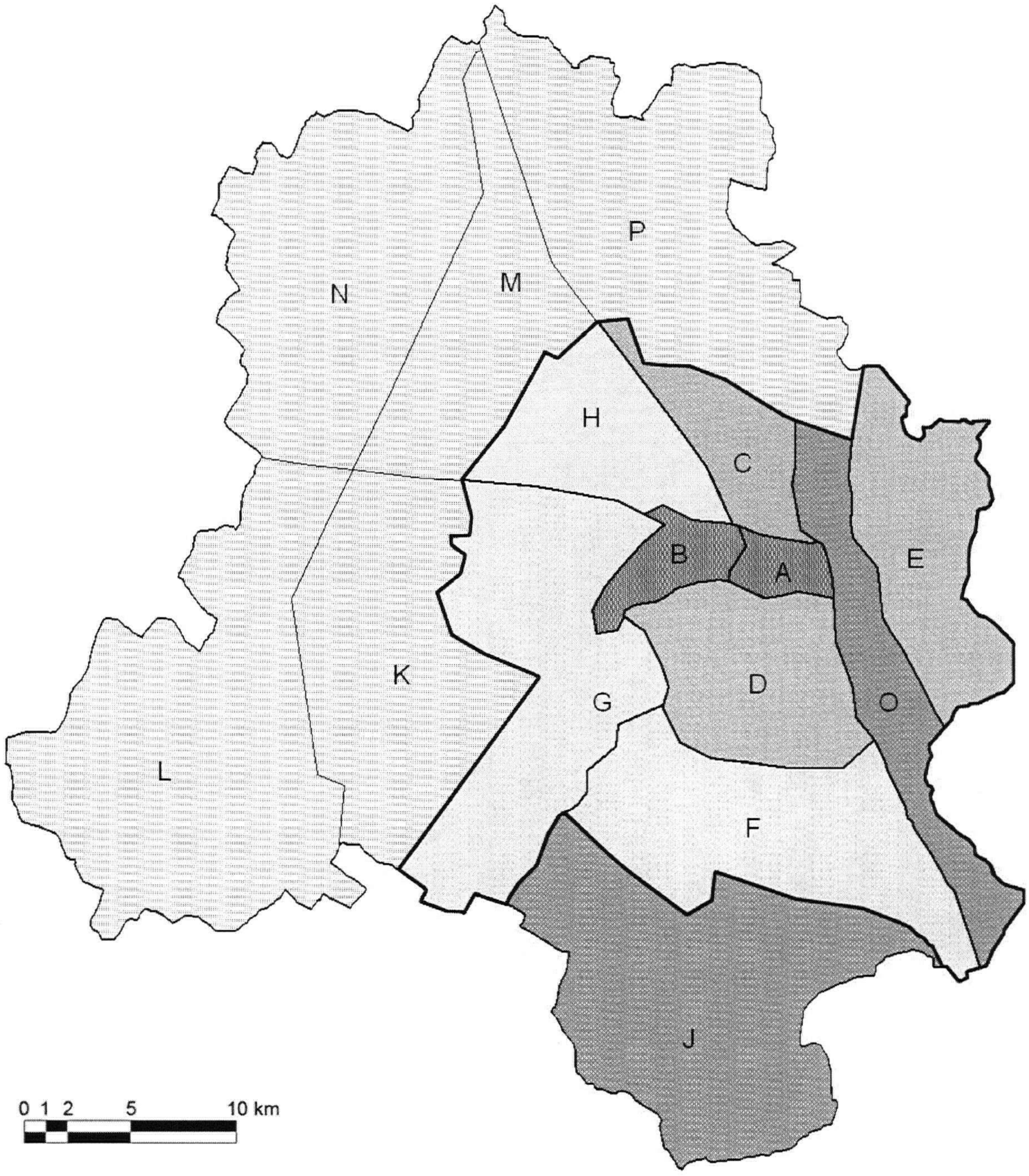


Figure 5.3: National Capital Territory (NCT) of Delhi Boundaries showing the Master plan Development 2021 Zones.

Source: Delhi Development Authority (DDA)

Land use Distribution of Delhi

LAND USE	% OF LAND
Residential	45-55
Commercial	3-4
Industrial	4-5
Green/ Recreational [51]	15-20
Public & Semi-Public Facilities	8-10
Circulation	10-12

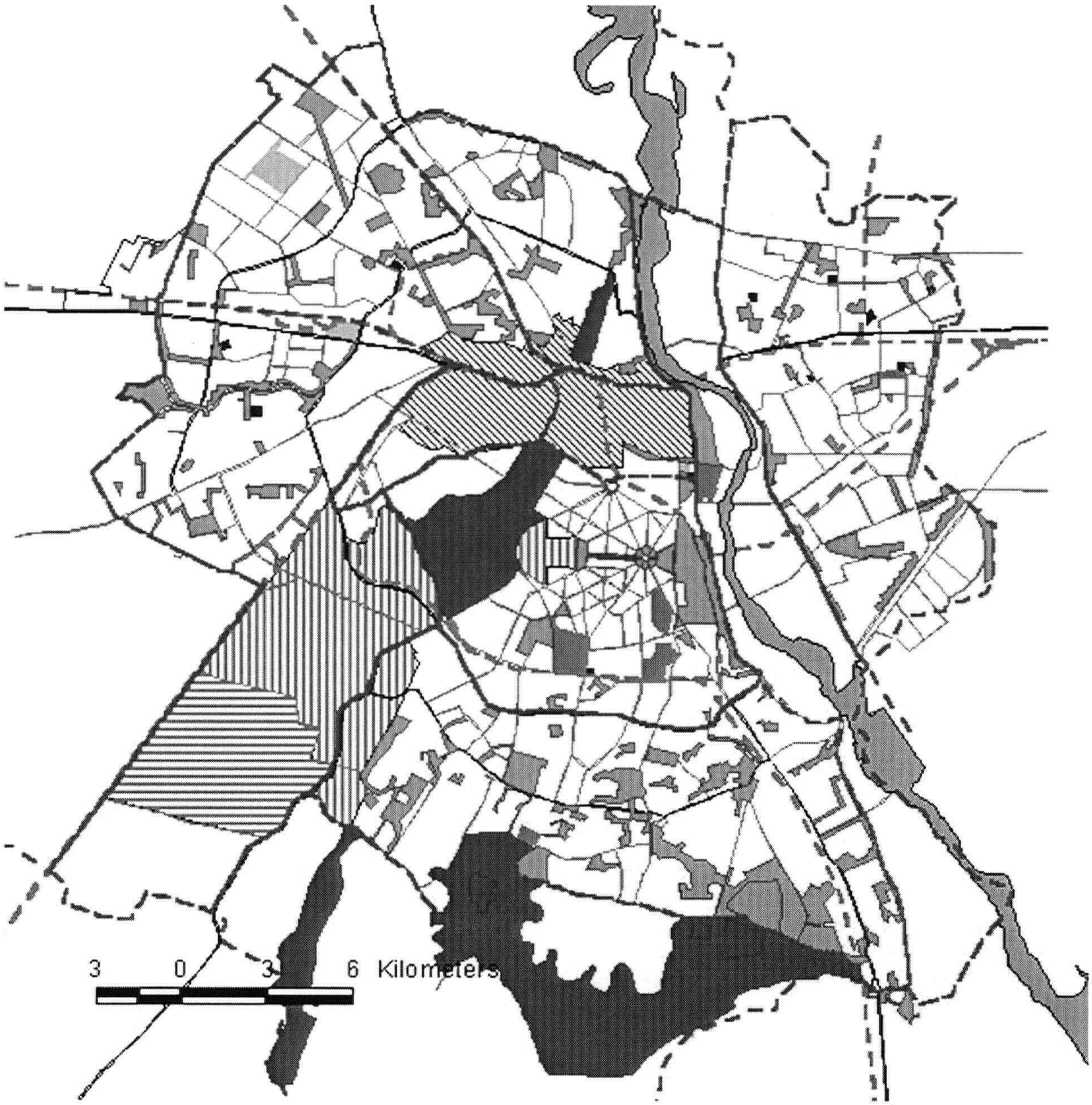
GREEN / RECREATIONAL AREAS

Delhi has a much greater green cover than any of the other metropolitan city in the country, and could well be called a "Green City". The green/ recreational use constitutes 8,722 ha of land as per Master Plan of Delhi 2001 (Fig. 5.4), which is around 19% of the total urban land area of 44,777 ha. This includes 1,577 ha under the Northern, Central and South Central Ridge (the remaining area of the Ridge is in the rural area). The balance area under recreational/ green use i.e. 7,145 ha. is in the form of District Parks, City Parks, and Community Parks comprising around 15% of the total urban land area. In addition to this, a large quantity of green area is provided in the form of Neighborhood Parks/Tot lots in the gross residential use zones, plantations/ greens in large campuses like President's Estate and Delhi University, roadside plantations, and plantations along drains. [52]

In the Master Plan Development for 2021 the green cover is to be provided at the rate of 15% of the total land excluding the Ridge/Regional Park. Out of this some area shall be developed in the form of formal parks for the community and the rest shall be developed as woodlands and incidental greens for balancing the environment. This will be in addition to the development of greens in specialized areas like Bio-diversity parks, plantation along the roads, drains, and river bank.

[51] This does not include green areas under various specific gross land use categories

[52] Delhi Development Authority. Draft Master Plan for Delhi 2021. 24 Sept. 2006 < http://ddadelhi.com/greens/greens_default.h



Regional Parks

District parks and open spaces

City Forests

Sports Centres

Figure 5.4: Open Green Space Network in Delhi Urban Zones. MPD 1981-2001

Source: Delhi Development Authority (DDA)

The green spaces in Delhi are divided into a level of hierarchies by DDA, detailed in the Master Plan. Various categories of these green spaces as mentioned in the greening project [53] initiated by DDA are:

Category	Nos.	Total Area in Ha.
1. City Forests	25	460
2. Regional Parks	4	860
3. District Parks	111	630
4. Neighborhood Parks	225	316
5. Zonal Greens/Green Belts	605	2415
6. Historical Landscapes	15	370
7. Sports Complexes	15	200

Population

During 1991-2001, the urban population of Delhi increased at 3.87 percent annual growth rate. The latter is influenced by the gradual shifting of the rural area and its merger with urban area. With the continuation of the present population trend, the total population of NCTD by the year 2011 and 2021 would be 18.2 million and 22.5 million respectively. [54]

6.2 Climate and Rainfall

Climate

The climate of the Delhi region is semi-arid type, with three well defined seasons. The hot summer extends from the end of March to the end of June. The ambient temperature rises to as high as 47° C during these months. The rainy monsoons fall between July and September. Winters are usually cold and night temperatures may reach as low as - 0.6° C between November and February. The average annual temperature recorded in Delhi is 31.5° C based on the records over the period of 70 years maintained by the Meteorological Department.

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[53] Delhi Development Authority. Draft Master Plan for Delhi 2021. 24 Sept. 2006 < http://ddadelhi.com/greens/greens_default.htm>

[54] Census of India and projections by DDA Sub-Group (MPD- 2021). < http://www.urbanindia.nic.in/moud/what%27snew/mps-eng.pdf>

The climate of Delhi is influenced by its remote inland position and prevalence of air of continental character, which is characterized by extreme summer heat, alternating with severe winter cold. Only during the three monsoon months of July, August and September, oceanic air penetrates the country deep to the Northern region.

Rainfall

For the Delhi area, 10 years (1992 -2001) of annual rainfall records have been analyzed by Delhi Jal Board (DJB). These records indicate that the mean recorded rainfall is 611 mm over 27 rain days, and that about 80% of the annual precipitation occurs over the three months of July, August and September. The annual pan evaporation losses for Delhi area are indicated to be much higher, totalling about 2,316 mm. The monthly distribution of rainfall and evaporation losses is given in following table 5.2.

Table 5.2: Rainfall and evaporation in Delhi area [55]

Month	Rainfall in mm	Evaporation in mm	Balance rainfall
January	14.51	99.2	-84.69
February	13.21	123.2	-109.99
March	9.87	189.1	-179.23
April	5.46	303.0	-297.54
May	9.16	310.0	-300.84
June	38.84	384.0	-345.16
July	191.56	155.0	36.56
August	197.4	155.0	42.40
September	105.32	165.0	-59.68
October	19.33	186.0	-166.67
November	2.81	141.0	-138.19
December	4.3	105.4	-101.10
Year	**611.77**	**2,315.9**	**-1707.13**

[55] Delhi Jal Board, DWSSP – Project Preparation Study – DFR 3-Part B-Water Supply- Volume I. 2004. p 4-10

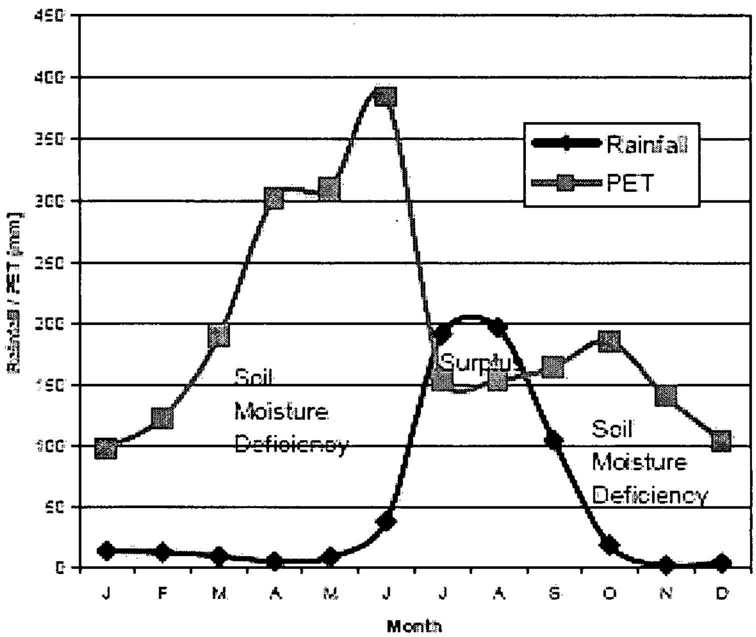


Figure 5.5: Rainfall and evaporation in the Delhi area

(Source: Delhi Jal Board, Project Preparation Study - DFR 3-Part B-Water Supply- Volume I. 2004. p 4)

Frequency analysis of one day storm on the basis of available 70 years data for Lodi Road observatory from 1901-1970 was done by Indian Meteorological Department and one day rainfall values likely for various periods were obtained as under:

Table 5.3: One day rainfall in different return periods

Return Period	**Estimated one day rainfall (mm)**
2 yrs	99.3
5 yrs	147.3
10 yrs	179.1

Precipitation is lost to evaporation unless it occurs in bulk. This is because rainfall up to 2.5 mm a day serves merely to wet the surface of the earth, evaporating subsequently to simply add to the humidity in the atmosphere. Water recharge thus occurs only on days when rainfall exceeds ~2.5 mm. Precipitation in excess of

2.5 mm a day occurs in Delhi mainly during the monsoon i.e. July, August and September. The normal monthly rainfall in Delhi is 190 mm in July, 200 mm in August and 110 mm in September. The rest of the year accounts for the balance of roughly 110 mm but does not figure in the groundwater budget. The number of days it rains more than 2.5 mm is 8, 8 and 4 for July, August and September respectively (Table 5.4). The Pan Evaporation rate is 5.0, 5.0 and 5.5 mm/day for July, August and September respectively. Evaporation from a pan is different from that from the soil. Typically monsoon wet soil is known to have an evaporation rate of 70% of the pan rate. [57] Since soil retains moisture, a similar evaporation rate obtains the following days. During the monsoon, the soil is wet so even when there is no rainfall evaporation occurs. The 70% of the total monsoon rainfall (190+190+120= 500 mm) is 350 mm, which is evaporation loss if water is allowed to seep into the ground for natural recharge and therefore only 150 mm of balance rainfall for the year is the actual water recharged naturally. The evaporation loss can be minimized if water is recharged artificially, losing minimum water to soil moisture.

Table 5.4: Rainfall Data from different stations in Delhi for last 70 years [58]

Stations	No. of years of data	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Safdarjang	79 a b	20.5 1.8	20.1 1.5	13.3 1.2	7.8 0.8	12.5 1.4	62.2 3.6	203.2 9.2	202.2 9.5	137.6 5.1	21.7 1.0	3.1 0.2	8.0 0.7	712.2 36.0
NewDelhi Palam	22 a b	14.7 1.3	14.1 1.5	9.3 1.0	6.1 0.6	18.9 1.5	54.2 3.5	241.1 10.9	284.3 10.7	119.4 4.9	16.8 1.4	6.4 0.2	8.6 0.6	793.9 38.3
Okhala (obsy)	21 a b	9.6 0.9	11.9 1.3	14.7 0.9	2.6 0.3	17.1 1.4	66.9 3.4	212.5 9.3	296.3 10.7	124.6 5.1	23.2 0.9	5.7 0.3	7.3 0.6	792.4 35.1
Mehruali	33 a b	13.9 1.1	10.1 0.7	7.3 0.6	9.4 0.6	3.6 0.3	28.3 1.5	159.9 5.8	152.5 5.9	98.7 3.0	11.7 0.3	1.5 0.2	2.3 0.3	499.0 20.3
Najafgarh	23 a b	8.9 0.8	8.2 0.7	4.7 0.2	4.2 0.4	3.0 0.4	25.1 1.3	122.0 5.5	122.8 5.6	75.9 3.2	21.7 0.8	0.5 0.0	1.8 0.2	398.9 19.1
Delhi (District)	a b	14.5 1.2	13.2 1.0	9.9 0.8	5.5 0.5	9.2 0.8	38.8 2.1	191.6 7.4	197.4 7.9	105.3 4.0	19.3 0.8	2.8 0.1	4.3 0.4	611.8 27.0

a) Normal rainfall in mm.
(b) Average number of rainy days(i.e. days with rainfall of 2.5 mm or more)

[57] Mohiddin, S.K., Shashank Shekhar, Uma Kapoor and P.N. Singh; Enhancing the Recharge Capabilities of Aravalli Ridge in NCT and parts of NCR Region of Delhi .Central Ground Water Board, New Delhi, India. 2006

[58] Centre for Science and Environment (CSE), Delhi. India. Aug. 2006 <http://www.rainwaterharvesting.org/index_files/climate_rainfall.htm>

5.3 Water Resources

Delhi receives its water from 3 sources:

1. **Surface Water**: 86% of Delhi's total water supply comes from surface water, namely the Yamuna River, which equals 4.6% of this resource through interstate agreements.
2. **Sub-surface water**: Ranney wells and tubewells. This source, which is met through rainfall and unused rainwater runoff, is 193 MCM (million cubic meters).
3. **Graduated Resources**: It is estimated at 292 MCM, however current withdrawal equals 312 MCM. [59]

Salinity and over exploitation has contributed to depletion and drastically effected the availability of water in different parts of the city. According to a report released by the Central Ground Water Board (CGWB), Delhi's ground-water level has gone down by about eight meters in the last 20 years at the rate of about a foot a year. With the present population, the current potable water requirement in Delhi is 866 Million Gallons per day (MGD) ; expected to rise to 1390 MGD by 2021. Delhi's water and wastewater management is controlled by the Delhi Jal Board (DJB) within the jurisdiction of Municipal Corporation of Delhi (MCD) area. DJB is presently supplying about 630 MGD of potable water from its existing installations which is not sufficient to meet the demand and as such there is a shortfall of 236 MGD per day of water even without considering leakage losses which are estimated to be about 190 MGD (Fig. 5.6).

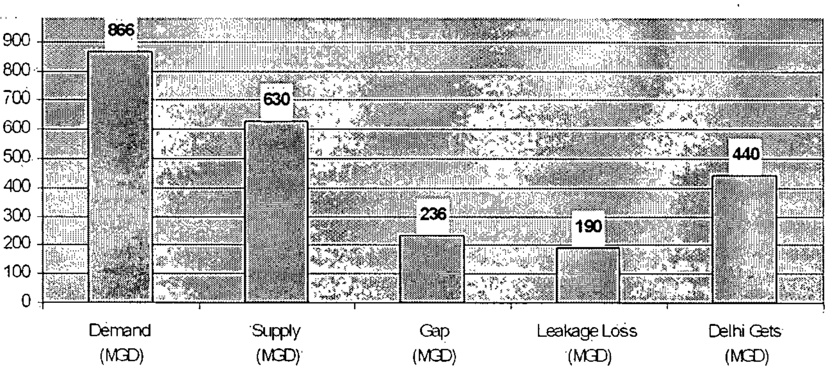


Figure 5.6: Water Demand Supply Gap in Delhi

[59] Centre for Science and Environment (CSE), Delhi. India. Aug. 2006 <http://www.rainwaterharvesting.org/index_files/climate_rainfall.htm>

Delhi Jal Board has following type of consumers:

1. New Delhi Municipal Council and Delhi Cantonment board

2. Bulk consumers

3. Domestic consumers categories

4. Commercial consumers categories

5. Industrial consumers categories

Presently there are about 1.5 million water connections and around 2996 MLD (Million Liters per day) of water produced at its six water treatment plants and is distributed among the 14.98 million consumers. Out of this, 93% present of consumers are domestic, 6% are commercial and only 1% are industrial consumers.[60] Almost 46 % of the population still does not have access to piped carriage systems. In addition there is the issue of unequal supply – 29 liters per capita per day (lpcd) of water supply in some areas, compared to 509 lpcd in cantonment area (Fig. 5.8).

With the demand-supply gap projections for water set to increase in the next ten years, DJB have identified new raw water sources including Tehri, Renukal, Kishau Lahawar dams. Plans also center on the construction of new and existing sewage treatment plants (STPs), which will enable an increase in treatment capacity. Rainwater harvesting is another option that DJB is seriously pursuing (Fig. 5.7).

Rainwater harvesting: DJB to revive interest

TIMES NEWS NETWORK

New Delhi: Seeing the interest in rainwater harvesting waning over the last two years, the Delhi Jal Board (DJB) is planning to develop the system in some buildings and public places in the city like Dilli Haat as models to be emulated.

DJB will develop these places so that it can create awareness amongst people about the advantages of rainwater harvesting. DJB is worried about rainwater harvesting initiatives in the city. In December 2002, Delhi government had introduced special funds, to be released through DJB, for developing the system in cooperative group housing societies. Since then, the system has been completed only in 90 societies. What is worrying is that over the last two financial years, this is showing a downward trend.

According to DJB's statistics, rainwater harvesting system was installed in 14 societies in 2003. This figure rose to 48 in 2004 but has been declining since then. It plunged to 28 in 2005 and a similar trend is continuing this year also. DJB spokesperson Sanjam Chima said: "It is a worrying trend. This is why we are initiating special schemes to encourage more societies and areas to adopt it." So far, Delhi government has been giving grants of Rs 50,000 to societies and RWAs interested in installing the system. DJB has asked the government to increase the amount to Rs 1 lakh.

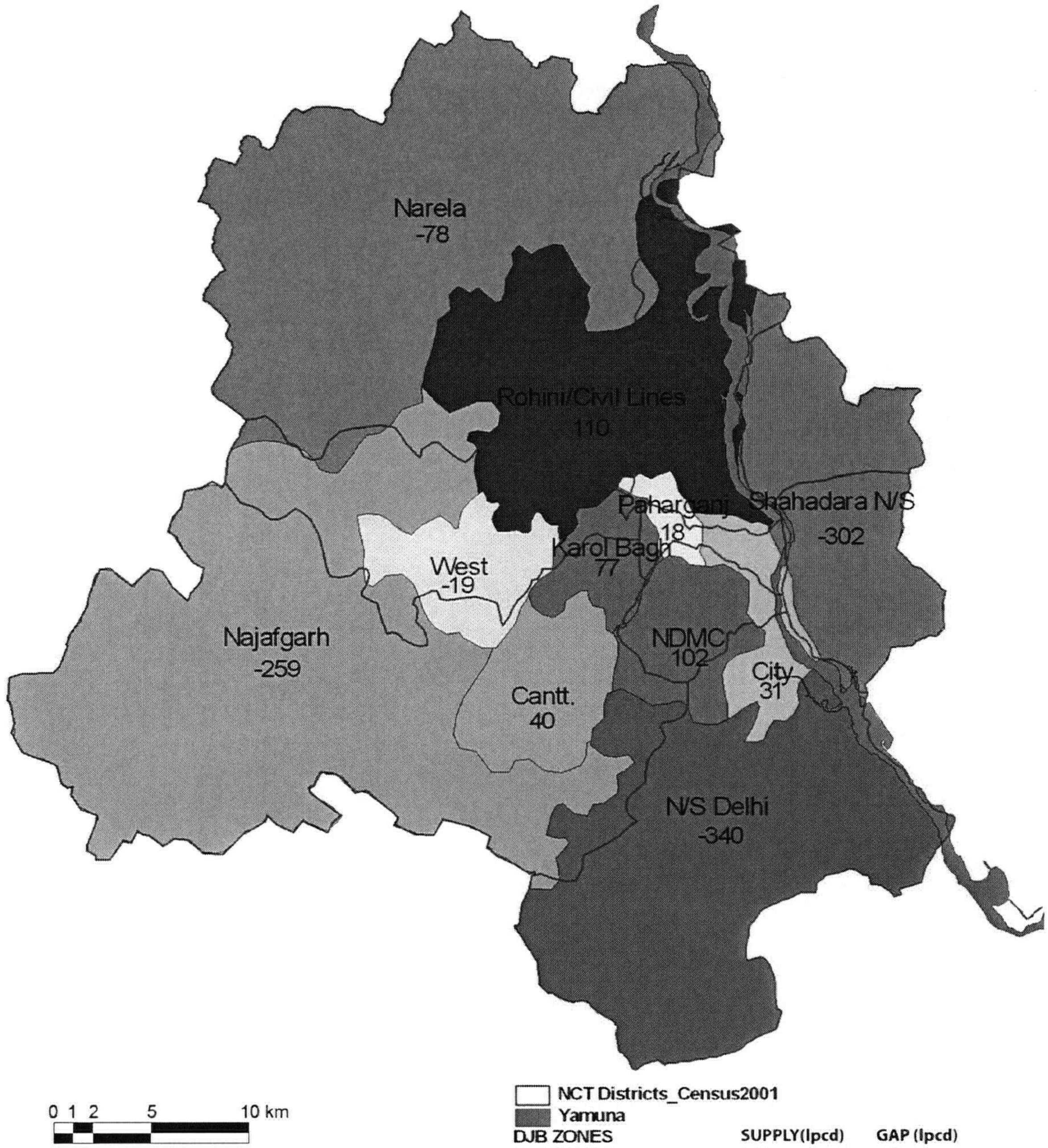
According to DJB's statistics, rainwater harvesting system was installed in 14 societies in 2003. This figure rose to 48 in 2004 but has been declining since then. It plunged to 28 in 2005 and a similar trend is continuing this year

The development agency will open "rain centres" in its various zones that will provide people guidance in installing the systems. DJB has now tied up with Centre for Science and Environment (CSE) and TERI to help in the initiative. CSE has already trained DJB engineers and will advise them on various technologies. CSE will also give training to plumbers registered with DJB on how to install the system.

DJB initiated awareness campaigns every year for the people. Usually, they are "Save Water" campaigns. This time, however, DJB has asked TERI to spread awareness on rainwater harvesting. Chima said: "We are getting advice on how to increase people's interest in the programme. We are also planning to install it on our own in high-profile buildings that are landmarks. Here we can put up boards to declare the benefits of rainwater harvesting." DJB has installed the system in 190 of its own buildings. This converts to 9.16 lakh square metre of area being harvested.

Figure 5.7: DJB - Rainwater Harvesting option, Daily Newspaper, The Times of India, New Delhi. Saturday, August 5, 2006

[60] Public - Public Partnership: A Dialogue Between Delhi's Citizen and the Government. 25 Sept. 2006. < http://www.navdanya.org/news/04sept8.htm>



DJB ZONES	SUPPLY(lpcd)	GAP (lpcd)
WEST	202	-19
NAJAFGARH	74	-224
SHAHADARA	130	-302
N/S DELHI	89	-340
NARELA	31	-77
NDMC	462	102
ROHINI/CIVIL LINES	274	110
PAHARGANJ	201	-16
CITY	277	31
CANTONMENT	509	39
KAROL BAGH	337	77

Figure 5.8:

DEMAND-SUPPLY GAPS IN DJB ZONES

Source: Delhi Jal Board (DJB)

5.4 Geological characteristics

The Union Territory of Delhi consists of flat and level plains interrupted by cluster of sand dunes and a long continuous chain of rocky ridges. The sand dunes are of varying dimensions and in general trend northeast - southwest. The crests of the dunes generally lie between 6 and 15 metres above the surrounding plains. The Delhi Ridge which is the culminating spur of the Mewat branch of the Aravallis, constitutes the most significant physiographic feature of the region. It enters the NCT from the south and extends in a north-easterly direction. The Ridge achieves the height of 318m above MSL which is probably the highest point.

The National Capital Territory of Delhi is part of the Indo-Gangetic alluvial plains. The river Yamuna, a tributary of the Ganga, flows through the Eastern part of the territory, and a Quartzitic Ridge, rising between up to 91 m above the surrounding plains acts as a groundwater divide between the western and eastern parts of Delhi. The alluvial formations overlying the quartzitic bedrock have different nature on either side of the ridge. The nearly closed Chattarpur alluvial basin covering an areas of about 48 Km^2 is occupied by alluvium derived from the adjacent quartzite ridge. Yamuna flood plains contain a distinct river deposit. Alluvial plains on eastern and western sides of the ridge are characterised by the occurrence of older alluviums of Aeolian origin. (Fig. 5.9)

As far back as 1887, the Gazetteer of Delhi described Delhi district as having 4 'natural divisions' - the **kohi** or hilly tracts; the **bangar** or level mainland; the **khadar** or sandy riverine of the Yamuna; and the low-lying **dabar** land that was subject to (seasonal) flooding. (These names derive from ancient terms used to assess the productivity of land). [61]

Kohi or Pahari (Hillsides) - The area immediately south of Delhi, including the Ridge, Mehrauli, Tughlaqabad, Fatehpur Ben", Dera Mandi and other neighbouring urban localities, are rocky and undulating. The low plateau better known as Kohi consists mainly of bare, unconsolidated rocks. The area occupies the regions with 305-335 m height above mean sea level or about 90 m above the alluvial plains of Yamuna. Northwards its height gradually falls, being only 2.5 m above the plains.

[61] Krishen, P. Trees of Delhi: A Field Guide, Dorling Kindersley (India) pvt. ltd. India 2006. p 19.

Bangar (Area irrigated by wells and canals) - This is an area, which in old times lay immediately to the west of the river Yamuna. The soils of Bangar are more fertile and productive than those of Khadar, being of a firmer consistency. Their texture is silty, sand or loam. The erosion ratio of the soil is high depicting low resistance to erosion.

Khadar (Riverine zone) - It is a low-lying strip of land adjoining the river Yamuna, covering an area of about 30562 hectares, out of which only 38% is under cultivation. The texture of the soil varies from coarse sand to clay and the clay content decreases with depth. The soil are base-saturated and their pH is on the alkaline side. These are low in organic matter, most of which is confined to the top layers alone. Two important factors affecting crop yield in the area are - high degree of salinity and water logging.

Dabar (Low-lying and rain-fed areas) - This area lies to the west of the hills and consists of low ground or basin, scooped out by their westward drainage. Being low-lying, it gets flooded during the rainy season. In cold weather, the Najafgarh drain carries a major part of the rainy water away. The texture of the soil in the area is coarse and consists mostly sandy loam. A considerable part of the surface is loose and soft due to regular cultivation but the subsoil mantle is invariably more compact.

All the soil types as mentioned in the Gazetteer of Delhi, 1887 have a different infiltration capacity. According to the Indian Council of Agricultural Research, infiltration rate varies from less than 2.5 mm/hr. for highly clayey soils to more than 25mm/hr. for sandy soils (Table 5.5). Depending on their underlying geology and infiltration capacity each area has a unique role to play in harvesting rainwater, either thorough retaining water in natural surface depressions or natural and artificial recharge to the aquifers.

Table 5.5: Infiltration Rates of Soils

Soil Type	Class	Infiltration rate (mm/hr.)
Dabar - Highly clayey soil	Very low	Below 2.5
Khadar - Shallow soils, Clayey soils low in organic matter	low	2.5 to 12.5
Bangar - Sandy loam, silty loam	medium	12.5 to 25
Kohi - Deep sand, well aggregated soils	high	Above 25

(Source: Indian Council of Agricultural Research)

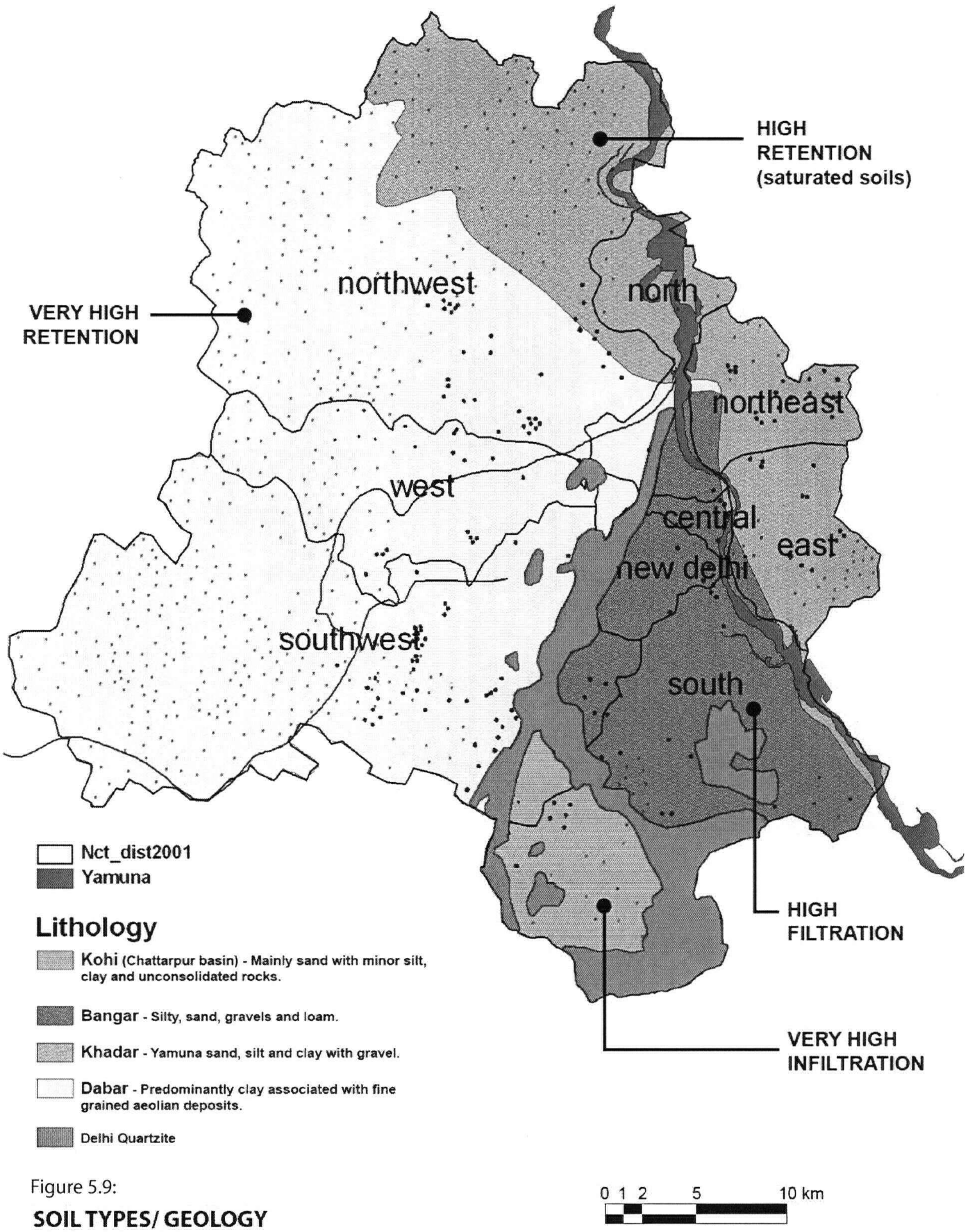


Figure 5.9:

SOIL TYPES/ GEOLOGY

Source: Survey of India

5.5 Hydro-geological characteristics

The groundwater table, in the Delhi region, at varying depths from 20–50 m below ground level, is found to be saline. The quality of groundwater is alkaline with pH ranging from 7.1 to 9.2, chloride content ranges between 21 and 1380 ppm. South of Delhi average chloride content is 250 ppm while in Najafgarh area it is around 1000 ppm rendering the water saline covering the area of 32 km. Sq. and marginally saline over the area of 129 sq km. [62] (Fig. 5.10). In some areas near the Yamuna these saline aquifers occur at a depth of about 65 m. This effectively makes the water resource unfit for consumption within that level. The repartition of the static groundwater resources between fresh, brackish, and saline water is given in [Table 5.6].

The groundwater study done by the NEERI for Ministry of Environment and Forestry in India revealed high nitrate and fluoride concentrations. Nitrate concentrations have been found to be higher than the permissible limit of 100 mg/l in groundwater areas such as IIT Delhi, NCERT campus, Mehrauli block, few city blocks, few Shahdra blocks, and Nazafgarh blocks. Same is the situation with fluoride levels in certain areas. Fluoride concentration exceeds the WHO norms of 1.5 mg/L in 30% of the NCT area. [63] Nitrate and pesticides are generated by agricultural activity in the rural areas in and around the NCT Delhi. Heavy metals are accumulating due to urban run off infiltration, and bacteriological contaminations affects most shallow aquifers. Electrical conductivity has also been reported to be high, making the groundwater further unfit for consumption.

Table 5.6: Repartition of static resources according to salinity [64]

Water Quality	**Total Dissolved Solids(TDS)**	**Static resources**	**% of total**
Fresh Water	< 1000 ppm	1866 MCM	30 %
Brackish Water	1000 < TDS < 5000 ppm	59 MCM	10%
Saline Water	> 5000 ppm	3635 MCM	60%

[62] Rainwater Harvesting. Centre for Science and Environment. 19 Sept. 2006. <http://www.rainwaterharvesting.org/index_files/ground_water_quality.htm>

[63] Maria ,Augustin; The Role of Groundwater in Delhi's Water Supply, CERNA, Ecole Nationale Supérieure des Mines de Paris. < www.cerna.ensmp.fr/Documents/AM-GroundwaterDelhi.pdf> p 6

[64] Ibid. p 6

Depletion of the Groundwater Resources

Although groundwater extraction is in theory regulated in Delhi, the authorities in charge of the enforcement of the regulation do not have the practical means of controlling private extraction. In practice, extraction is tolerated as a compensation for the failure of the public supply system. As a consequence, water table are falling at an increasing pace in several areas of NCT Delhi. The southern and western areas of Delhi, where piped supply does not match the growing residential demand are the most severely affected area. In the Chattarpur alluvial basin, were the water tables are falling at the highest rate, as well as in the western part of the state were recent urbanisation is taking place in areas affected by the occurrence of saline water at shallow depths, the availability of fresh water will come to an end in a few years if extraction continues at the current rate.

The groundwater table is Delhi has depleted to 20 –30 metres in various areas across the city. The average level of water table for blocks away from Yamuna is between 15–20 m (Fig. 5.11). It has been observed that the water table has receded by 10 m in many areas during the past 20–25 years. Nazafgarh block, City blocks, and Mehrauli blocks have shown a decline of more than 10 m. South and south-west districts have shown a fall of 10–30 m in the last four decades (Fig. 5.12). The decline in groundwater table has lead to increase in the thickness of unsaturated zones. The thickness of unsaturated zones in various parts of Delhi is shown in [Figure 5.13]. In some parts it is even greater than 25 m. The increase in the thickness of unsaturated zone results in increased loss of rainwater to soil moisture in the event of natural recharge. Therefore, it is beneficial for the areas with unsaturated zone depth more than 8 m to adopt artificial recharge techniques.

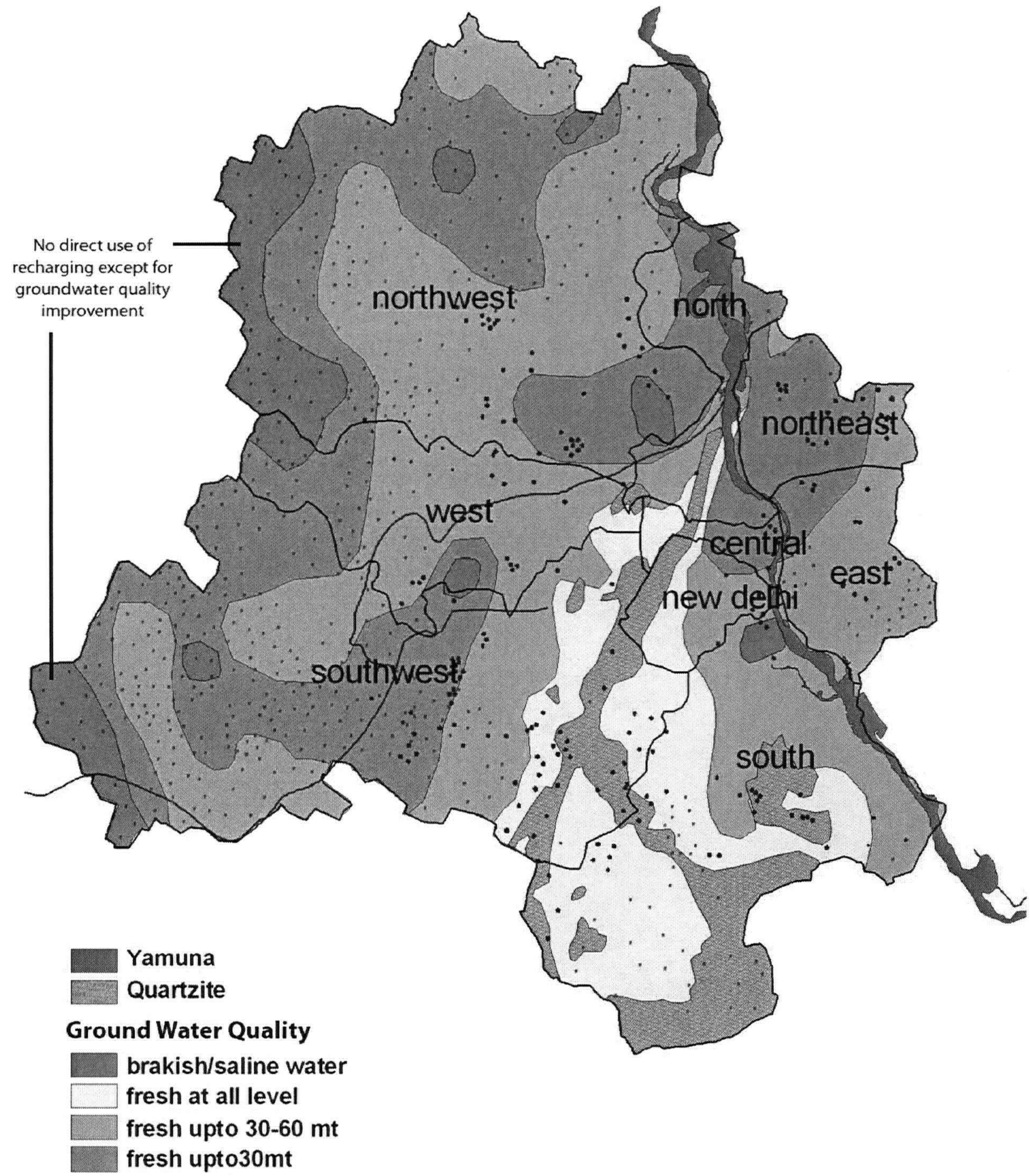


Figure 5.10:

Ground Water Quality 2004

Source: Central Ground Water Board (CGWB)

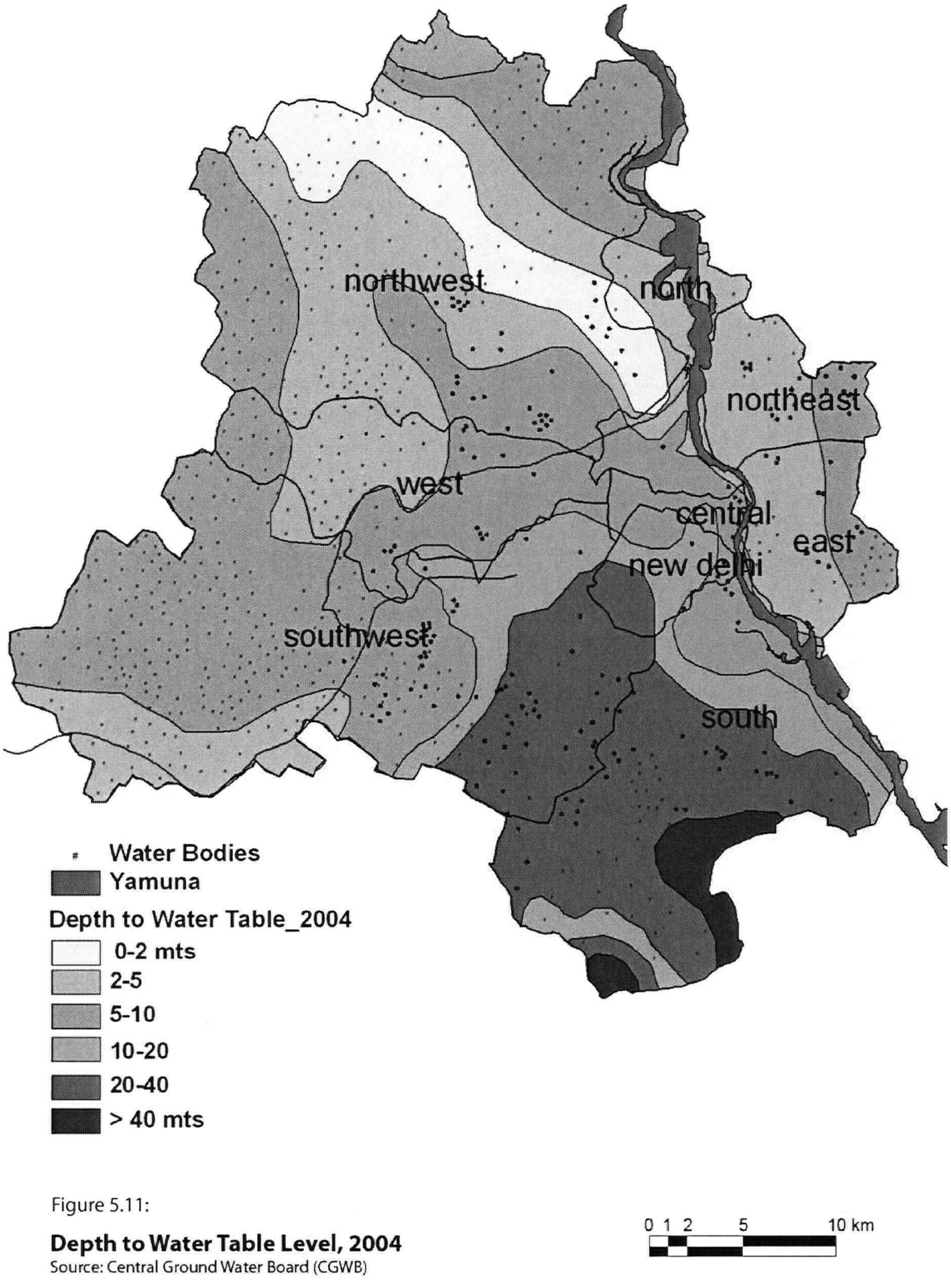


Figure 5.11:

Depth to Water Table Level, 2004

Source: Central Ground Water Board (CGWB)

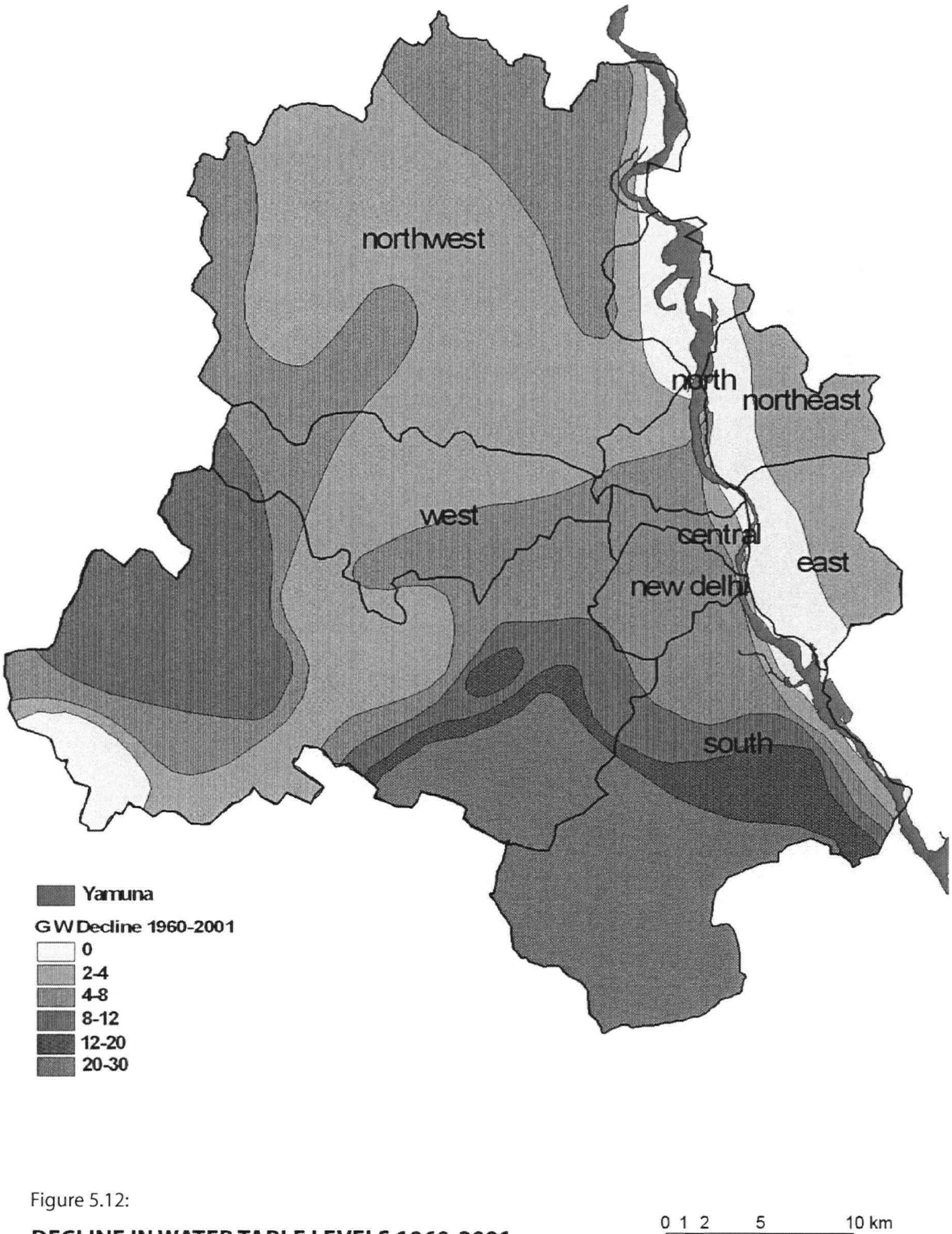


Figure 5.12:

DECLINE IN WATER TABLE LEVELS 1960-2001

Source: Central Ground Water Board (CGWB)

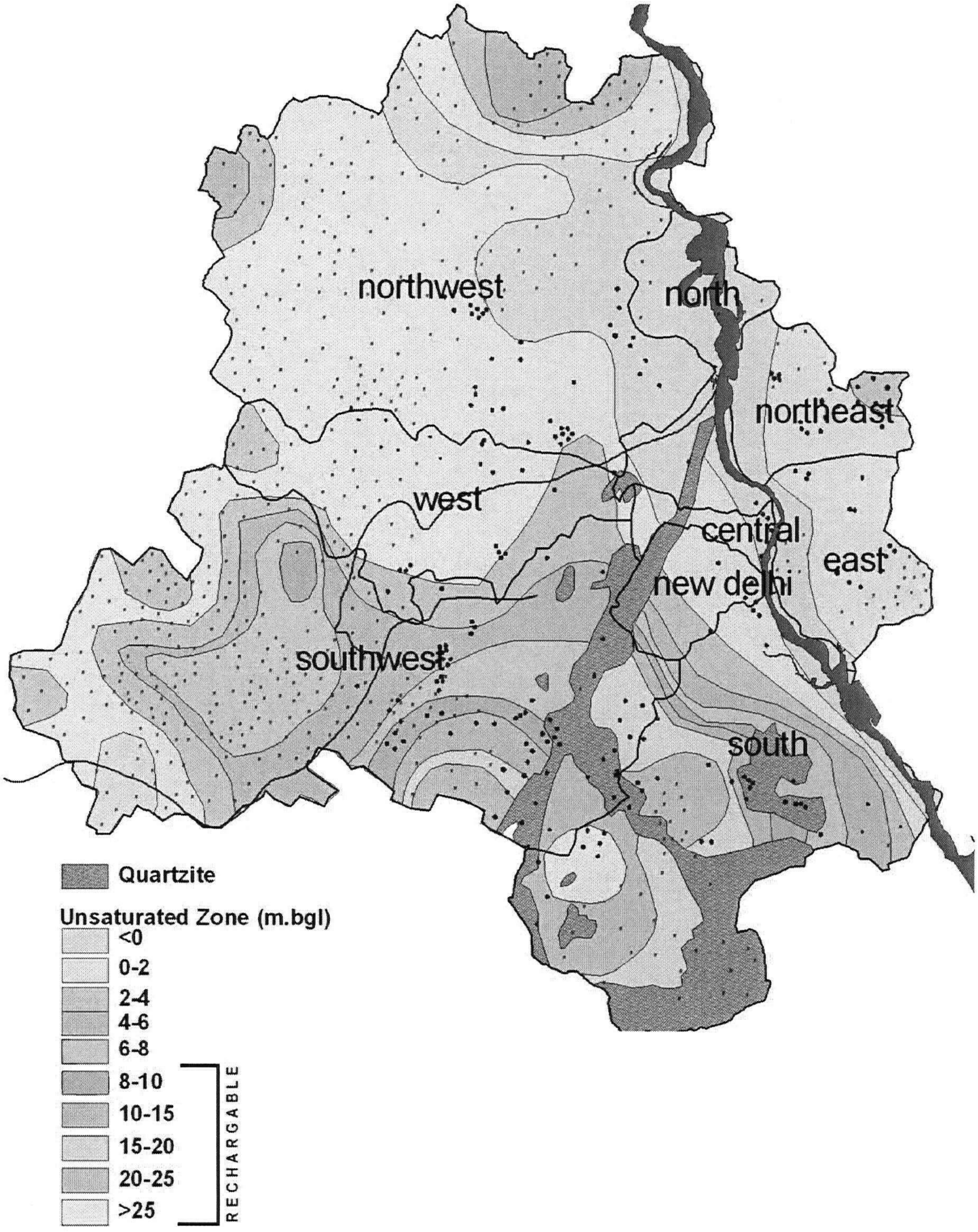


Figure 5.13:

Thickness of Unsaturated Zone

Source: Central Ground Water Board (CGWB)

The geological and hydro-geological data for Delhi, presented above in figures 5.10 - 5.13, yields a set of areas which have common characteristics (Fig. 5.14), when overlaid. Amongst these areas, there are some areas which are relatively more stressed or least stressed than other areas and therefore need immediate action. Areas with minimum or no stress and having physical conditions that support rainwater harvesting are also highlighted for immediate action as they can play a vital role in mitigating water stress in other areas at the regional level as discussed in Section 6.1.

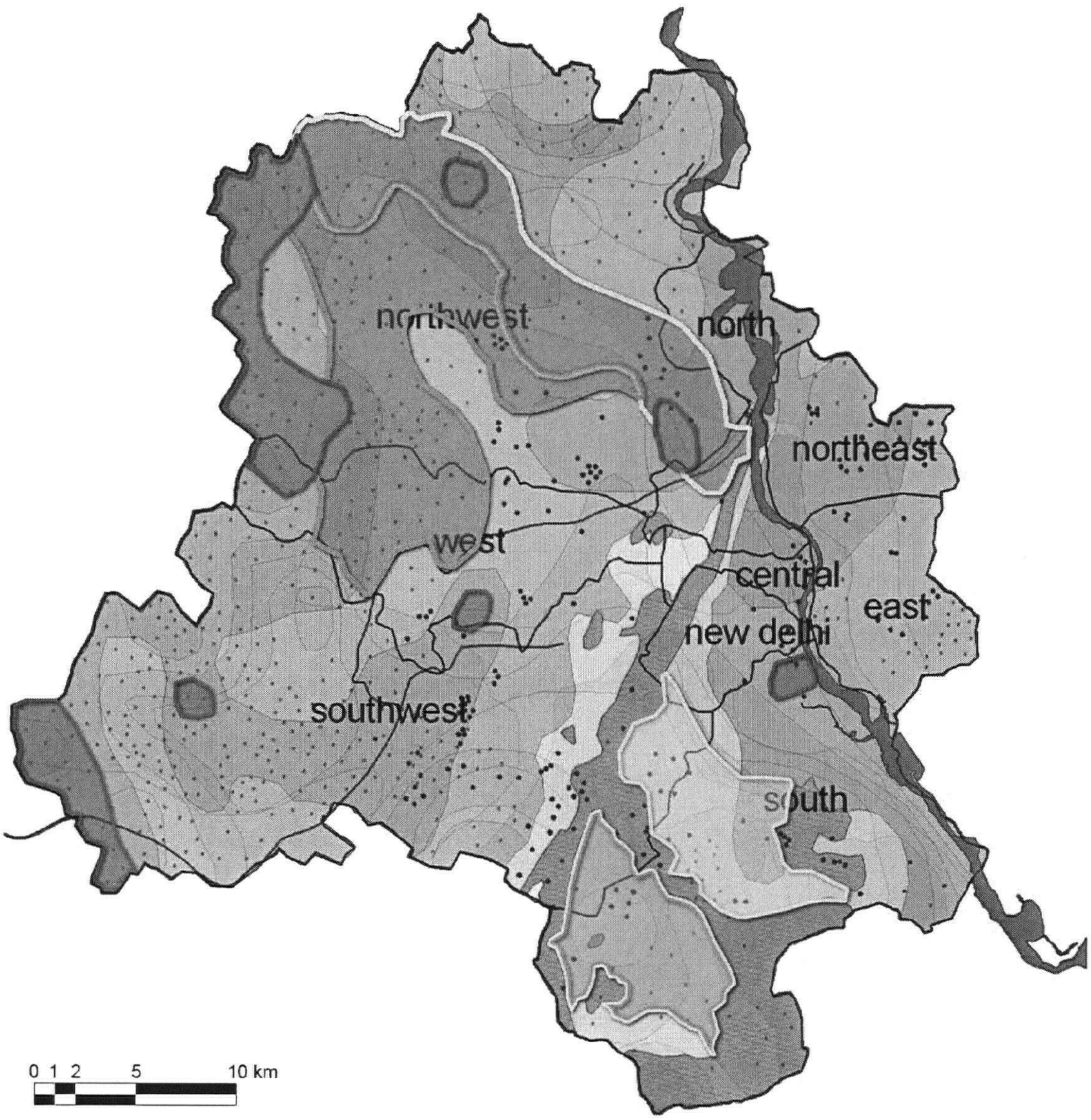


Figure 5.14: Overlay of Delhi's soil profiles, water table levels, unsaturated zone depths and groundwater quality.

Chapter - 6

Analysis of the Region and Study Areas

6.1 Defining and Assessing Priority Action Zones at regional level

In this section, the geological and hydro-geological data for Delhi, described in the previous chapter, is investigated in detail. After thorough analysis of the available data, five distinct areas [labelled from Re-1 to Re-5] are identified as shown in [Figure 6.1] which must be considered for any priority action in the context of this study. Each area is then studied in further detail [as tabulated later in this section] stating their specific characteristics, potentials and constraints, and rainwater harvesting recommendations. The recommendations are based on research and data from several agencies such as CGWB, DJB, DDA and IACR which relate to the specific conditions of each area. The recommendations are suggested at a conceptual level as more detailed hydro-geological surveys must be carried out for each area before developing the final action plan and carrying out any pilot projects. Nevertheless, the recommendations provide an initial framework within which the efforts can be focussed. The main neighbourhoods from the cadastral data of Delhi are also mapped for each area, so that the necessary actions can be carried out on a neighbourhood basis with realistic boundaries.

These priority action areas are associated with varying levels of water stress which are established based on four different attributes - 1) water demand-supply gap, 2) decline in groundwater levels, 3) depth of water table and 4) population density. Population density also signifies the extent of urbanization. Each attribute is relatively evaluated as Low - 0 points, Medium - 1 point, and High - 2 points, thus giving a stress rating for each area. It is found that some areas such as Area Re-2 [which is the only highlighted area falling in the urban Zonal boundaries] is extremely stressed due to high density of population and extreme water demand-supply gaps, while other areas such as Area Re-4, which fall in the peri-urban and rural zonal classification, are least stressed, have surplus water and less urbanization. Each of these areas, based on their physical parameters and stress levels can play a different role and adopt different techniques for rainwater harvesting as summarized in [Figure 6.13].

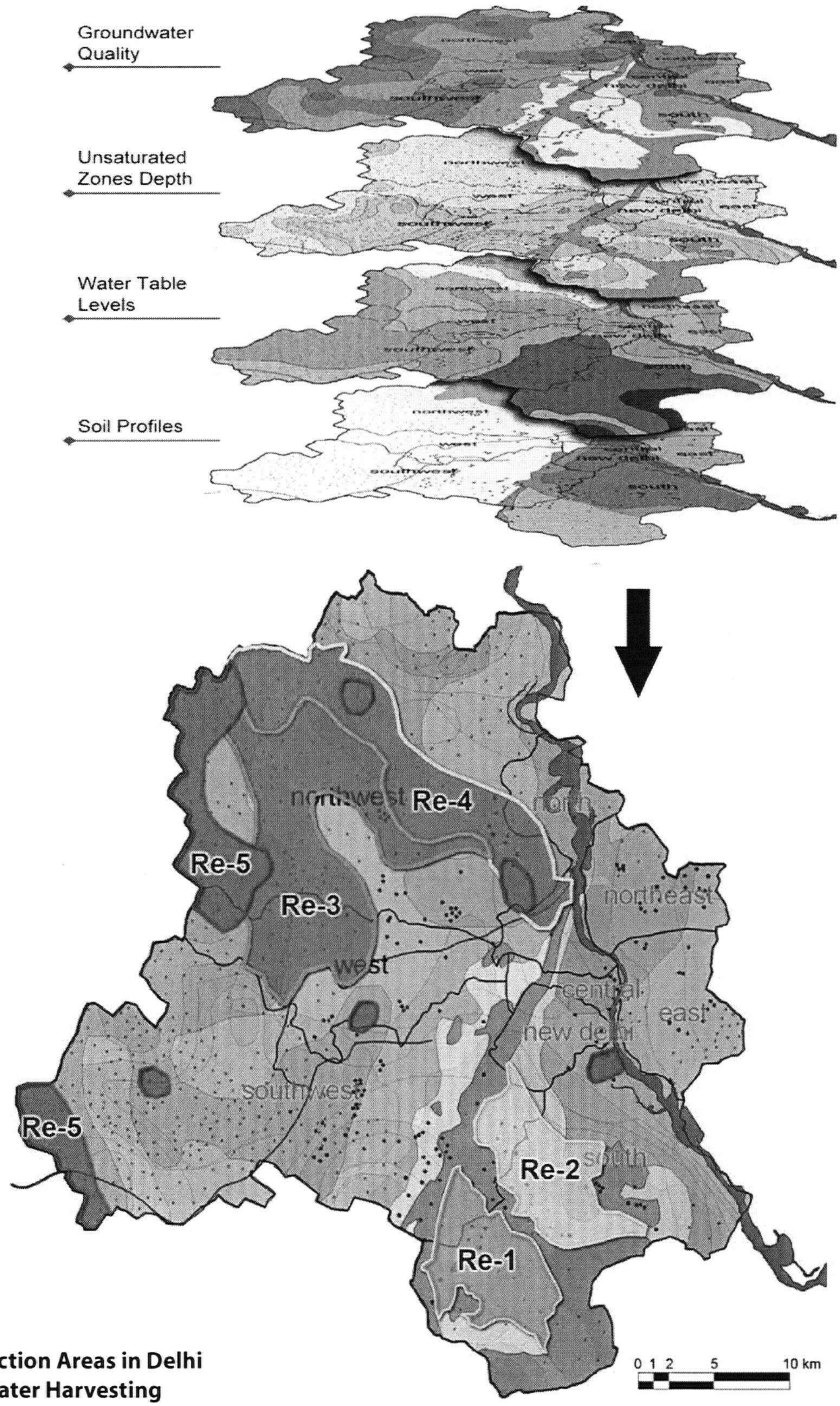


Figure 6.1:

Priority Action Areas in Delhi for Rainwater Harvesting

Figure 6.2: Action Area **Re-1** - key plan

Action Area	Re-1
Main MPD Zones	J

Neighbourhoods:

Vasant Kunj - Sector D, Ghatarni, Ayanagar, New Manglapuri, Chattarpur, Sultanpur, DLF farms, Sat Bari, Junapur, Shourpur, Chandan Hula, Asola, Fatehpur Beri

Area Characteristics:

- Sandy soils with minor silt, clay and unconsolidated rocks.
- Confined water basin with quartzite ridge around it.
- Depth to water table - 20 to 40 m.bgl.
- Decline in water table level since 1960 - 20 to 30 m
- Thickness of unsaturated Zone - > 20 m.bgl.
- Fresh water at all levels
- Water demand-supply gap - 340 lpcd
- Peri-urban, medium density of population - 90.6 persons/Ha
- Large number of seasonal streams and reasonable number of water bodies but mostly dry.

Potentials/Constraints:

- A confined water basin with high surroundings and most of the watershed in its natural state provides immense potential for harvesting surface runoff.

- Soil profile, thickness of unsaturated zone and groundwater quality is highly supportive of artificial recharge.

- High infiltration capacity of soils is a constraint for surface water storage for longer periods of time.

Stress Rating:

Rainwater Harvesting Development Recommendations:

Conservation of the watershed and restoration of the lost streams

Identifying locations for constructing check dams in the stream flows for increasing on-channel storage capacity, contact time with soil and therefore high percolation.

Making artificial recharge structures in the existing water bodies and directing the stream flows and surface runoff from the vicinity to them, wherever possible, thus increasing the rate and quantity of recharge.

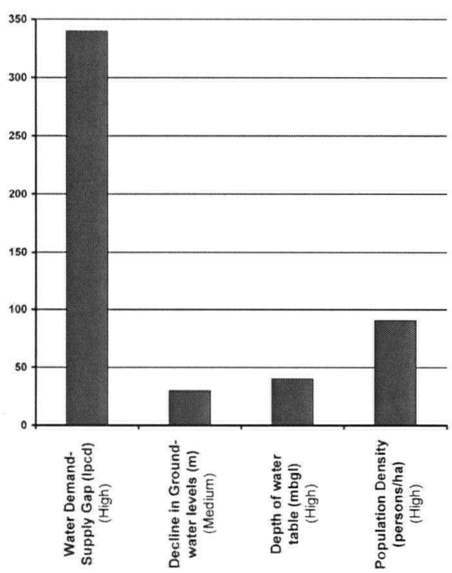


Figure 6.3:

Bar graph showing different parameters for Action Area **Re-1** stress rating.

Sources: CGWB, DJB, DDA, Census of India 2001.

Figure 6.4: Action Area **Re-2** - key plan

ZONE	AREA Ha	% RESID	% RECRE
A	1159	45.7	5.00
B	2304	58	7.70
C	3959	41.8	16.50
D	6855	33.72	33.52
E	8797	57.5	16.00
F	11958	35.6	25.90
G	11865	58.02	10.75
H	5677	51.22	15.56

Figure 6.5: Urban Zones Areas

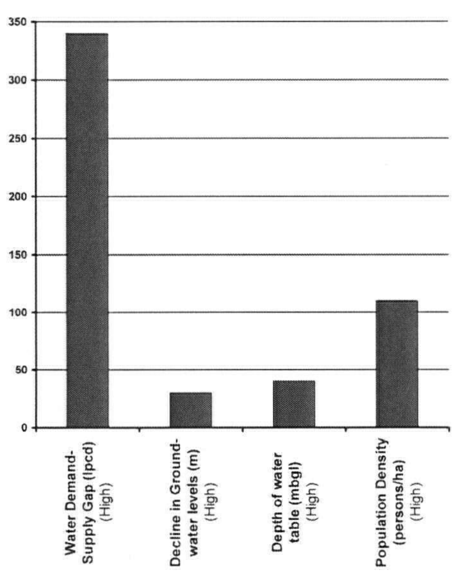


Figure 6.6:

Bar graph showing different parameters for Action Area **Re-2** stress rating.

Sources: CGWB, DJB, DDA, Census of India 2001.

Action Area	**Re-2**
Main MPD Zones	**F, J**

Neighbourhoods:

Vasant Vihar, R.K. Puram, Munirka, Hauz-Khas Enclave, Panchsheel Enclave, Sheikh Sarai, Chirag Delhi, GK-I, Katwaria Sarai, Sarvodya Enclave, Malviya Nagar, Adh Chini, Lado Sarai, Saket, Press Enclave, Pushp Vihar, Sainik Farm, Neb Sarai, Khanpur. Sangam Vihar.

Area Characteristics:

- Sandy Loam soil with silt and gravels.
- Depth to water table - 20 to 40 m.bgl.
- Decline in water table level since 1960 - 20 to 30 m
- Thickness of unsaturated Zone - 15 to 25 m.bgl.
- Fresh water at all levels in most parts. Some parts upto 60m.bgl.
- Water demand-supply gap - 340 lpcd
- Highly Urbanized, densely populated - 100 persons/Ha
- Second highest percentage of green spaces in Urban NCT zones
- Very few surface water bodies

Potentials/Constraints:

- Soil profile and thickness of unsaturated zone is highly suitable for artificial recharge.
- Extreme urbanization and dense population is a limitation for quantum of good quality surface runoff available for harvesting.
- One of the highest percentage of public green spaces amongst the Urban NCT Zones (Fig. 6.5) provides potential for artificial recharge through them.

Stress Rating:

Rainwater Harvesting Development Recommendations:

- The public green spaces should be recognized as effective catchment areas and redesigned with suitably located artificial recharge structures for capturing maximum rainwater within them and also stormwater runoff from the vicinity with proper filtration arrangements.
- Owing to large percentage of built-up area, rainwater from roofs and streets must be integrated with the urban green spaces.
- Resident welfare associations must be involved for design and construction and even financing.
- The design should be revelatory and construction, participatory, to serve the hidden agenda of spreading awareness and generating a sense of ownership amongst the local residents.

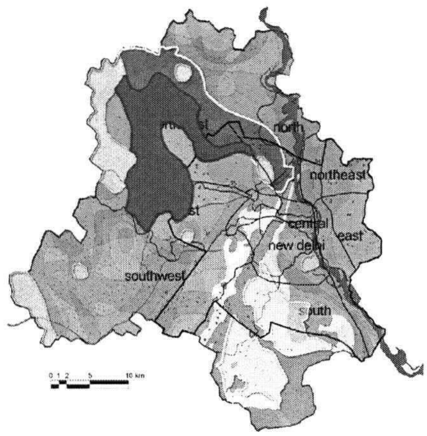


Figure 6.7: Action Area **Re-3** - key plan

Action Area	Re-3
Main MPD Zones	N, M, K

Neighbourhoods:

Chandan Vihar, Nihal Vihar, Paschim Vihar, Aman Puri, Nangloi Jat, Jafarpur, Tilangpur, Prem Nagar, Sultanpuri, Rama Vihar, Madanpur, Karala, Sultanpur, Chandpur, Pehladpur, Haidarpur, Rohini -Sector 5, 13, 24, 25.

Area Characteristics:

- Clayey soil associated with fine grained aeolian deposits.
- Depth to water table - 2 to 5 m.bgl.
- Decline in water table level since 1960 - 2 to 4 m
- Thickness of unsaturated Zone - 0 to 2 m.bgl.
- Fresh water upto 60 m.bgl.
- Water demand-supply gap - 78 lpcd in most parts
- Peri-urban, rural, Medium density of population - 65 persons/Ha
- Highest concentration of water reservoirs.

Potentials/Constraints:

- Largely rural area with low to medium density of population, clayey soil and large number of water bodies provide ample surface water storage opportunities with minimal constraints.

Stress Rating:

Rainwater Harvesting Development Recommendations:

This area should be largely considered for surface water storage and natural recharge of shallow aquifers through the numerous water bodies.

Existing water bodies and their catchments areas should be cleaned and protected from urbanization and pollutants before the water naturally recharges the aquifers.

Proper management and conservation policies must be devised and implemented for their long term sustainable use and benefits.

The water from these structure can be used for drinking, washing, agriculture and also energy production.

The water bodies should be desilted, widened and deepened to increase their storage capacities wherever possible.

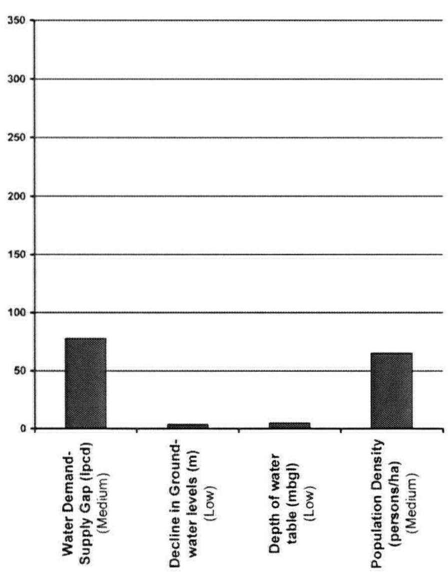


Figure 6.8:

Bar graph showing different parameters for Action Area **Re-3** stress rating.

Sources: CGWB, DJB, DDA, Census of India 2001.

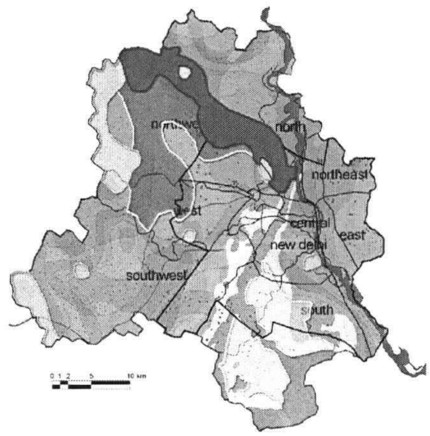


Figure 6.9: Action Area **Re-4** - key plan

Action Area	Re-4
Main MPD Zones	N, M, P, C

Neighbourhoods:

Kamla nagar, Roop nagar, Indira Vihar, Harijan Colony, Mukherji nagar, Adarsh nagar, West Sant nagar, Balswa, Model Town, Jahangirpur, Samaipur, Badli Industrial area, Rohini - Sector - 15, 16, 17, 18, Holambi kalan, Khera Garh, Ghaga, Daryapur kalan.

Area Characteristics:

- Mainly Yamuna sand with silt, clay and gravels.
- Depth to water table - 0 to 2 m.bgl. (water logged)
- Decline in water table level since 1960 - 2 to 4 m
- Thickness of unsaturated Zone - 0 m.bgl.
- Fresh water upto 30 m.bgl. Brackish water in some parts.
- Water demand-supply gap - 0. 110 lpcd surplus in most parts.
- Urban to rural, medium density of population - 65 persons/Ha.
- Large lakes in urban areas, numerous ponds in the rural areas and about 200 Ha of marshlands with 153 ha under water.

Potentials/Constraints:

- Availability of surplus water and large number of surface water bodies makes it highly potential for surface storage for redistribution to neighbouring zones.

- Shallow thickness of unsaturated zone and water table depths, makes water recharge unfeasible, due to danger of transferring pollutants from the run-off water to the aquifers.

Stress Rating:

Rainwater Harvesting Development Recommendations:

Rainwater should be harvested for surface storage in existing water bodies such as Bhalaswa lake (70 Ha.), Naini lake (2 Ha) and Jahangirpuri marshes (153 Ha) and promoted as source of water for local use and redistribution to neighbouring zones.

Existing water bodies and their catchments areas should be cleaned and protected from urbanization and pollutants as utmost priority before the water naturally recharges the aquifers.

Jahangirpuri marshes should be developed as natural wetlands.

Water bodies in urban areas would need to be linked up with stormwater runoff in the vicinity to augment the inflow with proper filtration arrangements.

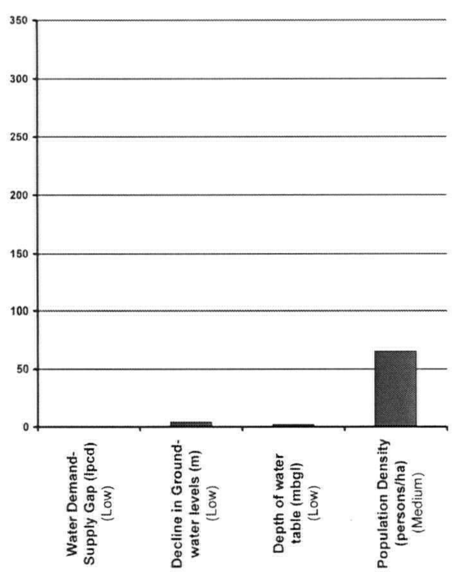


Figure 6.10:

Bar graph showing different parameters for Action Area **Re-4** stress rating.

Sources: CGWB, DJB, DDA, Census of India 2001.

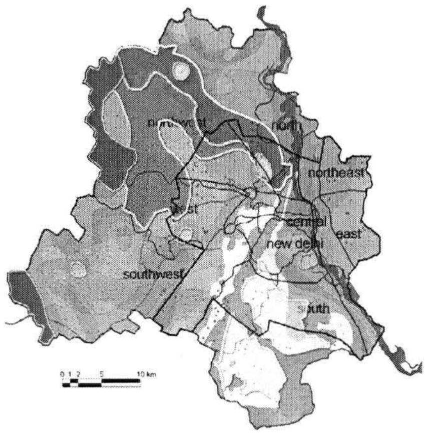


Figure 6.11: Action Area **Re-5** - key plan

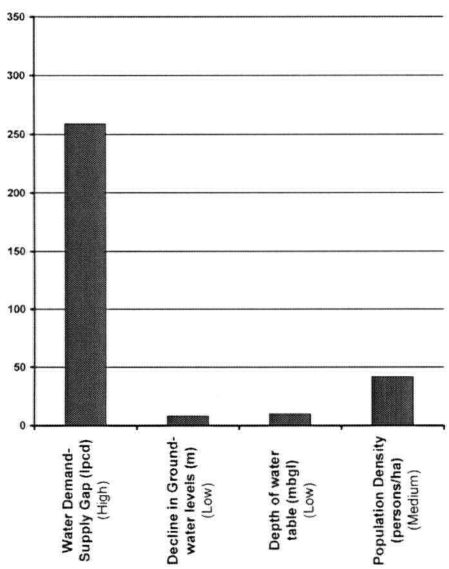


Figure 6.12:

Bar graph showing different parameters for Action Area **Re-5** stress rating.

Sources: CGWB, DJB, DDA, Census of India 2001.

Action Area	**Re-5**
Main MPD Zones	**N, L**

Neighbourhoods:

Auchandi, Qutab garh, Khor Jal, Garhi Pindala, Nizampur, Rashid pur, Tikri kalan, Baba Haridas nagar, Dhansa, Ghalibpur, Daurala.

Area Characteristics:

- Clayey soil associated with fine grained aeolian deposits.
- Depth to water table - 5 to 10 m.bgl.
- Decline in water table level since 1960 - 4 to 8 m
- Thickness of unsaturated Zone - 0 to 6 m.bgl.
- Brackish / saline water at all levels
- Water demand-supply gap - 78-259 lpcd
- Rural, low density of population - 41.7 persons /Ha
- Presence of large number of water bodies in the natural settings

Potentials/Constraints:

- Saline /brackish water is the main constraint for recharge
- Availability of large number of water bodies without much pressure of urbanization and clayey soils offers great potential for surface storage.

Stress Rating:

Rainwater Harvesting Development Recommendations:

The best option in this area is to store surplus runoff in local water reservoirs, such as village ponds, wells and traditional water structures such as baolies.

Water from these storage areas should be promoted for domestic use and irrigation.

Artificial water recharge should only be practiced if there is surplus water available to improve the quality of groundwater.

The water bodies could be desilted, widened and deepened to increase their storage capacities wherever possible

Their catchments areas should be identified, restored if needed and protected from urbanization and pollutants by involving local residents and formulating and implementing policies for the same.

Broad summary of the analysis above is shown below in [Figure 6.13]. It is clearly evident that majority of the action areas are suitable for storing the harvested rainwater in natural or artificial surface depressions. The stored water can be used for local water needs and/or redistribution to other areas. The surplus water can be recharged naturally or artificially increasing the total quantity of harvested rainwater. Since most of the action areas are supportive of surface storage and fall in the rural or peri-urban areas which are inundated with numerous water bodies, potential of natural surface storage is studied in greater detail in section 6.2.

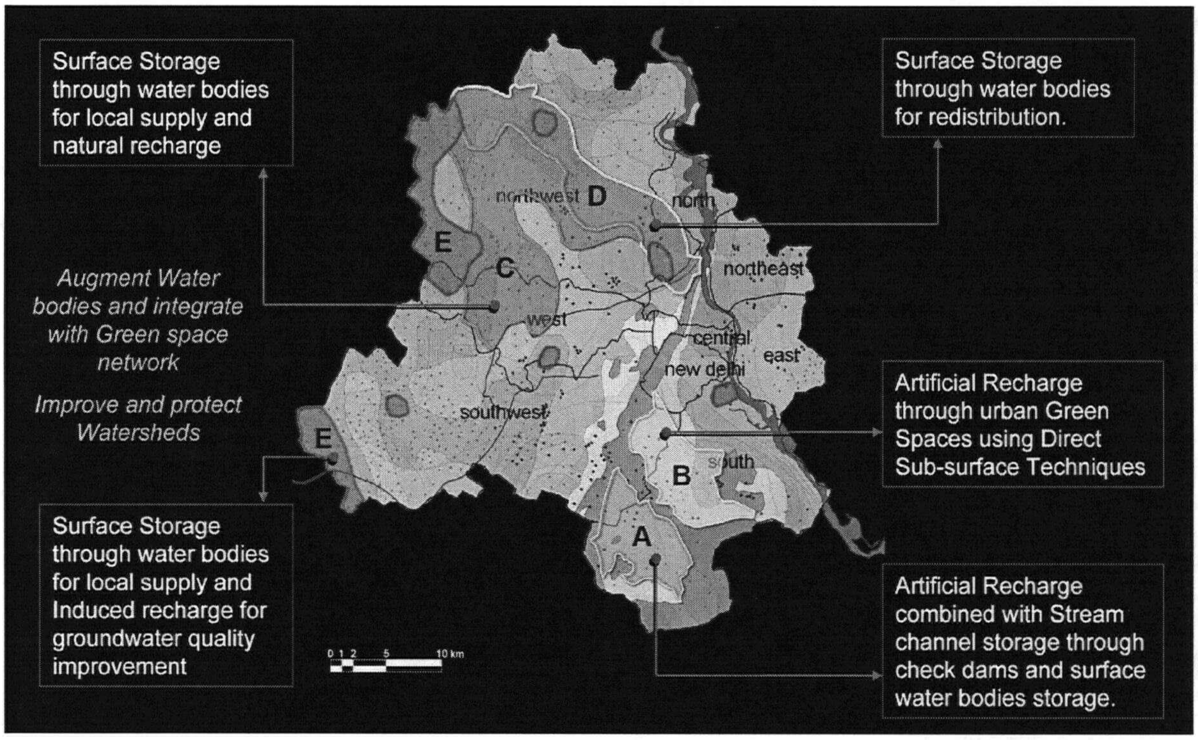


Figure 6.13: Conceptual action plan summary for the Priority Action Areas

6.2 Recommendations for Natural Surface Storage Option

Status of water bodies in NCT Delhi according to several recent studies:

- Total number of recorded water bodies in NCT Delhi is 794
- Out of these approximately 300 water bodies fall in the MPD 2001 urban Zones.
- Only 3% (22) water bodies are planned

- Condition of 25% is not recorded. Out of the rest 75%, 22% have dried up and most of them are in the Urban MPD zones.
- 50% of the water bodies which have water have scope of revival [65]
- 30% have either been encroached or allotted for other land uses.
- 50 % of water bodies are > 0.5 Ha (1 acre) in size.
- The total surface area under water bodies is around 677 Ha. [66]

Urban expansions and the rampant construction activity in the past have had a negative impact on the water systems as the site development had ignored the local hydrological consideration. Planners aim at systematic colonization of the hinterland and leave resource management to water departments and central water authorities working on a strictly engineering approach to deliver water. Thus the destruction and/or diversion of natural drainage lines in the landscape, reclamation of low lying lands, refilling of ponds and sundry water bodies continues unabated. Primacy is given to the contiguous development of dense built-up area on the basis of transport, service and commercial linkages and not to hydrological and associated ecological considerations. Extensive urban development and influx of people from rural to urban areas has also lead to unauthorized squatter settlements along the drainage channels and in the catchment areas leading to excessive sewage generation and disposal of this sewage into the drainage channels and water bodies Due to such approach, lack of policies, their proper enforcement and lack of monitoring has led the water bodies and their catchment areas in a state of neglect and disrepair.

Considering the general state of water bodies and their catchment areas following universal measures must be taken for their long term sustainable and beneficial functioning in the ecosystem:

- Prevention of pollution from point and non-point sources through interception,
- Diversion and treatment of domestic sewage.

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[65] Gupta, Kokil; Dissertation: Mainstreaming Urban Water Bodies. Dept. of Environmental Planning; School of Planning and Architecture. New Delhi. 2004

[66] Blueprint for Water Augmentation in Delhi. India National Trust for Architectural and Cultural Heritage (INTACH), New Delhi. India. 1998

- Desilting and weed control through conventional methods of dredging and manual labour.
- Development of self regulating wetland systems.

Depending on the specific condition/status of the water bodies different strategies must be adopted as stated below in table 6.1.

Table 6.1 - Action Plan for water bodies depending on their condition

Condition and status	Action Plan/Strategy
Surviving in original state	Maintain and develop
Wet and planned	Enhance potential and prioritize use
Wet and allotted for different land-use	De-notify allotted use and protect
Dry and vacant	Desilt and restore. Redirect stormwater channels or harvest treated waste water
Threatened and encroached	Relocate slums, in-situ waste management plan through community participation, comprehensive environment improvement plan
Killed / built upon	Allot same amount of area in the same zone for creation of new water bodies to maintain the local water balance.

Assuming an average depth of 1.75 m of these water bodies as per INTACH report, as much as 12 MCM of harvested rainwater can be stored in them at any given time. The storage capacity of these water bodies can be further enhanced by deepening and/or widening as suitable on case by case basis. **If all the water bodies are deepened by 1 m their storage capacity can be increased from 12 MCM to 19 MCM.** By combining recharge structures such as recharge shafts or injection wells with these water bodies the amount of recharge can be further increased many folds. This would also be immensely helpful bridging water demand-supply gap and also mitigating the problem of urban flooding during monsoons.

6.3 Defining and Introducing Study Areas

To assess and demonstrate the potential of public green spaces in Delhi two study areas are selected in the priority action area B [as shown in Fig. 6.14 & 6.15] which is the most stressed and also is the only area falling in the urban boundaries of Delhi (MPD zone F). One study area looks at the green spaces within a neighbourhood and the other is a regional green space. They are studied across various scenarios discussed later in section 6.4.

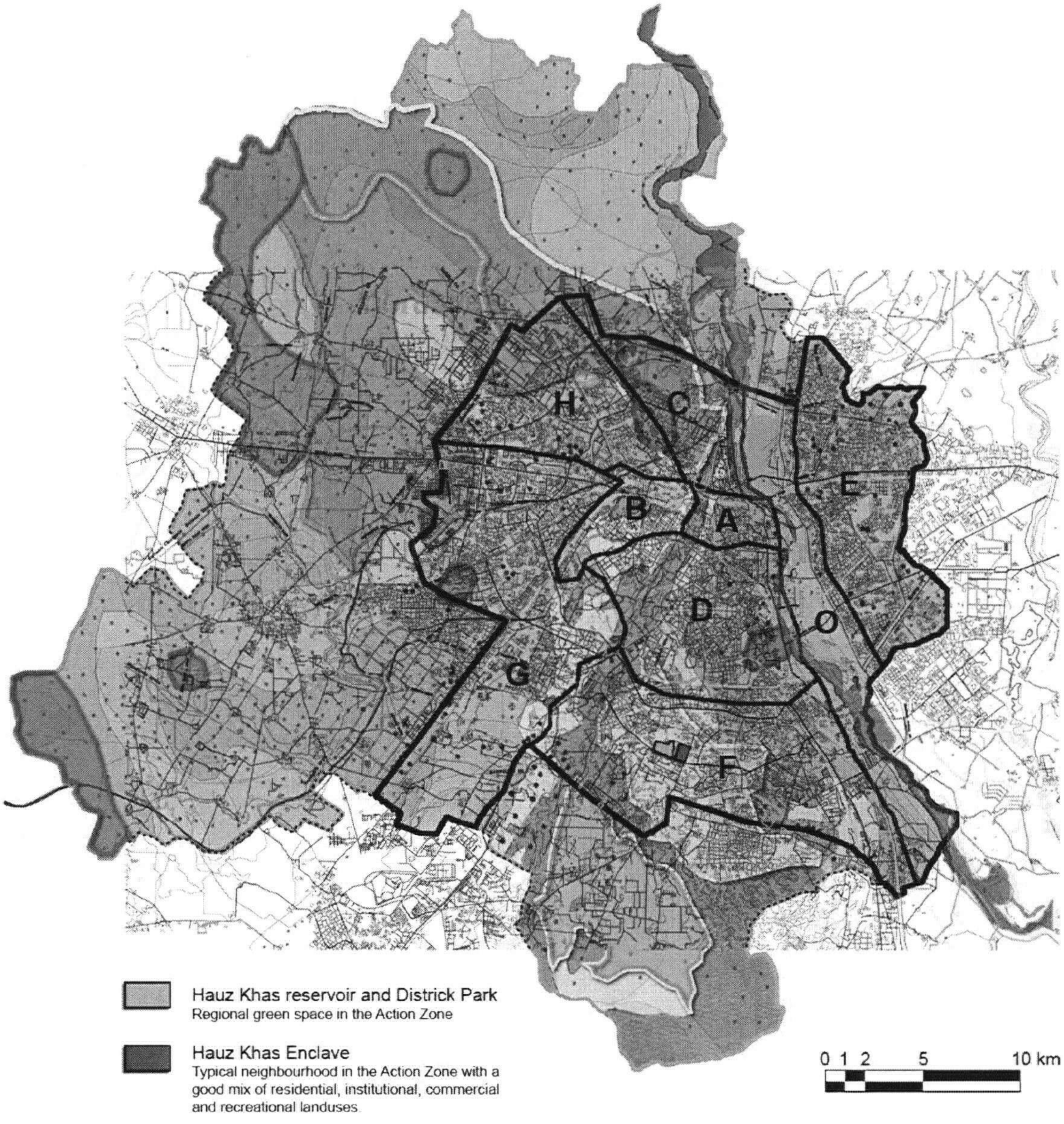
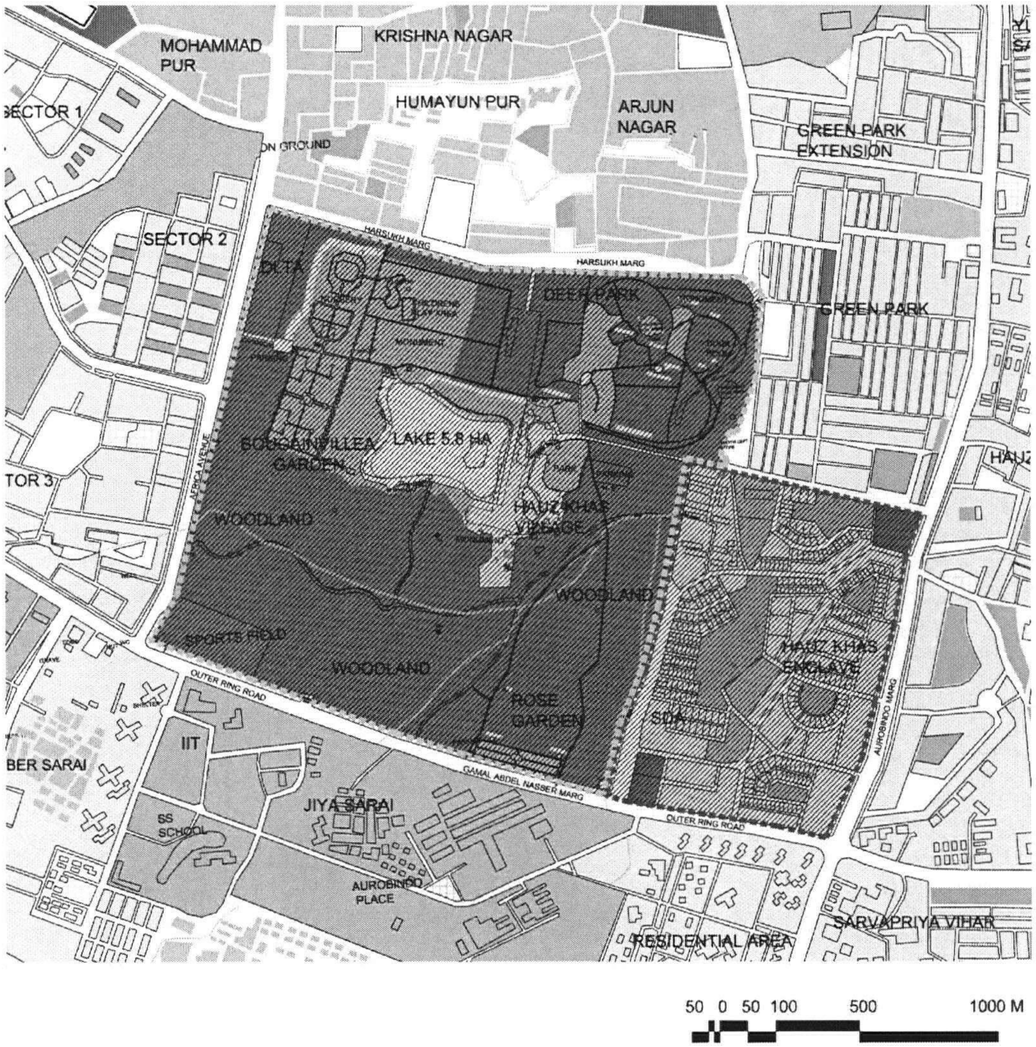


Figure 6.14: Key Plan showing location of Study areas in the Priority Action Area B (MPD zone F)



LEGEND:

- RESIDENTIAL
- COMMERCIAL
- INSTITUTIONAL
- NEIGHBOURHOOD GREENS
- PARK FOREST
- PARK GREENS
- URBAN VILLAGE
- UNPLANNED COLONIES
- Neighbourhood Study Area
- Regional Study Area

Figure 6.15: Enlarged Land-use map showing the Neighbourhood and Regional Study Areas with their surroundings.

6.3.1 Neighbourhood Green Spaces - Hauz-Khas Enclave

Hauz Khas Enclave is located in MPD Zone F, South Delhi and is approachable from two main roads: Aurobindo marg on the east, and Gamal Abdel Nasser Marg (Outer Ring Road) on the south. It has a rich mix of residential, commercial, institutional and recreational land uses. There are five public green spaces (A - E) which are identified in this neighbourhood as shown below in [Figure 6.16], for further study.

Figure 6.16: Public Green Spaces A to E in Hauz Khas Enclave neighbourhood (Air photo source: Google map)

The highlighted public green spaces in this neighbourhood vary in size from 40,000 m^2 to 4,000 m^2. They are typical of any neighbourhood in Delhi, in their general layout and profile (Fig. 6.17). Most of the area is dedicated to a well maintained turf lawn with a peripheral walkway raised above the ground. The walkways are generally made of brick or stone unit pavers. In some cases a part of the green space is developed as kids play area with swings and often has no or very limited ground cover. This area usually has bare and compacted soil with surface depressions due to extra activity. Larger trees are planted near the boundary with very few scattered in the middle. In some large green spaces with higher canopy coverage the ground is left bare without any ground cover. These areas get fragmented grass cover during the rainy season and dry up again during summers. Planter areas are created randomly by digging into the ground for seasonal plantings and act as water storage depressions. Irrigation demand for these green spaces is estimated to be 10L/m^2/day in summers, 5L/m^2/day during monsoons and 7L/m^2/day in in winters acoording to ICAR.

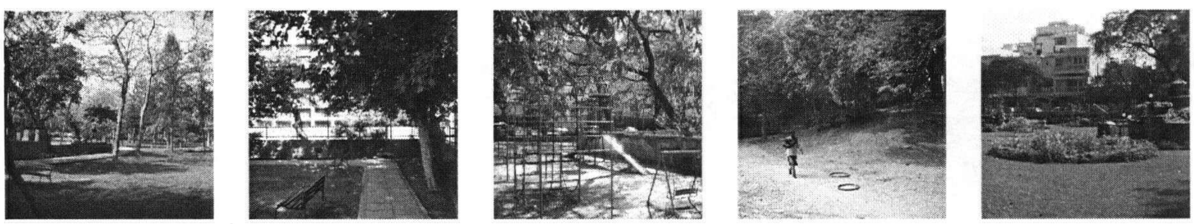


Figure 6.17: Area profile of public green spaces in Hauz Khas Enclave neighbourhood

6.3.2 Regional Green Space - Hauz-Khas Reservoir and District Park

Hauz Khas District Park is also located in MPD Zone F, South Delhi and is approachable from three main roads: Africa Avenue on the west, Gamal Abdel Nasser Marg (Outer Ring Road) on the south and Ch. Harsukh Marg on the North. It is an oasis in the midst of a busy and densly populated area. It comprises of historical monuments, a lake, reserved forest area, sports fields and an ornamental rose garden (Fig. 6.18). The complex is a paradise for morning and evening walkers and a popular picnic spot. The park spreads over an area of 142.35 ha serving as green lungs for the whole of South Delhi with a 5.8 ha lake in the middle.

Figure 6.18: Hauz-Khas reservoir and District park boundaries (Air photo source: Google Earth)

Historical Background

Alauddin Khilji had got this complex built around 1300 A.D. as a picnic spot for himself. The complex comprised of a lake which was fed by trapping the stormwater generated in southern ridge in an embankment from where it was diverted to the Hauz (existing lake). The Hauz is situated between the hillocks on its East, South and West sides. It may have been a natural depression filled up by the runoff from the hillocks. The water in the lake and the stormwater drains were major sources of surface water in the park. The three stormwater drains carried good quality rainwater from surrounding areas, historically. These drains were trapped in an embankment next to the lake and used to recharge water in the Tank.

Presently, these drains have become non functional as none of them carry good quality stormwater. Diversion of the Stormwater inflow and change in the catchment characteristics has lead to drying up of the lake in recent times. The irrigation needs of this regional green space are currently met by pumping groundwater from 6 tubewells which are run for average 6-7 hours every day all around the year as told by the local gardeners. This has resulted in decline in the water table levels and deterioration in the groundwater quality. The bed of the Hauz Khas lake had been concretized about a decade earlier in an attempt to retain rainwater. The bed is uneven with a depth varying from 2.2 to 1.6 m. The adjacent banks have been paved over with red sandstone, the pavement being sloped towards the lake. Further, the lake does not have any natural banks. It appears to have been excavated from the natural soil and has steep slopes which are protected with stone pitching covered with cement plaster (Fig. 6.19).

In recent years, Delhi Government with technical assistant from Indian National Trust for Art and Cultural Heritage (INTACH) has tried to revive the lake by diverting the treated effluent water from nearby sewage treatment plants (STP's) after passing it through various duckweed ponds for further improving the water quality. The lake, is therefore filled with varying levels of water around the year but due to lack of a proper natural cycle and maybe lack of proper management, it is going through major eutrophication (Fig. 6.18). It can pose serious environmental hazards if not handled properly and immediately.

Figure 6.19: Area profile of Hauz Khas Reservoir and District park.

6.4: The Scenarios

Considering the vast diversity of public green spaces in Delhi and the different levels at which rainwater harvesting can be adopted in these areas owing to availability of resources, four different scenarios are formulated for the specific study areas identified in section 6.3. They defining a range of possibilities for the study areas in which different interventions for the given goal can happen. For the thesis, scenario map ranges across two attributes - the physical scale and the intervention level (Fig. 6.20). The physical scale of the sites ranging from the neighbourhood level to the regional level and the intervention level ranging form minimum intervention to maximum intervention. The minimum intervention at the neighbourhood scale represents the base case scenario with minimum cost, minimum alterations to the physical environment and minimum involvement of stakeholders. The maximum intervention at the regional scale represents the ultimate option within the scope, maximizing the water gains through rainwater harvesting. All the four scenarios are analyzed to determine the potential water gains, cost burden and cost benefits through the research demonstrating their technical and financial feasibility. Working with a range of scenarios provides a broad spectrum in which the solutions can be adopted now and in future for all the sites in the region which may have different characteristics and might face different circumstances at different times.

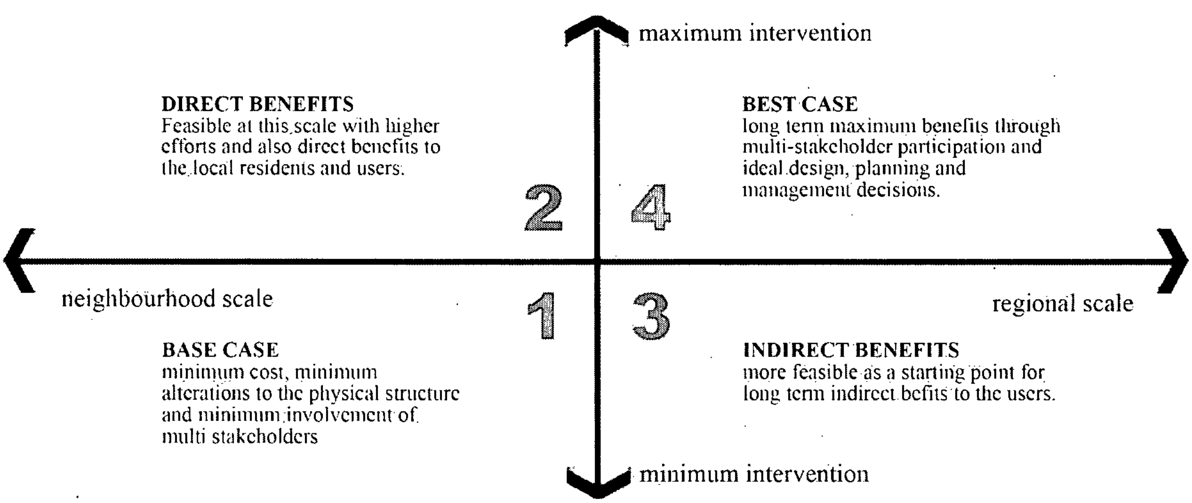


Figure 6.20: Scenario Map, Scale and Intervention

The objectives and variations in each scenario are shown below in Figure 6.21 and Table 6.2, clearly indicating the interventions considered at minimum and maximum levels [which, in principle, remain similar across different scales].

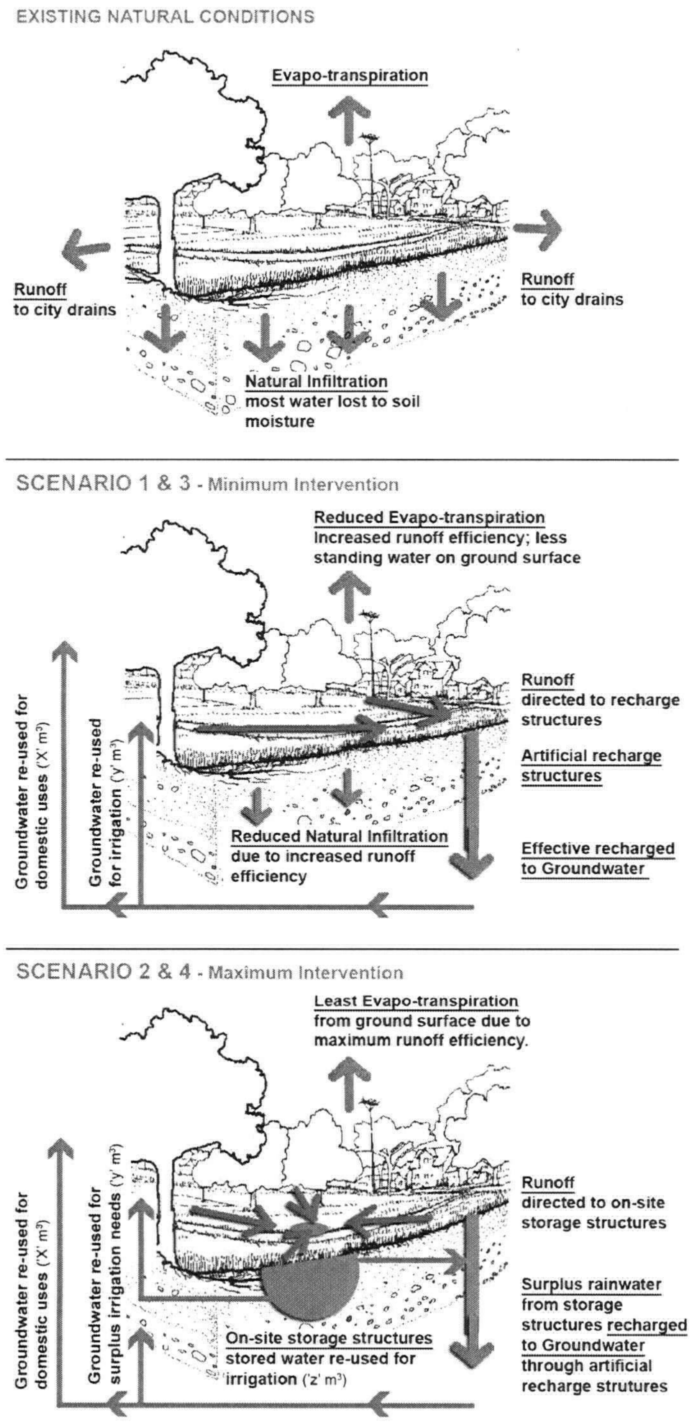


Figure 6.21: Objectives and variations in different scenarios

Analysis & Interventions	Scenario 1 & 3	Scenario 2 & 4
Existing surface analysis	✓	✓
Existing slope analysis	✓	✓
Canopy cover analysis	✓	✓
Runoff analysis	✓	✓
Activity pattern analysis	✗	✓
Surrounding areas drainage analysis	✗	✓
Natural depressions filling	✓	✓
Minor slope adjustments	✓	✓
Major slope adjustments	✗	✓
Layout modifications	✗	✓
Broad Catchment delineation	✓	✓
Mini-catchments delineation	✗	✓
Extended catchments	✗	✓
Artificial recharge	✓	✓
On-site storage	✗	✓
Irrigation demand analysis	✗	✓
Rainwater re-used for irrigation (from storage)	✗	✓
Rainwater re-used for Domestic purposes (groundwater pumping)	✓	✓
Evaporation control measures	✗	✓
Cost analysis	✓	✓

Table 6.2: Scenarios principle processes

Design Criteria and Assumptions for the analysis

For the analysis of the Study areas across different scenarios in the consequent sections several design criterions and assumptions are followed which are listed below:

1. For designing the optimum capacity of the recharge structures and settlement tank (desilting chambers), the following parameters are considered:
   - Size of the catchment
   - Intensity of rainfall
   - Rate of recharge, which depends on the geology of the site
2. The capacity of recharge tank is designed to retain runoff from at least 15 minutes rainfall of peak intensity. For Delhi, peak hourly rainfall is 90 mm (based on 25 year frequency) and 15 minutes peak rainfall is 22.5 mm/hr, say, 25 mm, according to CGWB norms.
3. **Interception Loss due to canopy cover:** 20% of total annual rainfall for a 100 % deciduous trees canopy coverage. For different canopy coverages, the loss is prorated.
4. **Irrigation Demand:**
   - Summer (March-June): 10 litres/m^2/day
   - Rainy Season (July-September): 5 litres/m^2/day (second day after a rainy day)
   - Winter (October - February): 7 litres/m^2/day

6.4.1 Scenario 1 - Neighbourhood scale with minimum intervention

This scenario works strictly within the physical boundaries of neighbourhood green spaces with minimum interventions which include construction of the recharge structures, depression filling from the excavated earth from recharge structures, minor slope adjustments and construction of culverts and drainage channels only where essentially needed to direct the flow of water towards the recharge structures. No major alteration are considered for the overall layout of the green spaces for this scenario keeping the cost at minimum. The green spaces are studied for their surface area characteristics and slopes to establish respective runoff coefficients and suitable location of the recharge structures is then suggested based on the water flow analysis.

Scenario 1: Neighbourbood **Green Space A**

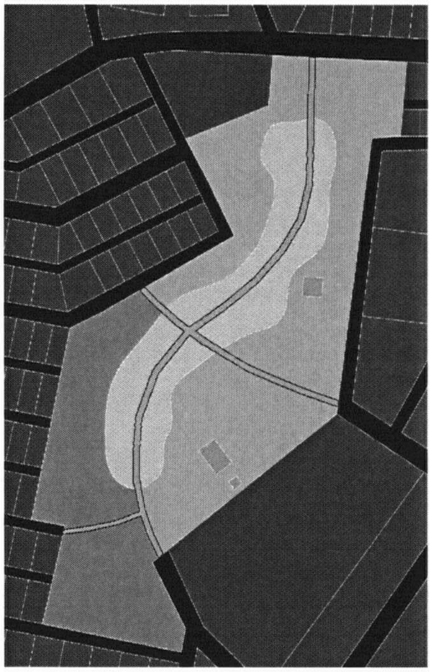


Figure 6.22: Surface Area Analysis

Area Analysis / physical characteristics:

Total Area - 40,079 m²

Most of the area is bare with sparse plant cover and no designated planter areas. Some parts closer to row houses have maintained green patches with scattered trees. Negligible surface depressions. The whole site is bifurcated by a ridged embankment along the length (Fig. 6.22). Existing slope conditions are shown in figure 6.23.

Approximately 75% area under canopy cover.

	Description	Area (m^2)	Runoff Coefficient
	Paved pathways - stone/brick pavers	1,552	0.85
	Maintained Green with slope < 2%	10,365	0.3
	Bare or sparse plant cover, slope < 2%	19,092	0.35
	Bare or sparse plant cover, slope > 7%	8,674	0.45
	Built area	396	0.9

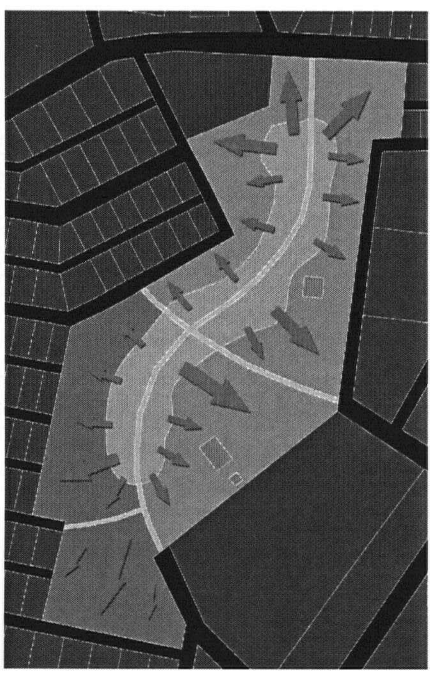


Figure 6.23: Slope Analysis (Existing condition)

Interventions:

Area	Intervention	Cost (INR)	Challenges
Greens, Bare land	Depression filling, minor slope adjustments	9,000	Labour intensive
Edges	Drainage channels	150,000	Clogging
Overall	Recharge structures	875,000	Siltation, maintenance

Recharge Structures (Fig. 6.24):

Type	Size - LxBxD (m)	Nos.
R1 - Recharge trench (2 borewell)	11.0 x 2.0 x 3.5	3
R2 - Recharge shaft (1 borewell)	5.0 x 2.0 x 3.5	1
R3 - Recharge trench (2 borewells)	22.0 x 2.0 x 2.0	1
R4 - Circular recharge shaft (1 borewell)	4.0 m diameter x 3.5 D	1

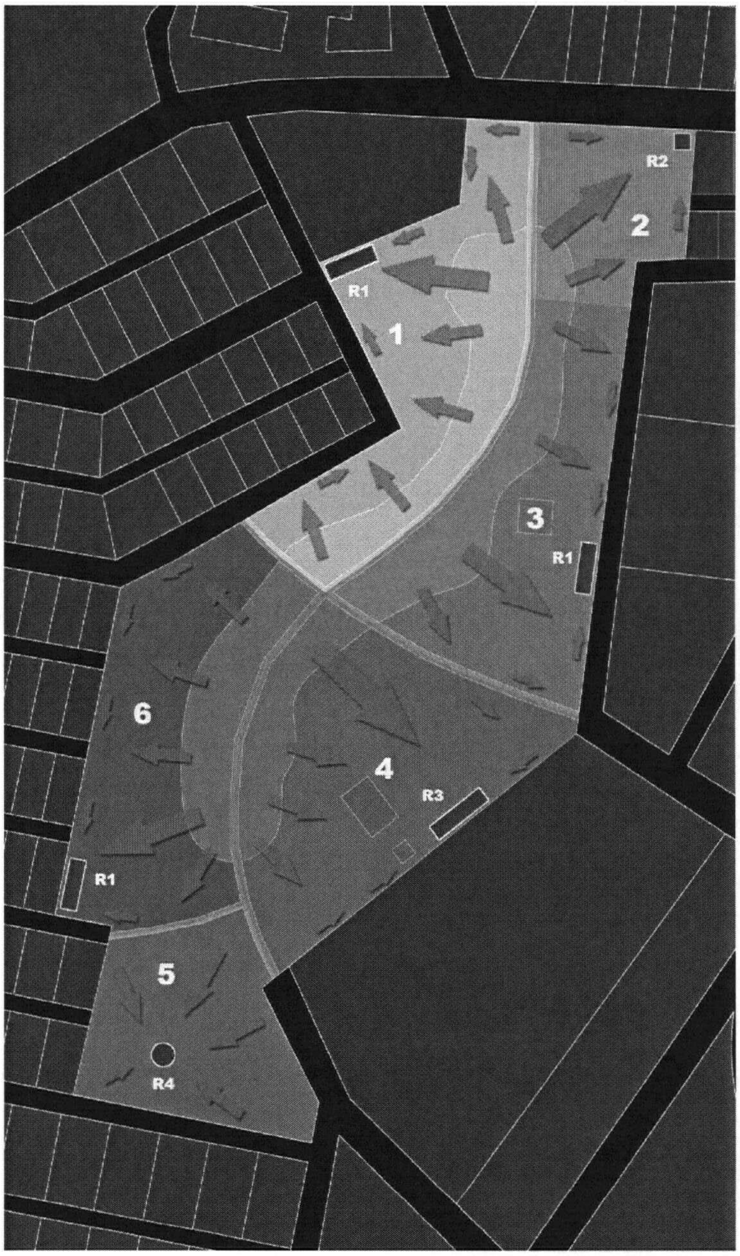


Figure 6.24: Catchment areas and Location of Recharge structures (■)

Based on the runoff coefficients and areas of each surface type, total runoff from this study area is calculated (Appendix B) which is available for artificial recharge and accounts for the total annual water yield from this site.

Annual Water Gain: 6,532.5 m³

Scenario 1: Neighbourbood **Green Space B**

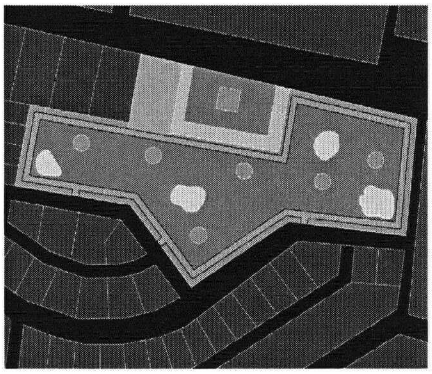


Figure 6.25: Surface Area Analysis

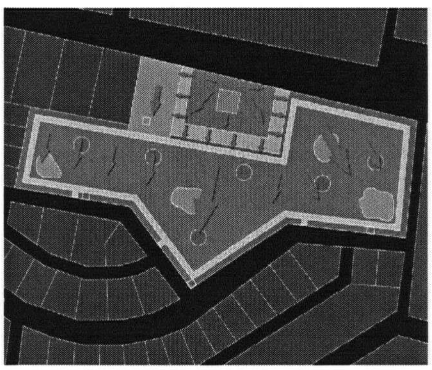


Figure 6.26: Slope Analysis (Existing condition)

Area Analysis / physical characteristics:

Total Area - 16,485 m^2.

Most of the area is maintained green with negligible surface depressions. There is a steep embankment on 3 sides of the green space surrounding a historical monument (Fig. 6.25). Existing slope conditions are shown in figure 6.26.

Approximately 50% area under canopy cover.

	Description	Area (m^2)	Runoff Coefficient
	Paved pathways - stone/brick pavers	1,750	0.85
	Maintained Green with slope < 2%	9,562	0.3
	Bare or sparse plant cover, slope < 2%	1,807	0.35
	Bare or sparse plant cover, slope > 7%	866	0.45
	Planters - loose soil	2,356	0.1
	Built area	144	0.9

Interventions:

Area	Intervention	Cost (INR)	Challenges
Greens, Bare land	Depression filling, minor slope adjustments	6,000	Labour intensive
Pathways, Edge planters	Culverts, drainage channels	105,000	Clogging
Overall	Recharge structures	356,000	Maintenance

Recharge Structures (Fig. 6.27):

Type	Size - LxBxD (m)	Nos.
R1 - Recharge shaft (1 borewell)	3.0 x 3.0 x 2.0	1
R2 - Recharge shaft (1 borewell)	5.0 x 2.0 x 3.5	1
R3 - Recharge trench (1 borewell)	8.0 x 2.0 x 3.5	2

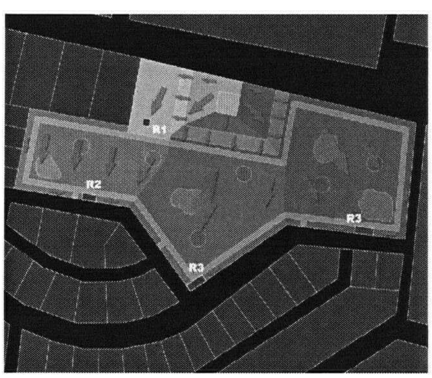


Figure 6.27: Catchment areas and Location of Recharge structures (■)

Based on the runoff coefficients and areas of each surface type, total runoff from this study area is calculated (Appendix B) which is available for artificial recharge and accounts for the total annual water yield from this site.

Annual Water Gain: 2,584.6 m^3

Scenario 1: Neighbourbood Green Space C

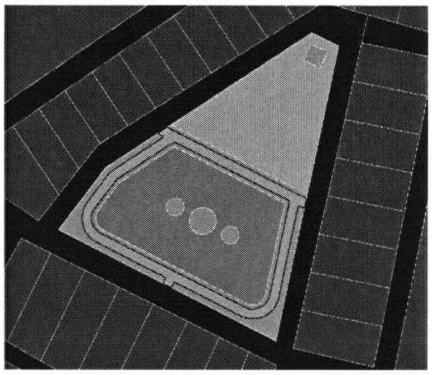


Figure 6.28: Surface Area Analysis

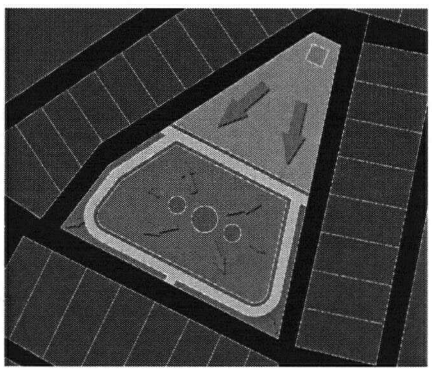


Figure 6.29: Slope Analysis (Existing condition)

Area Analysis / physical characteristics:

Total Area - 4,928 m^2.

Half of the park is maintained green and the rest is used as a play area for children with high use. The soil here is compacted and considerable surface depressions around play areas. Negligible surface depressions in the maintained green area with clear drainage ways (Fig. 6.28). Existing slope conditions are shown in figure 6.29.

Approximately 20% area under canopy cover.

	Description	Area (m^2)	Runoff Coefficient
	Paved pathways - stone/brick pavers	619	0.85
	Maintained Green with slope < 2%	1,879	0.3
	Bare or sparse plant cover, slope < 2% (play area)	1,485	0.35
	Planters - loose soil	909	0.1
	Built area	36	0.9

Interventions:

Area	Intervention	Cost (INR)	Challenges
Greens, Play area	Minor slope adjustments	2,160	Labour intensive
Pathways, Edge planters	Culverts, Drainage channels	52,500	Clogging
Overall	Recharge structures	117,600	Maintenance

Recharge Structures (Fig. 6.30):

Type	Size - LxBxD (m)	Nos.
R1 - Recharge shaft (1 borewell)	4.0 x 2.0 x 2.0	1
R2 - Recharge shaft (1 borewell)	4.0 x 2.0 x 3.5	1

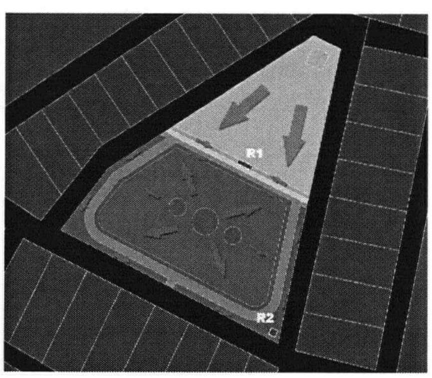


Figure 6.30: Catchment areas and Location of Recharge structures (■)

Based on the runoff coefficients and areas of each surface type, total runoff from this study area is calculated (Appendix B) which is available for artificial recharge and accounts for the total annual water yield from this site.

Annual Water Gain: 810.1 m^3

Scenario 1: Neighbourbood Green Space D

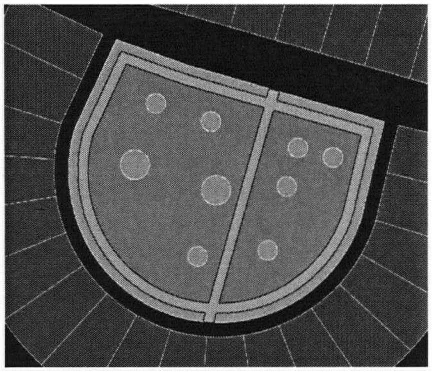


Figure 6.31: Surface Area Analysis

Area Analysis / physical characteristics:

Total Area - 6,007 m^2.

The green space is almost flat and well maintained with negligible surface depressions. The only surface depressions are that of planter areas which are all along the park edge and some randomly located in the middle. Clear drainage ways with no marshes (Fig. 6.31). Existing slope conditions are shown in figure 6.32.

Approximately 20% area under canopy cover.

	Description	Area (m^2)	Runoff Coefficient
	Paved pathways - stone/brick pavers	985	0.85
	Maintained Green with slope < 2%	3,870	0.3
	Planters - loose soil	1152	0.1

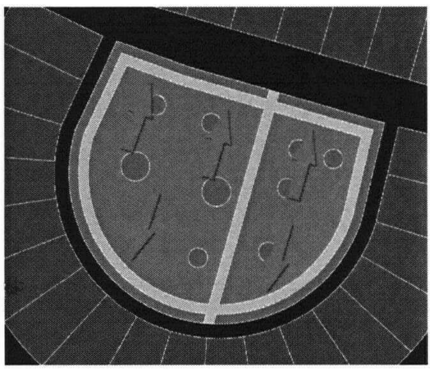


Figure 6.32: Slope Analysis (Existing condition)

Interventions:

Area	Intervention	Cost (INR)	Challenges
Green area	Depression filling	4,560	Labour intensive
Pathways, Edge planters	Culverts, Drainage channels	50,750	Clogging
Overall	Recharge structures	141,000	Maintenance

Recharge Structures (Fig. 6.33):

Type	Size - LxBxD (m)	Nos.
R1 - Recharge shaft (1 borewell)	3.0 x 2.0 x 3.5	1
R2 - Recharge shaft (1 borewell)	5.0 x 2.0 x 3.5	1

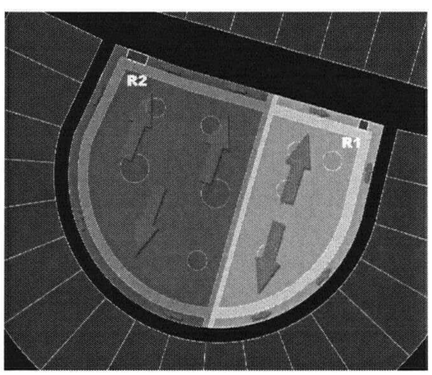


Figure 6.33: Catchment areas and Location of Recharge structures (■)

Based on the runoff coefficients and areas of each surface type, total runoff from this study area is calculated (Appendix B) which is available for artificial recharge and accounts for the total annual water yield from this site.

Annual Water Gain: 1003.9 m^3

Scenario 1: Neighbourbood **Green Space E**

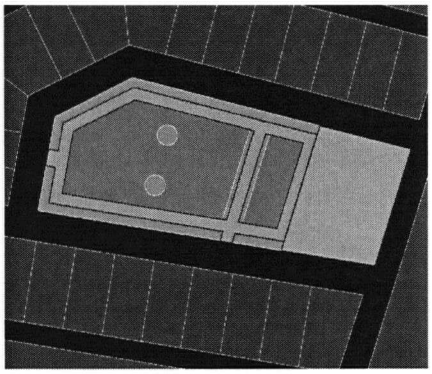


Figure 6.34: Surface Area Analysis

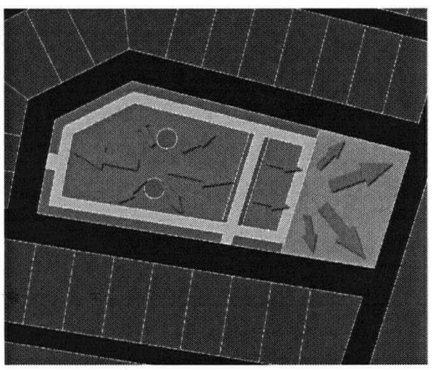


Figure 6.35: Slope Analysis (Existing condition)

Area Analysis / physical characteristics:

Total Area - 4,002 m^2.

Part of the park is used as a play area for children with high use, compacted soil and considerable surface depressions around play areas. Negligible surface depressions in the maintained green area with clear drainage ways (Fig. 6.34). Existing slope conditions are shown in figure 6.35.

Approximately 20% area under canopy cover.

	Description	Area (m^2)	Runoff Coefficient
	Paved pathways - stone/brick pavers	684	0.85
	Maintained Green with slope < 2%	1,629	0.3
	Bare or sparse plant cover, slope < 2% (play area)	1,030	0.35
	Planters - loose soil	659	0.1

Interventions:

Area	Intervention	Cost (INR)	Challenges
Greens, Bare land	Minor slope adjustments	1,920	Labour intensive
Pathways, Edge Planters	Culverts, Drainage channels	48,125	Clogging
Overall	Recharge structures	100,050	Maintenance

Recharge Structures (Fig. 6.36):

Type	Size - LxBxD (m)	Nos.
R1 - Recharge shaft (1 borewell)	3.0 x 2.0 x 3.5	1
R2 - Recharge shaft (1 borewell)	2.5 x 2.0 x 3.5	1

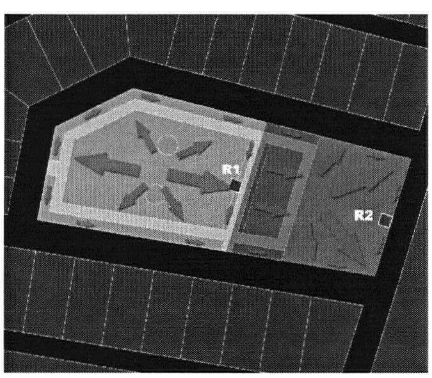


Figure 6.36: Catchment areas and Location of Recharge structures (■)

Based on the runoff coefficients and areas of each surface type, total runoff from this study area is calculated (Appendix B) which is available for artificial recharge and accounts for the total annual water yield from this site.

Annual Water Gain: 701.8 m^3

Summary - Scenario 1

Total green space area, water gain and capital cost for scenario 1 is summarized below in figure 6.37. The water gain is equated as cost saving to the government and/or local residents, [for assessing the financial feasibility], by comparing it with the amount otherwise paid to purchase water from private water tankers at the rate of Rs 100/m^3 as per details provided by Delhi Water tankers Association.

Total Area (m^2)	**Water Gain** (m^3)	**Capital Cost** (Indian Rupees-Rs.)	**Capital Cost** ($ Cdn.)	**Water gain equated as cost savings** (Indian Rupees-Rs.)	**Water gain equated as cost savings** ($Cdn.)
71,500	11,634	979,665	24,492	1,163,400	29,085

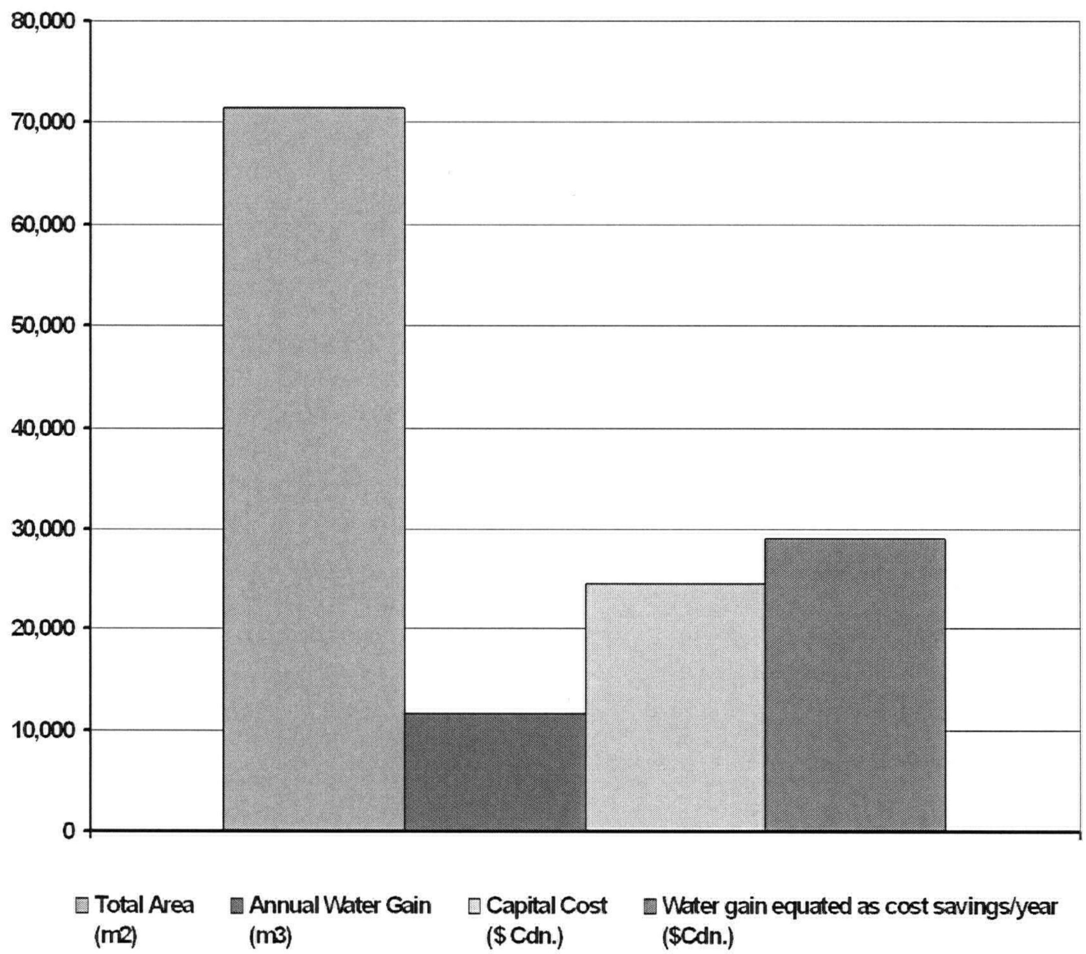


Figure 6.37: Bar Graph showing Scenario 1 Summary

6.4.2 Scenario 2 - Neighbourhood scale with maximum intervention

This scenario aims at maximizing water gains through complete surface modifications in the study areas [as needed] for optimum runoff efficiency; tapping the rainwater from the areas surrounding the neighbourhood green spaces; and storing the harvested rainwater to meet daily irrigation needs of the maintained green areas before recharging it to the aquifers. It is found that the stormwater from the streets and residences [neighbouring the green spaces], currently drain away from the green space through open drainage channels to the main streets which have covered stormwater drains (Fig. 6.38, Fig. 6.39). The extended catchment areas are therefore defined according to the open stormwater drainage network such that the rainwater from the residences and streets [which drain their stormwater through open drainage channels] can be diverted to the green spaces for recharge with reasonable physical modifications and cost. The streets and residences in consideration have negligible canopy coverage and therefore have insignificant interception losses. The rainwater from the residences and streets is not used for storage as it may contain some contaminants and silt and therefore directly led to the recharge structures after passing through desilting chambers. Surface modifications to the green spaces are considered after studying the activity patterns and area usages in the green space (Fig. 6.40, and Fig. 6.41) with a view to improve their quality and usability at the same time.

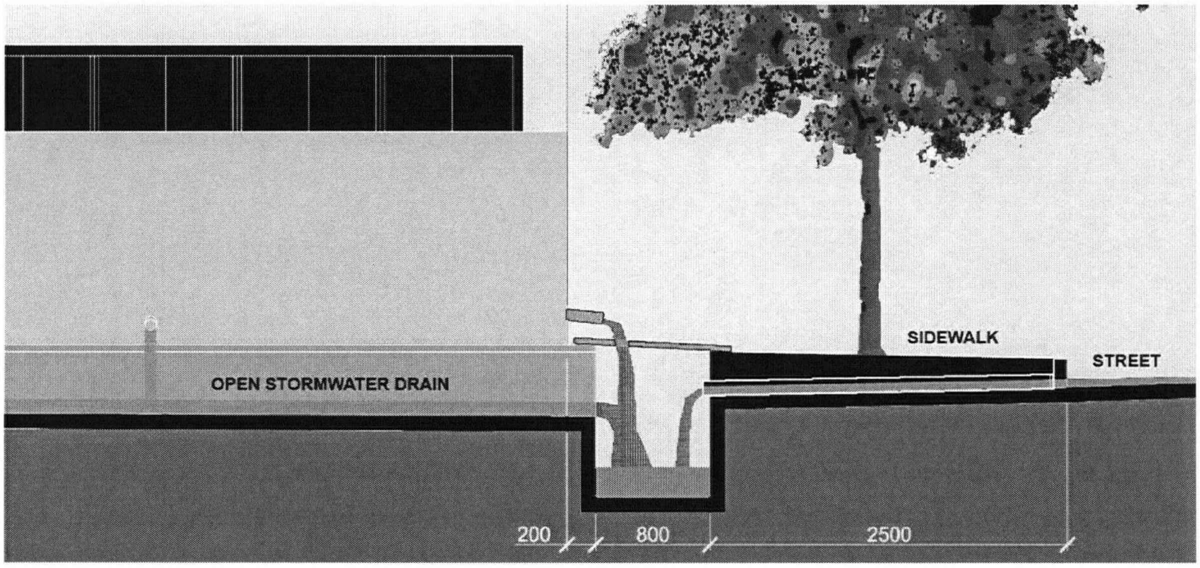


Figure 6.38: Cross Section showing neighbourhood Open Stormwater Drain network.

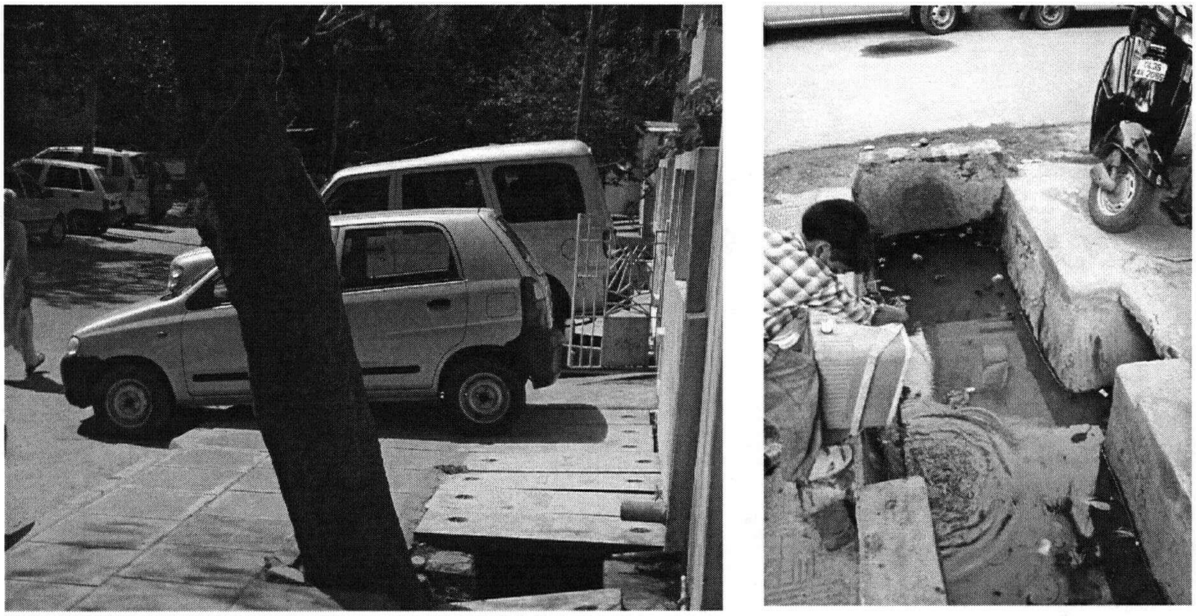


Figure 6.39: Images showing neighbourhood Open Stormwater Drain network.

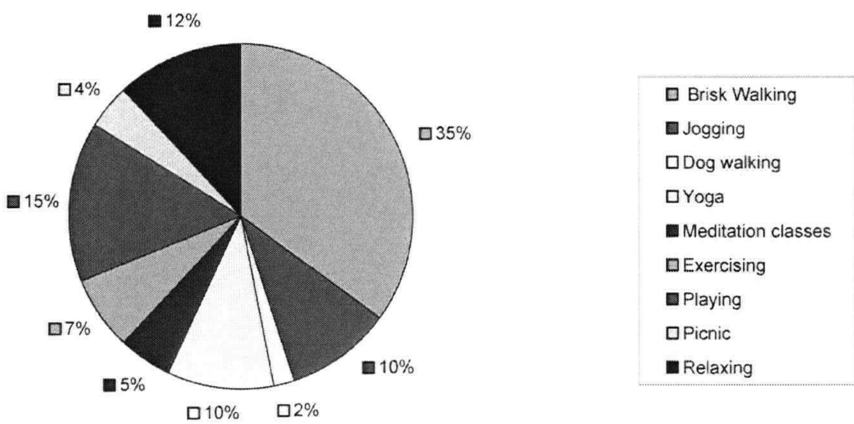


Figure 6.40: Green Spaces Activity Profile

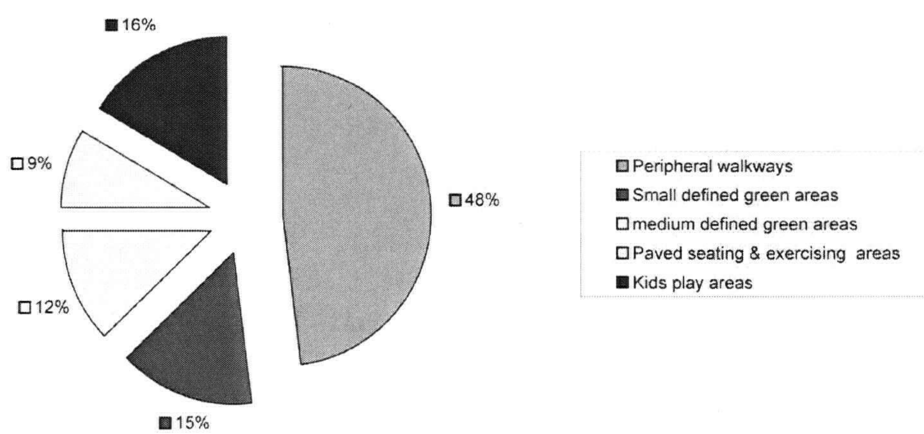


Figure 6.41: Areas percentage in a Green Space bases on activities and number of users.

Scenario 2: Neighbourbood Green Space A

Area Analysis / physical characteristics:

Figure: 6.42

Surface Area Analysis including extended catchment area

Based on the existing layout and slopes as studied in scenario 1, the site is modified as appropriate to maximize runoff efficiency and hence the total water yield. The site is surrounded mainly with compact multi-family row houses. The eastern edge has larger plots with stacked group housing with their own smaller green spaces but their stormwater is currently drained into the local streets open drainage channels. There are two large schools on the south-eastern edge which are not included in the catchment area as they will be initiating their own rainwater harvesting systems (Fig. 6.42). Extended catchment boundaries are shown in figure 6.43. Suggested adjustments to the slopes is shown in figure 6.44 along with the recommended location of the recharge structures, storage structures and desilting chambers.

	Description	Area (m^2)	Runoff Coefficient
	Paved pathways - stone/brick pavers	4,511	0.85
	Maintained Green with slope < 2%	6,626	0.35
	Bare or sparse plant cover, slope < 2%	19,094	0.4
	Bare or sparse plant cover, slope > 7%	8,397	0.45
	Planters - loose soil	1058	0.3
	Built area in the green space	396	0.9
	Residential built area	53,480	0.85
	Street area - asphalt, concrete	15,806	0.75

Figure: 6.43: Extended catchment boundaries

Additional Storage and Recharge Structures:

Type	Size - LxBxD (m)	Nos.
S - Cylindrical storage structures	3.0 m dia, 3.0 m depth	2
R1 - Recharge trench (3 borewell)	40.0 x 2.0 x 3.5	1
R2 - Recharge trench (2 borewell)	17.0 x 2.0 x 3.5	1
R5 - Recharge trench (4 borewell)	60.0 x 2.0 x 3.5	1
R6 - Recharge trench (3 borewells)	34.0 x 2.0 x 3.5	1
R7 - Recharge trench (3 borewells)	55.0 x 2.0 x 3.5	1

Desilting chambers	3.0 x 3.0 x 2.4	5

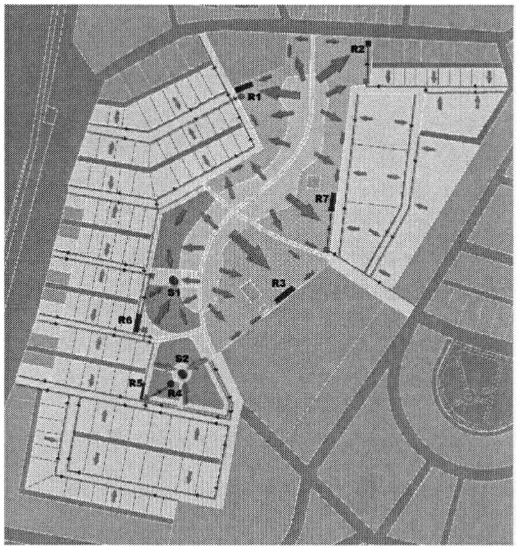


Figure: 6.44

Location of Water Storage structures (●), Recharge structures (■) and Desilting chambers (■)

Interventions:

Intervention	Cost (INR)
Storage structures (21 m^3 ferro-cement cylindrical tanks - 2 nos) including excavation and foundation	50,400
Installing submersible pumps in the storage structures	8,000
Re-grading the catchment areas concavely, sloping towards the storage structures where installed.	495,000
Widening, laying additional pathways	675,000
Construction of cast in-situ desilting chambers (5 nos)	204,750
Connecting storage structures and silt traps to recharge structures through PVC pipes	62,000
Widening and constructing additional recharge structures wherever necessary.	3,286,700
Adjusting open drainage channels slope towards the recharge structures in the green spaces.	450,000

Irrigation Demand and Cost savings:

Irrigation land (maintained green + planters)	7,684 m^2
Current irrigation demand @ average 6L/m^2/day during winter and rainy season	46,100L/day or 46.1 m^3/day
Electricity consumption for groundwater extraction @ 0.4Kwh /m^3/m of extraction considering depth of groundwater at 40 m bgl.	738 Kwh/day
Cost of water extraction @ Rs 5.0/Kwh (excluding cost of equipment, borewells and piping)	Rs 3690/day
Minimum water stored annually, assuming it only rains 2.5 mm on each of the 27 rainy days.	429 m^3
Minimum electricity cost saving annually to the government.	Rs. 34,320
Maximum electricity cost saving annually to the government with maximum storage	Rs. 90,700

Based on the runoff coefficients and areas of each surface type, total runoff from this study area is calculated (Appendix B) giving the total volume of water which is available for recharge and/or localized storage for irrigation purposes.

Annual Water Gain: 36,409.9 m^3

Scenario 2: Neighbourbood **Green Space B**

Area Analysis / physical characteristics:

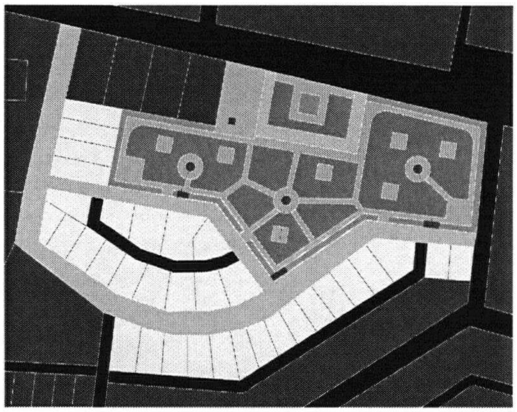


Figure: 6.45

Surface Area Analysis including the extended catchment area

The green space is as modified in scenario 1 (to be considered as Phase 1) with approximately 50% area under canopy cover. The northern edge is a primary street with covered stormwater drain and acting as a divide to the development on the other side of the street. The eastern side has a large commercial complex which must initiate its own integrated rainwater harvesting systems. The western and southern edges have large multi-family houses which drain their water rainwater in the open drains running along the secondary and tertiary streets (Fig.6.45). Extended catchment boundaries are shown in figure 6.46. Suggested adjustments to the slopes is shown in figure 6.47 along with the recommended location of the recharge structures, storage structures and desilting chambers.

	Description	Area (m^2)	Runoff Coefficient
	Paved pathways - stone/brick pavers	4,536	0.85
	Maintained Green with slope < 2%	8,204	0.35
	Bare or sparse plant cover, slope < 2%	1,006	0.4
	Bare or sparse plant cover, slope > 7%	866	0.45
	Planters - loose soil	1,730	0.3
	Built area in the green space	144	0.9
	Residential built area	12,128	0.85
	Street area - asphalt, concrete	6,759	0.75

Figure: 6.46

Extended catchment boundaries

Additional Storage and Recharge Structures:

Type	Size - LxBxD (m)	Nos.
S - Cylindrical storage structures	3.0 m dia, 3.0 m depth	3
R2 - Recharge trench (2 borewell)	17.0 x 2.0 x 3.5	1
R3 - Recharge trench (3 borewells)	34.0 x 2.0 x 3.5	1
R4 - Recharge trench (2 borewells)	14.0 x 2.0 x 3.5	1
Desilting chambers	3.0 x 3.0 x 2.4	3

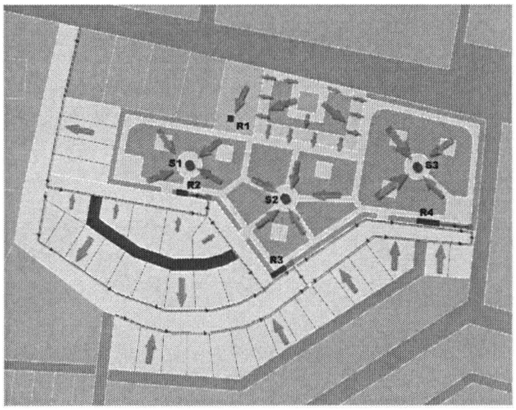


Figure: 6.47

Location of Water Storage structures (●), Recharge structures (■) and Desilting chambers (■)

Interventions:

Intervention	Cost (INR)
Storage structures (21 m^3 ferro-cement cylindrical tanks - 3 nos) including excavation and foundation	75600,
Installing submersible pumps in the storage structures	12,000
Re-grading the catchment areas concavely, sloping towards the storage structures where installed.	615,000
Widening and laying additional pathways	630,000
Construction of cast in-situ desilting chambers (3 nos)	126,750
Connecting storage structures and silt traps to recharge structures through PVC pipes	46,500
Widening and constructing additional recharge structures wherever necessary.	1,018,000
Adjusting open drainage channels slope towards the recharge structures in the green spaces.	22,500

Irrigation Demand and Cost savings:

Irrigation land (maintained green + planters)	9934 m^2
Current irrigation demand @ average 6L/m^2/day during winter and rainy season	59,600L/day or 59.6 m^3/day
Electricity consumption for groundwater extraction @ 0.4Kwh /m^3/m of extraction considering depth of groundwater at 40 m bgl.	954 Kwh/day
Cost of water extraction @ Rs 5.0/Kwh (excluding cost of equipment, borewells and piping)	Rs 4770/day
Minimum water stored annually, assuming it only rains 2.5 mm on each of the 27 rainy days.	493 m^3
Minimum electricity cost saving annually to the government.	Rs. 39,440
Maximum electricity cost saving annually to the government with maximum storage	Rs. 136,000

Based on the runoff coefficients and areas of each surface type, total runoff from this study area is calculated (Appendix B) giving the total volume of water which is available for recharge and/or localized storage for irrigation purposes.

Annual Water Gain: 11,364.2 m^3

Scenario 2: Neighbourbood **Green Space C**

Area Analysis / physical characteristics:

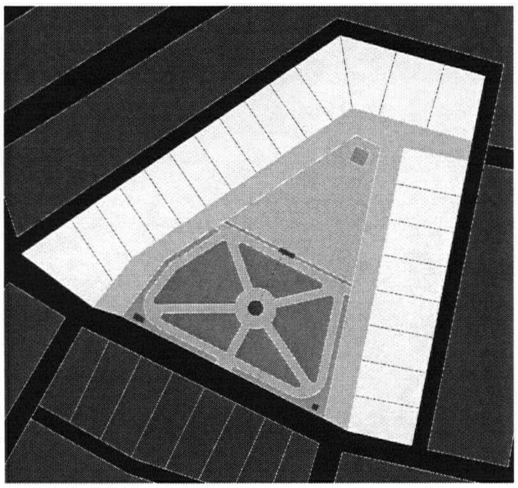


Figure: 6.48

Surface Area Analysis including the extended catchment area

The green space is as modified in scenario 1 (to be considered as Phase 1) with approximately 20% area under canopy cover. The southern edge is a primary street with covered stormwater drain and acting as a divide to the development on the other side of the street. Other sides are medium sized multi-family housing draining rainwater in the open drains in the streets surrounding the green space. The water flow does not require any modifications to the drainage channels except stopping the water flow from entering the covered stormwater drain in the primary street and diverting it to the recharging structures (Fig. 6.48). Extended catchment boundaries are shown in figure 6.49. Suggested adjustments to the slopes is shown in figure 6.50 along with the recommended location of the recharge structures, storage structures and desilting chambers.

	Description	Area (m^2)	Runoff Coefficient
	Paved pathways - stone/brick pavers	1,157	0.85
	Maintained Green with slope < 2%	1,744	0.35
	Bare or sparse plant cover, slope < 2% (Play area)	1485	0.4
	Planters - loose soil	506	0.3
	Built area in the green space	36	0.9
	Residential built area	6,982	0.85
	Street area - asphalt, concrete	2,338	0.75

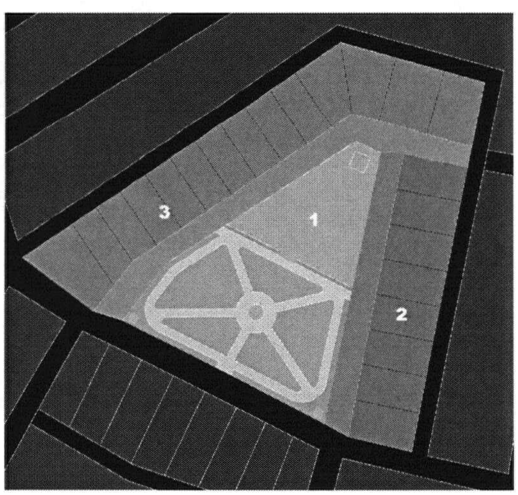


Figure: 6.49

Extended catchment Boundaries

Additional Storage and Recharge Structures:

Type	Size - LxBxD (m)	Nos.
S - Cylindrical storage structures	2.4 m dia, 3.0 m depth	1
R1 - Recharge trench (2 borewell)	12.0 x 2.0 x 2.0	1
R2 - Recharge trench (1 borewell)	7.0 x 2.0 x 3.5	1
R3 - Recharge trench (2 borewells)	14.0 x 2.0 x 3.5	1
Desilting chambers	3.0 x 3.0 x 2.4	2

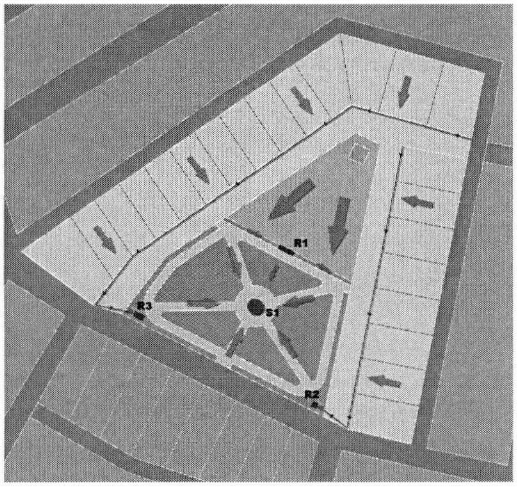


Figure: 6.50

Location of Water Storage structures (●), Recharge structures (■) and Desilting chambers (■)

Interventions:

Intervention	Cost (INR)
Storage structures (13.5 m^3 ferro-cement cylindrical tanks - 1 nos) including excavation and foundation	17,800
Installing submersible pumps in the storage structures	4,000
Re-grading the catchment areas concavely, sloping towards the storage structures where installed.	127,500
Widening and laying additional pathways	112,500
Construction of cast in-situ desilting chambers (2 nos)	81,900
Connecting storage structures and silt traps to recharge structures through PVC pipes	18,600
Widening and constructing additional recharge structures wherever necessary.	440,150
Connecting the open drainage channels on the street to the recharge structures in the green space.	15,000

Irrigation Demand and Cost savings:

Irrigation land (maintained green + planters)	2250 m^2
Current irrigation demand @ average 6L/m^2/day during winter and rainy season	13,500L/day or 13.5 m^3/day
Electricity consumption for groundwater extraction @ 0.4Kwh /m^3/m of extraction considering depth of groundwater at 40 m bgl.	216 Kwh/day
Cost of water extraction @ Rs 5.0/Kwh (excluding cost of equipment, borewells and piping)	Rs 1080/day
Minimum water stored annually, assuming it only rains 2.5 mm on each of the 27 rainy days.	110 m^3
Minimum electricity cost saving annually to the government.	Rs. 8,800
Maximum electricity cost saving annually to the government with maximum storage	Rs. 29,200

Based on the runoff coefficients and areas of each surface type, total runoff from this study area is calculated (Appendix B) giving the total volume of water which is available for recharge and/or localized storage for irrigation purposes.

Annual Water Gain: 4,955.6 m^3

Scenario 2: Neighbourbood Green Space D

Area Analysis / physical characteristics:

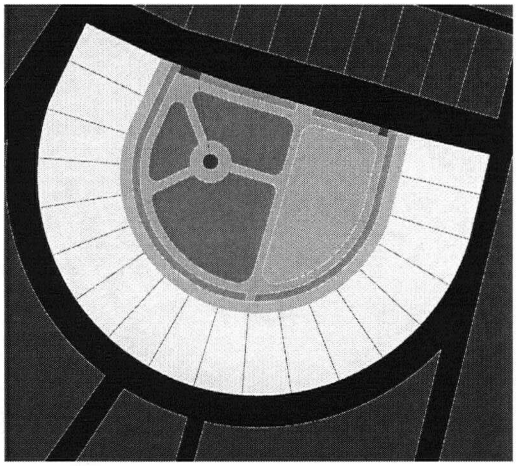


Figure: 6.51

Surface Area Analysis including the extended catchment area

The green space is as modified in scenario 1 (to be considered as Phase 1) with approximately 20% area under canopy cover. The Northern edge is a primary street with covered stormwater drain and acting as a divide to the development on the other side of the street. Other sides are medium sized multi-family housing draining rainwater in the open drains in the streets surrounding the green space. The water flow does not require any modifications to the drainage channels except stopping the water flow from entering the covered stormwater drain in the primary street and diverting it to the recharging structures (Fig. 6.51). Extended catchment boundaries are shown in figure 6.52. Suggested adjustments to the slopes is shown in figure 6.53 along with the recommended location of the recharge structures, storage structures and desilting chambers.

	Description	Area (m^2)	Runoff Coefficient
	Paved pathways - stone/brick pavers	1,415	0.85
	Maintained Green with slope < 2%	2,295	0.35
	Bare or sparse plant cover, slope < 2% (Play area)	1,478	0.4
	Planters - loose soil	819	0.3
	Residential built area	8,111	0.85
	Street area - asphalt, concrete	959	0.75

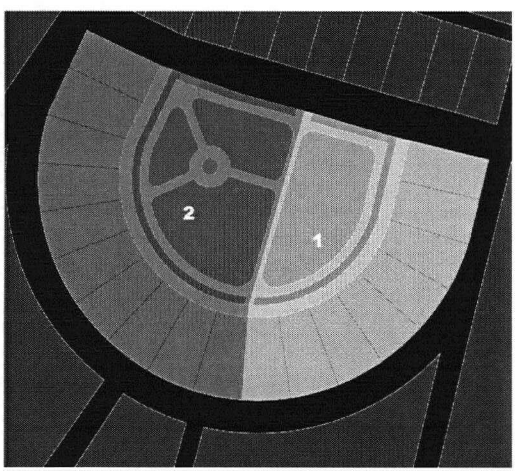


Figure: 6.52

Extended catchment boundaries

Additional Storage and Recharge Structures:

Type	Size - LxBxD (m)	Nos.
S - Cylindrical storage structures	2.8 m dia, 3.0 m depth	1
R1 - Recharge trench (2 borewell)	12.0 x 2.0 x 3.5	1
R2 - Recharge trench (2 borewell)	17.0 x 2.0 x 3.5	1
Desilting chambers	3.0 x 3.0 x 2.4	2

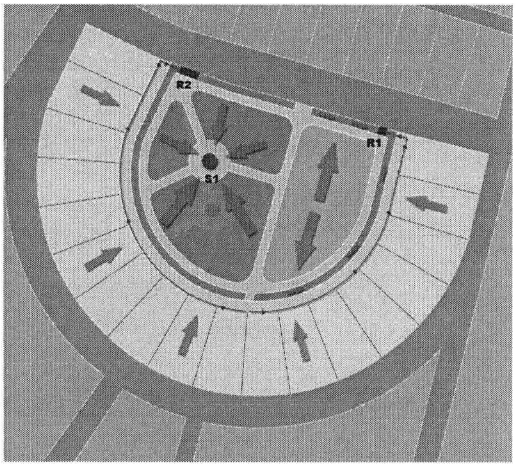


Figure: 6.53

Location of Water Storage structures (●), Recharge structures (■) and Desilting chambers (■)

Interventions:

Intervention	Cost (INR)
Storage structures (18.5 m^3 ferro-cement cylindrical tanks - 1 nos) including excavation and foundation	21,000
Installing submersible pumps in the storage structures	4,000
Re-grading the catchment areas concavely, sloping towards the storage structures where installed.	172,500
Widening and laying additional pathways	101,250
Construction of cast in-situ desilting chambers (2 nos)	81,900
Connecting storage structures and silt traps to recharge structures through PVC pipes	15,500
Widening and constructing additional recharge structures wherever necessary.	443,800
Connecting the open drainage channels on the street to the recharge structures in the green space.	11,250

Irrigation Demand and Cost savings:

Irrigation land (maintained green + planters)	3114 m^2
Current irrigation demand @ average 6L/m^2/day during winter and rainy season	18,680L/day or 18.68 m^3/day
Electricity consumption for groundwater extraction @ 0.4Kwh /m^3/m of extraction considering depth of groundwater at 40 m bgl.	299 Kwh/day
Cost of water extraction @ Rs 5.0/Kwh (excluding cost of equipment, borewells and piping)	Rs 1495/day
Minimum water stored annually, assuming it only rains 2.5 mm on each of the 27 rainy days.	125 m^3
Minimum electricity cost saving annually to the government.	Rs. 10,000
Maximum electricity cost saving annually to the government with maximum storage	Rs. 40,000

Based on the runoff coefficients and areas of each surface type, total runoff from this study area is calculated (Appendix B) giving the total volume of water which is available for recharge and/or localized storage for irrigation purposes.

Annual Water Gain: 5,142.5 m^3

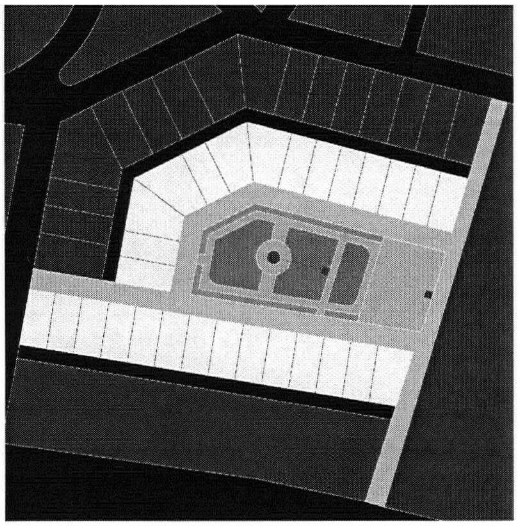


Figure: 6.54

Surface Area Analysis including the extended catchment area

Scenario 2: Neighbourbood Green Space E

Area Analysis / physical characteristics:

The green space is as modified in scenario 1 (to be considered as Phase 1) with approximately 20% area under canopy cover. The Eastern edge has a large bounded Government office complex which must initiate its own integrated rainwater harvesting systems and therefore are not included in the study area catchment. Other sides are medium sized multi-family housing draining rainwater in the open drains in the streets surrounding the green space (Fig. 6.54). Extended catchment boundaries are shown in figure 6.55. Suggested adjustments to the slopes is shown in figure 6.56 along with the recommended location of the recharge structures, storage structures and desilting chambers.

	Description	Area (m^2)	Runoff Coefficient
	Paved pathways - stone/brick pavers	977	0.85
	Maintained Green with slope < 2%	1,483	0.35
	Bare or sparse plant cover, slope < 2% (Play area)	1,031	0.4
	Planters - loose soil	513	0.3
	Residential built area	8,249	0.85
	Street area - asphalt, concrete	4,142	0.75

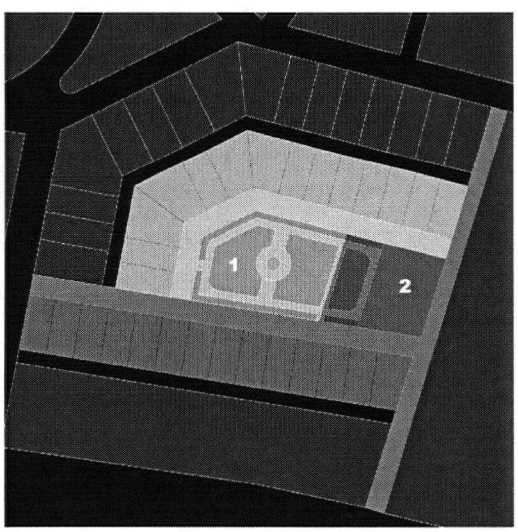


Figure: 6.55

Extended Catchment boundaries

Additional Storage and Recharge Structures:

Type	Size - LxBxD (m)	Nos.
S - Cylindrical storage structures	2.4 m dia, 3.0 m depth	1
R1 - Recharge trench (2 borewell)	16.0 x 2.0 x 3.5	1
R2 - Recharge trench (2 borewell)	19.0 x 2.0 x 3.5	1
Desilting chambers	3.0 x 3.0 x 2.4	2

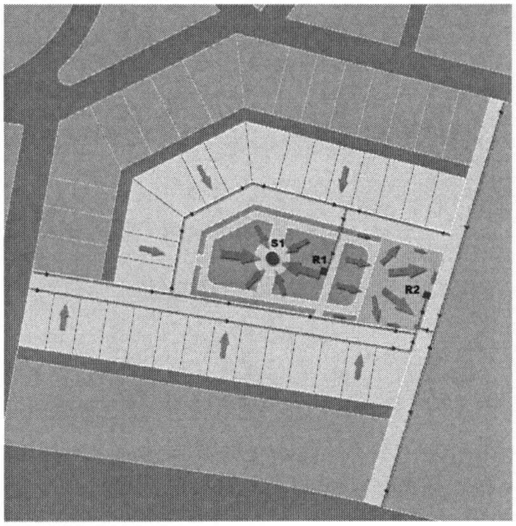


Figure: 6.56

Location of Water Storage structures (●), Recharge structures (■) and Desilting chambers (■)

Interventions:

Intervention	Cost (INR)
Storage structures (13.5 m^3 ferro-cement cylindrical tanks - 1 nos) including excavation and foundation	17,800
Installing submersible pumps in the storage structures	4,000
Re-grading the catchment areas concavely, sloping towards the storage structures where installed.	112,500
Widening and laying additional pathways	67,500
Construction of cast in-situ desilting chambers (2 nos)	81,900
Connecting storage structures and silt traps to recharge structures through PVC pipes	18,600
Widening and constructing additional recharge structures wherever necessary.	525,750
Adjusting open drainage channels slope towards the recharge structures in the green spaces.	131,250

Irrigation Demand and Cost savings:

Irrigation land (maintained green + planters)	1996 m^2
Current irrigation demand @ average 6L/m^2/day during winter and rainy season	11980L/day or 11.98 m^3/day
Electricity consumption for groundwater extraction @ 0.4Kwh /m^3/m of extraction considering depth of groundwater at 40 m bgl.	192 Kwh/day
Cost of water extraction @ Rs 5.0/Kwh (excluding cost of equipment, borewells and piping)	Rs 960/day
Minimum water stored annually, assuming it only rains 2.5 mm on each of the 27 rainy days.	78 m^3
Minimum electricity cost saving annually to the government.	Rs. 6,240
Maximum electricity cost saving annually to the government with maximum storage	Rs. 29,200

Based on the runoff coefficients and areas of each surface type, total runoff from this study area is calculated (Appendix B) giving the total volume of water which is available for recharge and/or localized storage for irrigation purposes.

Annual Water Gain: 5,958.3 m^3

Summary - Scenario 2

Total green space area, water gain and capital cost for scenario 2 is summarized below in figure 6.57. The water gain is equated as cost saving to the government and/or local residents, [for assessing the financial feasibility], by comparing it with the amount otherwise paid to purchase water from private water tankers at the rate of Rs 100/m^3 as per details provided by Delhi Water tankers Association.

Total Area (m2)	**Water Gain** (m3)	**Capital Cost** (Indian Rupees-Rs.)	**Capital Cost** ($ Cdn.)	**Water gain equated as cost savings** (Indian Rupees-Rs.)	**Water gain equated as cost savings** ($Cdn.)
190,460	63,830	10,406,150	260,154	6,383,000	159,575

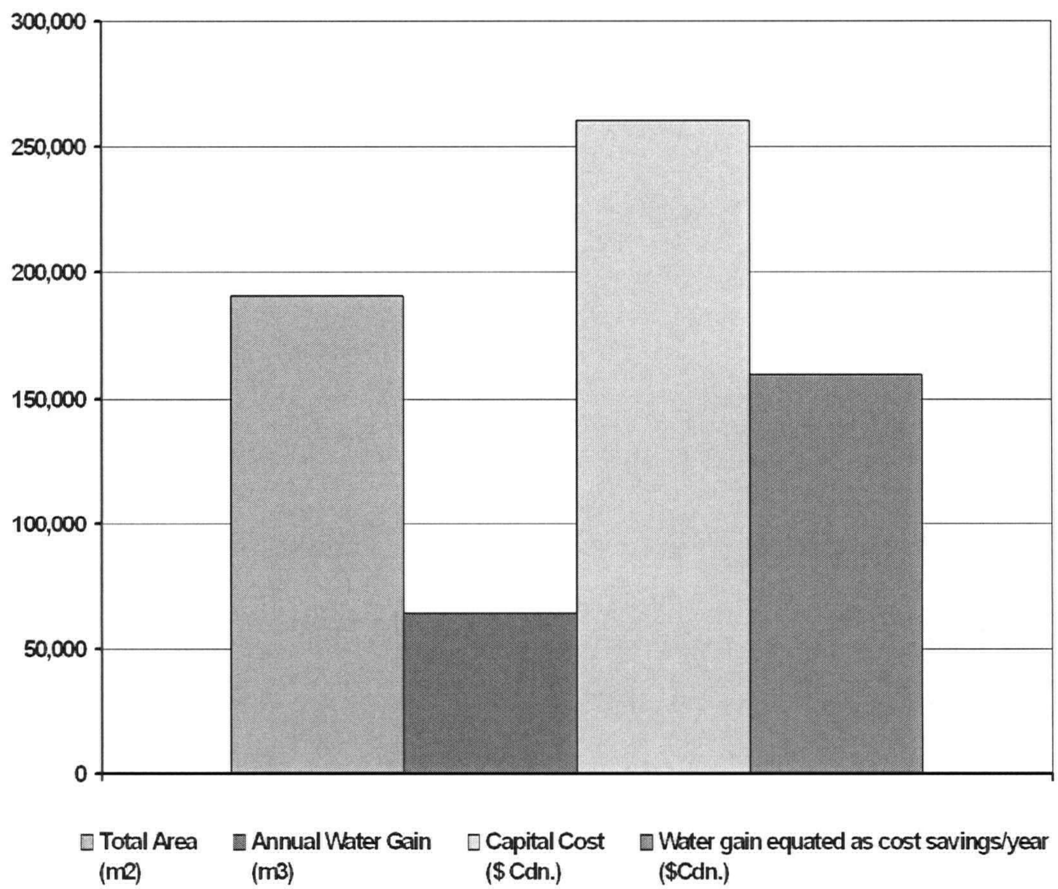


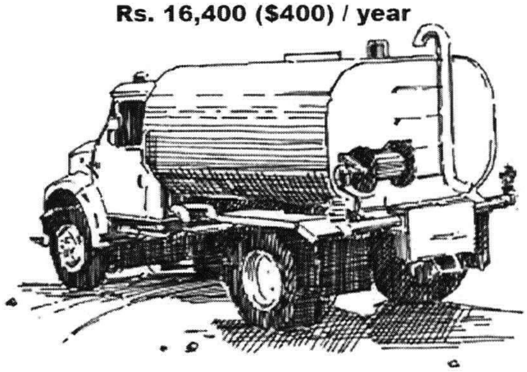
Figure 6.57: Bar Graph showing Scenario 2 Summary

Direct Cost Benefits to the Local Neighbouhood Residents in the Study Area (Scenario 1 & 2)

Current water demand-supply gap in the Study Area (water stressed MPD urban zone 'F')	-340 lpcd (litres/capita/day)
Water deficit for each household in a month [considering an average household of 4 people]	~ 41000 litres
Cost of meeting water gap through private tankers	Rs 4100 per month @ Rs 100/1000 litres as per details provided by Delhi Water tankers Association.
Total cost to a household during four summer months	~ Rs. 16,400
Cost of Constructing or deepening a borewell	Rs 5000 - 30,000

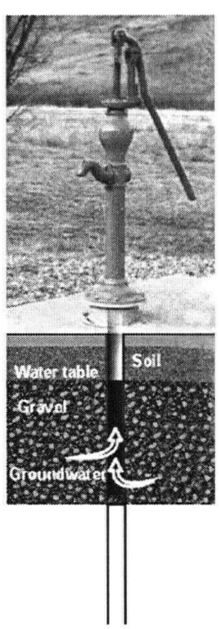
S p e n d i n g s

Rs. 16,400 ($400) / year



OR

Rs. 20,000 ($500) / year (avg.)



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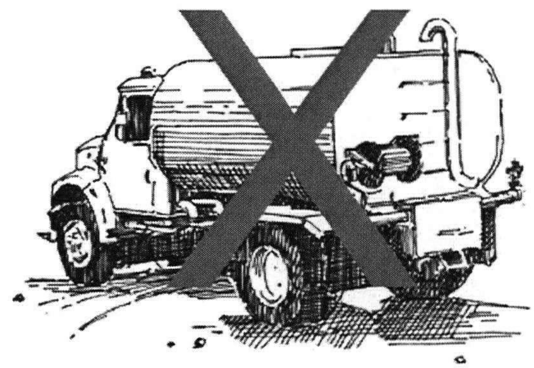


No drop in water level, therefore **no cost for deepening borewell**, rather 1 m rise in water level results in **electricity savings of Rs 250/year**

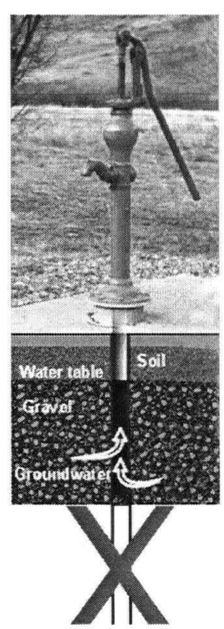


Figure 6.58: Cost benefits to local neighbourhood residents.

6.4.3 Scenario 3 - Regional Scale with minimum intervention

Area Analysis / physical characteristics: Regional Green Space - Hauz Khas District Park

The interventions in this scenario are limited to the boundaries of the district park [in the regional green space] which falls under the jurisdiction of Delhi Development Authority and is well maintained by a full time maintenance staff making it feasible for implementing the interventions at reasonable costs. The district park includes a large lake, duck pond, maintained green areas, natural woodland areas, plant nurseries and paved walkways as shown below in figure 6.59. Each area has a distinct runoff coefficient (listed below) based on its characteristics which is used to calculate the total runoff from each area to give the total annual rainwater that can be harvested for recharge (for detailed runoff calculations refer Appendix B).

Figure 6.59: Regional Green Space - Scenario 3 - Surface Area Analysis

	Area Description	Area (m²)	Runoff Coefficient
	Paved pathways - stone/brick pavers	79,340	0.85
	Maintained Green with slope < 2%	236,375	0.3
	Bare or sparse plant cover, slope < 2% (Play areas)	25,490	0.35
	Woodland / Forest	534,345	0.45
	Planters - loose soil	22,055	0.1
	Built area	4720	0.9
	Water bodies	62,840	1.0
	Street / parking - asphalt, concrete	7,905	0.75

Figure 6.60: Regional Green Space - Scenario 3 - Existing Slope Analysis

Figure 6.60 above shows existing slopes based on aerial photographs, topographic maps and physical site survey. Based on this slope analysis and water divide lines, the site is then divided into mini catchments (Fig. 6.61) to maximize runoff and minimize initial water losses. Runoff from each catchment is then computed (Appendix C) which is used to establish the number and size of recharge structures. Strategic location of recharge structures is shown in figure 6.62 based on natural water flow. Minor adjustments to the site grading are considered for this scenario to improve the water yield without inflicting high costs (for cost details refer Appendix D).

Approximate cost of the interventions:	**Rs. 18,043,000**
Annual Water Gain:	**193,937.5 m^3**

Figure 6.61: Regional Green Space - Scenario 3 - Catchment area boundaries

Recharge Structures:

Type	Size - LxBxD (m)	Nos.
R1 - Recharge trench (3 borewells -200mm dia. 25m deep)	30.0 x 2.0 x 3.5	21
R2 - Recharge shaft (3 borewells -200mm dia. 25m deep)	25.0 x 2.0 x 3.5	11
R3 - Recharge trench (1 borewell -200mm dia. 25m deep)	3.0 x 3.0 x 2.0	18
R4 - Recharge trench (2 borewells -200mm dia. 25m deep)	15.0 x 2.0 x 3.5	4
R5 - Recharge trench (2 borewells -200mm dia. 25m deep)	20.0 x 2.0 x 3.5	5
R6 - Recharge trench (1 borewell -200mm dia. 25m deep)	8.0 x 2.0 x 3.5	3
R7 - Recharge trench (1 borewell -200mm dia. 25m deep)	4.0 x 2.0 x 3.5	4

Figure 6.62: Regional Green Space - Scenario 3 - Location of recharge structures (■) and revised slopes.

Summary - Scenario 3

Total regional green space area, water gain and capital cost for scenario 3 is summarized below in figure 6.63. The water gain is equated as cost saving to the government and/or local residents, [for assessing the financial feasibility], by comparing it with the amount otherwise paid to purchase water from private water tankers at the rate of Rs 100/m^3 as per details provided by Delhi Water tankers Association.

Total Area (m2)	**Water Gain** (m3)	**Capital Cost** (Indian Rupees-Rs.)	**Capital Cost** ($ Cdn.)	**Water gain equated as cost savings** (Indian Rupees-Rs.)	**Water gain equated as cost savings** ($Cdn.)
973,070	193,938	18,043,050	451,076	19,393,800	484,845

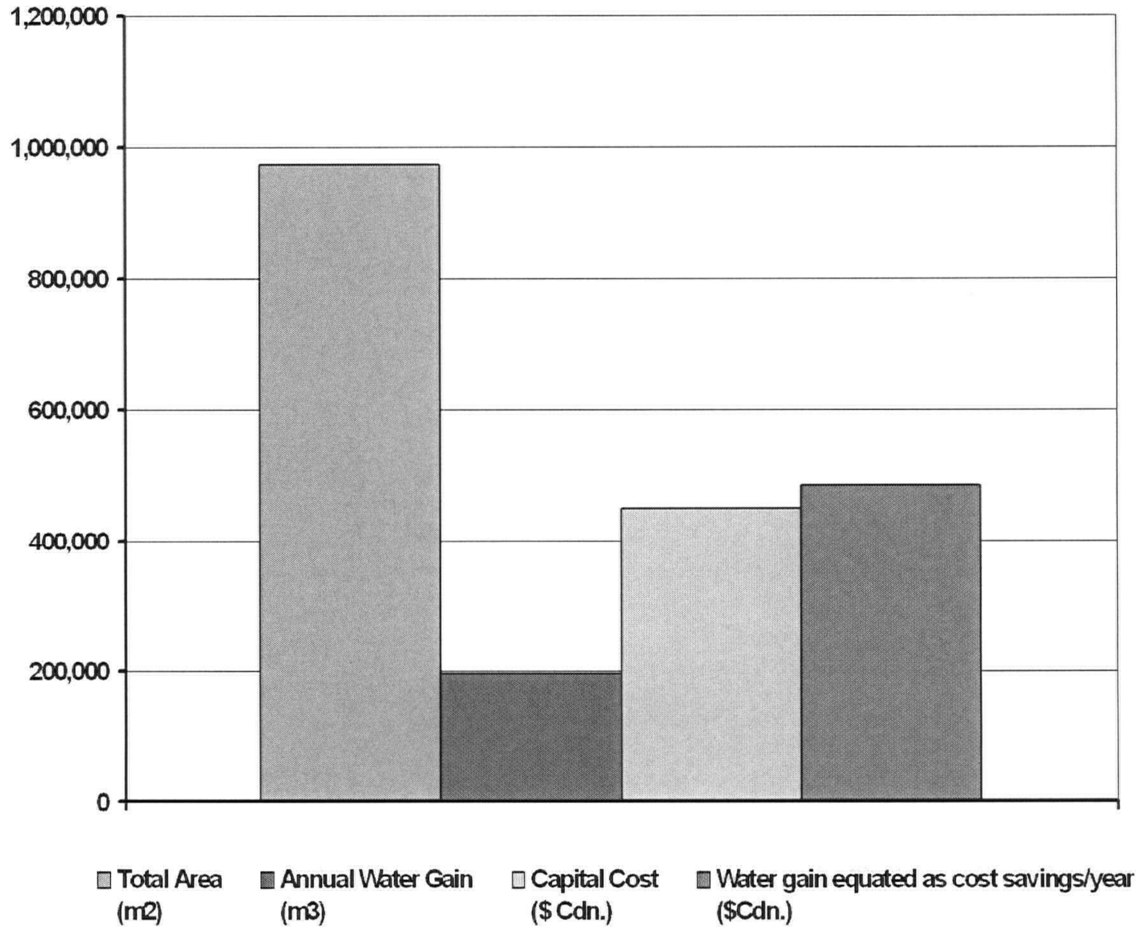


Figure 6.63: Bar Graph showing Scenario 3 Summary

6.4.4 Scenario 4 - Regional scale with maximum intervention

Area Analysis / physical characteristics: Regional Green Space - Hauz Khas District Park

The interventions in this scenario extend to the entire regional green space including reserved forest land under the jurisdiction of Ministry of Environment and Forestry and the sports fields along the western edge (Fig. 6.64). Figure 6.64 also shows different surface areas with individual characteristics. There are some dry stream channels in the forest reserve which become active during the rainy season. Each surface area has a distinct runoff coefficient (listed below) based on its characteristics which is used to calculate the total runoff from each area to give the total annual rainwater that can be harvested for recharge (for detailed runoff calculations refer Appendix B).

Figure 6.64: Regional Green Space - Scenario 4 - Surface Area Analysis

	Description	Area (m^2)	Runoff Coefficient
	Paved pathways - stone/brick pavers	126,615	0.85
	Maintained Green with slope < 2%	189,100	0.35
	Bare or sparse plant cover, slope < 2% (Play areas)	93,830	0.4
	Woodland / Forest	899, 925	0.45
	Planters - loose soil	14,300	0.3
	Built area	23,000	0.9
	Water bodies	62,840	1.0
	Street / parking - asphalt, concrete	13,890	0.75

Figure 6.65: Regional Green Space - Scenario 4 - Existing Slope Analysis

Figure 6.65 above shows existing slopes within the study area. Based on this slope analysis and water divide lines, the site is then divided into mini catchments (Fig. 6.66) to minimize initial water losses and maximize runoff. Runoff from each catchment is then computed (Appendix C) which is used to establish the number and size of recharge structures. Strategic location of recharge structures and storage structures is shown in figure 6.67 based on natural water flow. Check dams are proposed at the mouth of the dry stream channels where they meet the stormwater drain to capture the rainwater before it merges with the polluted water of the stormwater drainage channels. Optimum adjustments to the site grading are considered for this scenario including re-designing the layout of the maintained green areas to maximize the water yield.

Annual Water Gain: 305,220.6 m^3

Figure 6.66: Regional Green Space - Scenario 4 - Catchment Area Boundaries

Storage and Recharge Structures:

Type	Size - LxBxD (m)	Nos.
S - Cylindrical storage structures	3 m dia, 3m depth	18
	2.4 m dia, 3m depth	4
R1 - Recharge trench (3 borewells -200mm dia. 25m deep)	30.0 x 2.0 x 3.5	21
R2 - Recharge shaft (3 borewells -200mm dia. 25m deep)	25.0 x 2.0 x 3.5	27
R3 - Recharge trench (1 borewell -200mm dia. 25m deep)	3.0 x 3.0 x 2.0	18
R4 - Recharge trench (2 borewells -200mm dia. 25m deep)	15.0 x 2.0 x 3.5	11
R5 - Recharge trench (2 borewells -200mm dia. 25m deep)	20.0 x 2.0 x 3.5	11
R6 - Recharge trench (1 borewell -200mm dia. 25m deep)	8.0 x 2.0 x 3.5	8
R7 - Recharge trench (1 borewell -200mm dia. 25m deep)	4.0 x 2.0 x 3.5	4

Figure 6.67: Regional Green Space - Scenario 4 - Location of Water Storage structures (●) and Recharge structures (■)

Interventions:

Intervention	Cost (INR)
Storage structures (21 m^3 ferro-cement cylindrical tanks - 18 nos) including excavation and foundations	453,600
Storage structures (13.5 m^3 ferro-cement cylindrical tanks - 4 nos) including excavation and foundations	71,200
Installing submersible pumps in each storage structure (total 22 nos.)	88,000
Re-grading the catchment areas, sloping towards the storage structures where installed.	5,370,000
Widening, re-structuring and laying additional pathways	10,125,000
Connecting storage structures to recharge structures through PVC pipes	102,300
Constructing drainage channels along catchment boundaries directing the flow of water towards the recharge structures wherever necessary.	1,350,000
Constructing check dams in seasonal stream channels - 5 nos. (~50m wide x 1.5 m high)	125,000
RCC walls to divide the lake into three compartments. (2 walls, average 165m long, 0.3 m thick and 2.2m high)	1,137,400
Widening and constructing additional recharge structures wherever necessary.	27,408,300
Total cost of the interventions:	Rs. 46,230,800

Irrigation Demand and Cost savings:

Irrigation land (perennially maintained green + planters)	71,600 m^2
Current irrigation demand @ average 6L/m^2/day during winter and rainy season	429,600L/day or 429.6 m^3/day
Electricity consumption for groundwater extraction @ 0.4Kwh /m^3/m of extraction considering depth of groundwater at 40 m bgl.	6874 Kwh/day
Cost of water extraction @ Rs 5.0/Kwh (excluding cost of equipment, borewells and piping)	Rs 34,370/day
Minimum water stored annually, assuming it only rains 2.5 mm on each of the 27 rainy days.	3150 m^3
Minimum electricity cost saving annually to the government.	Rs. 252,000
Maximum electricity cost saving annually to the government with maximum storage	Rs. 933,000

Table 6.3: Evaporation Loss and control analysis for the Lake in Regional Green Space

Area of the lake	58515 m^2
Evaporation rate for open reservoirs in Delhi during the monsoon months of July August and September [67]	5mm/day
Evaporation loss per day for the entire lake	292 m^3
Evaporation loss savings possible by application of water evaporation retardant (WER) film over the surface of water per day	upto 50% ~ 146 m^3
Unit cost of the WER film	Rs. 500/kg
Total quantity of WER film required @ 50mg/m^2/day [68]	~3 kg/day
Total cost of WER film per day (annual recurring cost)	Rs 1500/day
If the saved water is used for irrigation, the cost savings to the government in electricity to pump 146m^3 of groundwater per day	146 x 0.4 x 40 x 5 = Rs 11680 / day
If the saved water is allowed to recharge, the cost savings to the government to purchase water through private water tankers @ Rs 100/m^3	146 x 100 = 14600/day
Average evaporation loss savings possible over a period of 3 months by dividing the lake into three compartments.	~ 35% = 9200m^3 (over 3 months)
Approximate one time cost of RCC walls to divide the lake into three compartments. [69] (2 walls, average 165m long, 0.3 m thick and 2.2m high)	Rs. 1,137,400 @ 5170/m^3
If the saved water is used for irrigation, the cost savings to the government in electricity to pump 9200m^3 of groundwater for 3 months period	9200 x 0.4 x 40 x 5 = Rs 736,000
If the saved water is allowed to recharge, the cost savings to the government to purchase water through private water tankers @ Rs 100/m^3	Rs. 920,000

"Savings from the prevention of water loss due to evaporation have been reported to be as high as 0.70 million cubic metres of water (equivalent to one month's water supply for Jaipur City, India) using Cetyl and Stearyl Alcohol as an evaporation retardant." [70]

[67] Only the monsoon months are considered for evaporation losses as within this time the harvested rainwater in the lake will be recharge to the ground through recharge structures constructed at the bottom of the lake.

[68] Subramanya, K., Engineering Hydrology, Tata McGraw Hill publishing company limited, New Delhi, 2000.

[69] A detailed stuctural analysis is needed to abtain a more accurate cost for the RCC partition walls.

[70] United Nations Environment Programme, Division of Technology, Industry, and Economics. March 2007. < http://www.unep.or.jp/ietc/publications/techpublications/techpub-8e/evapo.asp >

Summary - Scenario 4

Total green space area, water gain and capital cost for scenario 4 is summarized below in figure 6.68. The water gain is equated as cost saving to the government and/or local residents, [for assessing the financial feasibility], by comparing it with the amount otherwise paid to purchase water from private water tankers at the rate of Rs 100/m^3 as per details provided by Delhi Water tankers Association.

Total Area (m2)	**Water Gain** (m3)	**Capital Cost** (Indian Rupees-Rs.)	**Capital Cost** ($ Cdn.)	**Water gain equated as cost savings** (Indian Rupees-Rs.)	**Water gain equated as cost savings** ($Cdn.)
1,423,500	305,221	46,230,800	1,155,770	30,522,100	763,053

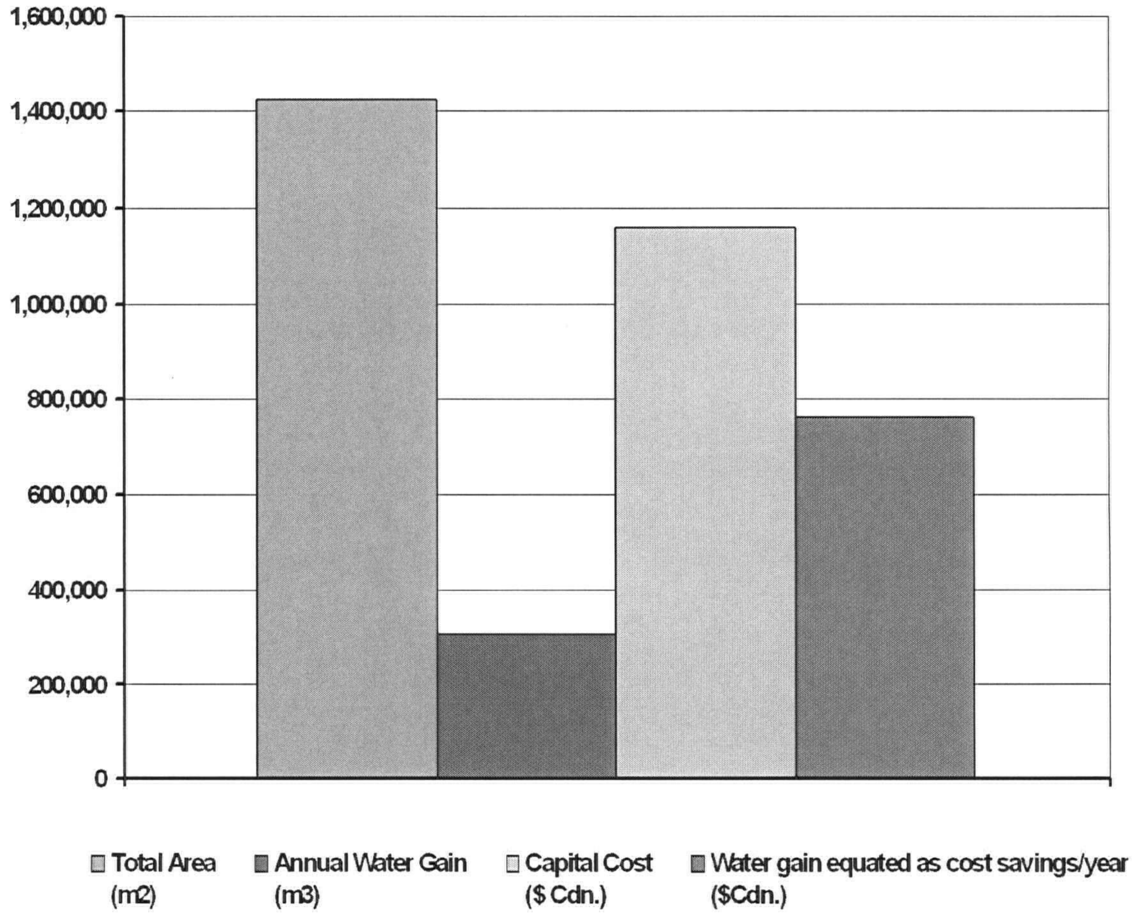


Figure 6.68: Bar Graph showing Scenario 4 Summary

6.5 Regional Water Gains

The regional water gain through public green spaces for the entire Delhi region is calculated based on the findings from the study areas analysis. The water gains and costs for different scenarios are pro-rated for the total neighbourhood and regional scale green areas of New Delhi as stated below.

Total Public Green Areas in Delhi [71]	-	8,722 Ha (87,220,000 m^2)
Neighbourhood green spaces	-	316 Ha (3,160,000 m^2)
Regional green spaces as District/Regional Parks	-	2,060 Ha (20,600,000 m^2)
Total Regional green spaces area (including Forest reserves/Zonal greens)	-	8,406 Ha (84,060,000 m^2)

	Total Area (m^2)	Annual Water Gain (m^3)	Capital Cost (Indian Rs.)	Capital Cost ($ Cdn.)	Water gain equated as cost savings (Indian Rs.)	Water gain equated as cost savings/year ($Cdn.)
Neighbourhood Green Spaces with minimum intervention	3,160,000	514,132	43,297,083	1,082,427	51,413,200	1,285,330
Neighbourhood Green Spaces with maximum intervention	8,420,000	2,821,845	460,042,964	11,501,074	282,184,500	7,054,613
Regional Green Spaces with minimum intervention	20,600,000	4,105,689	381,973,373	9,549,334	410,568,900	10,264,223
Regional Green Spaces with maximum intervention	84,060,000	18,023,800	2,730,004,249	68,250,106	1,802,380,000	45,059,500

[71] This does not include green areas under various specific gross land use categories and the unclassified and undeveloped green areas in the newly included peri-urban and rural zones as per MPD 2021.

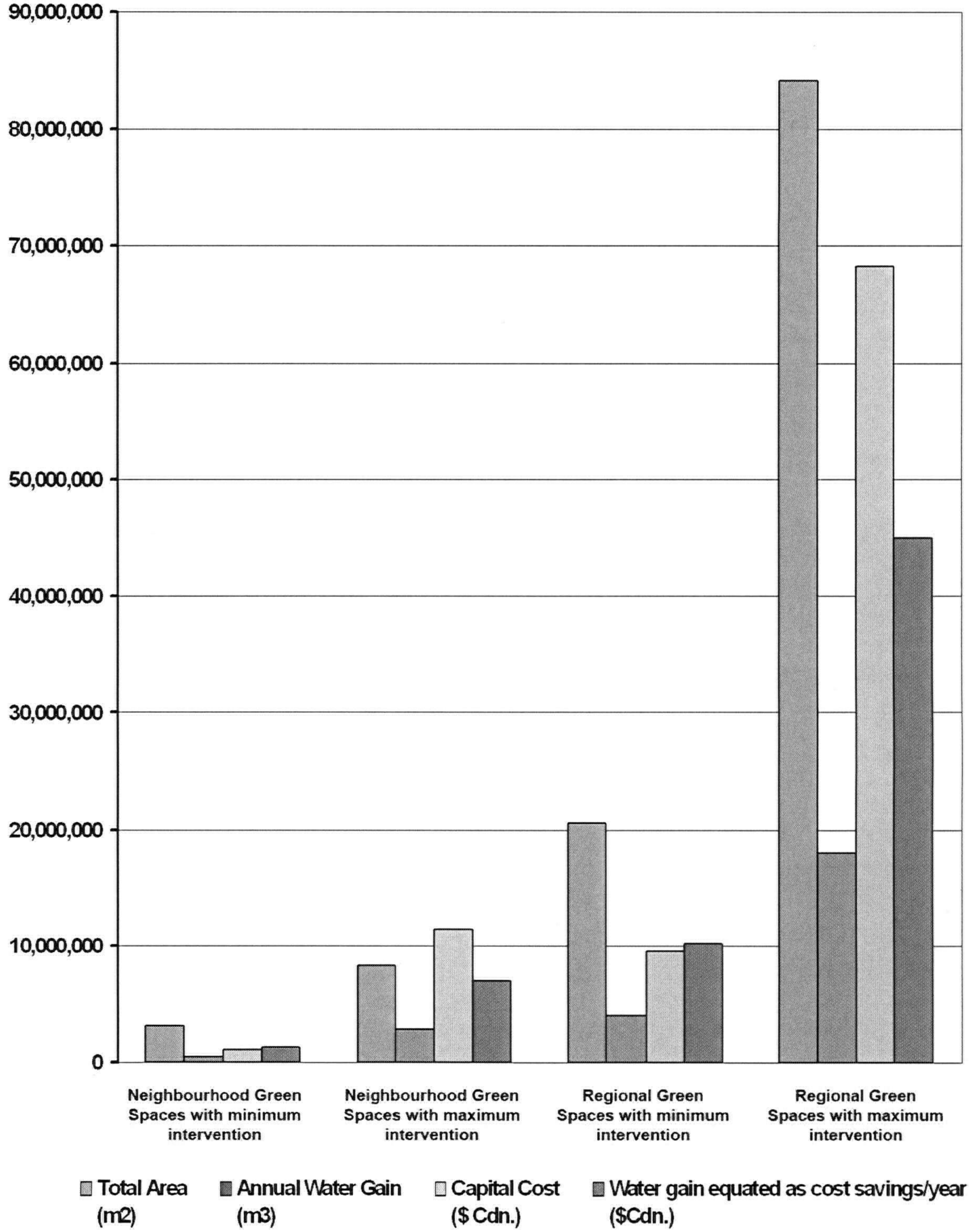


Figure 6.69: Bar Graph showing Regional summary of the four scenarios.

6.6 Chapter Summary

According to CGWB and DJB studies, National Capital Territory of Delhi with a current population of more than 15 million (13.8 million as per Census of India 2001) is facing a demand-Supply Gap of 236 MGD (323,025,000 m^3 annually). The percentage of this gap that can be bridged by various rainwater harvesting options and scenarios in public green spaces [which account for only 19% of the total urban land area] is shown below in table 6.4 and figure 6.70.

Table 6.4: Annual water gains through various scenarios at regional level:

	Annual Water Gain (MCM)	**Percentage of Demand-Supply Gap**
Scenario 1	0.5	0.2%
Scenario 2	2.8	0.9%
Scenario 3	4.1	1.3%
Scenario 4	18.0	5.6%
Scenario 1 & 3 - Minimum Interventions Total	4.6	1.5 %
Scenario 2 & 4 - Minimum Interventions Total	20.8	6.5%
Scenario 5 - Maximum Public Green Space Interventions combined with Surface Water body harvesting potential	~ 40.0	12.5 %

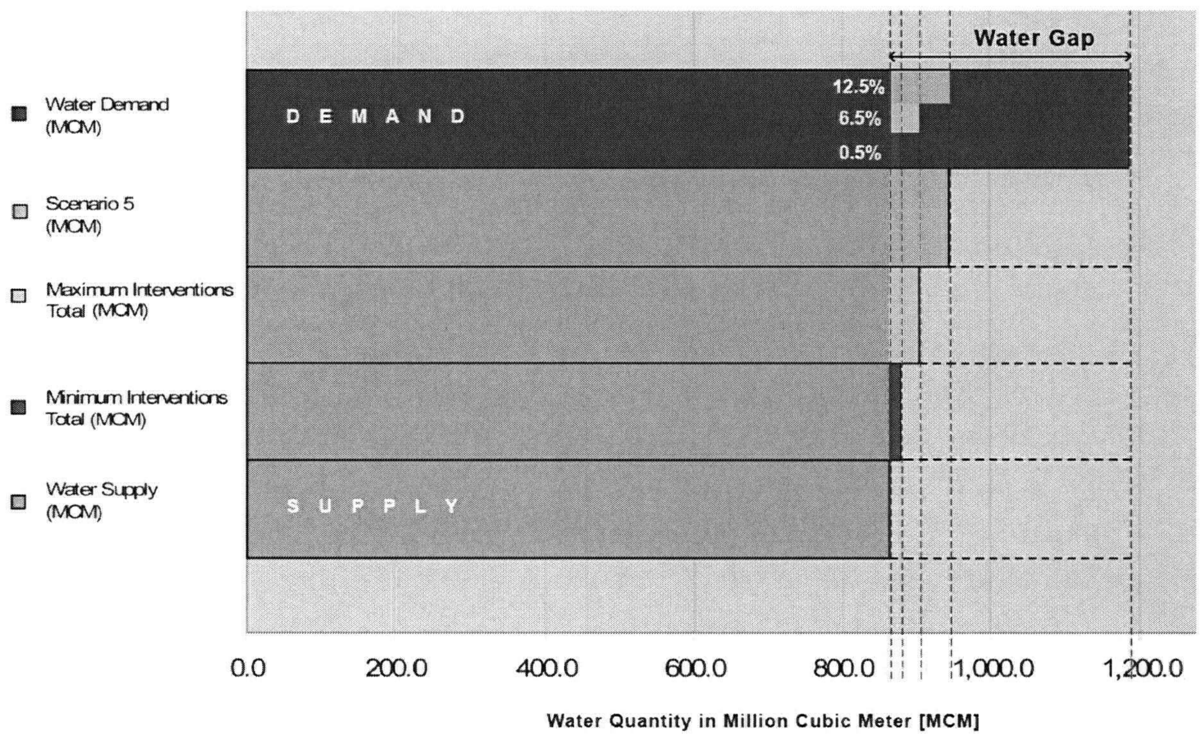


Figure 6.70: Percentage of water Gap bridged by different scenarios

Chapter - 7

Conclusions and Recommendations

This chapter outlines the summary of findings from this study - key observations from the literature review, conclusions based on the analysis and recommendations. The recommendations focus on the path ahead and things that need to be done in future to achieve maximum benefits from the findings of this research. Due to many limitations and scope of this study some key elements such as water conservation, management and maintenance issues are not studied in detail in this study but they remain an essential part of rainwater harvesting systems. They are briefly addresses in the recommendations so that future efforts can be focussed on these issues for a holistic and long lasting integration of these systems into the mainstream design, management and construction cycles.

Literature review shows us that fresh water is one of the most valuable natural resource on our planet. It is unevenly distributed across the globe and faces severe crisis due to growing population, increased needs, misuse and excessive urbanization. At global level, at least 1.1 billion of the world's people - about one in five - did not have access to safe water in 2000. At local level, Delhi is facing acute water crisis with a current demand supply gap of 236 MGD without accounting for the transmission losses, which are further estimated to be about 10-15% of the total water supply in Delhi, which is 630 MGD currently. The gap is expected to widen to 564 MGD by the year 2021. It is therefore absolutely essential to protect the water resources and use alternative methods of water procurement such as rainwater harvesting which is one of the most feasible, cost effective and easy to implement solution.

Harvested rainwater quantity and quality depends on the catchment area and urban green spaces, owing to their large surface areas, can provide good opportunity for collecting large quantities of rainwater as compared to other urban surfaces. They also offer opportunity for storing the rainwater either in existing large surface natural depressions or sub surface storage in aquifers through recharge. Storage is one of the most important component so that it can be re-used immediately or in the future and is difficult in current urban development patterns due to large volumes The urban green spaces can also be helpful in further improving the quality of harvested rainwater through natural processes.

7.1 Conclusions

Regional Action Plan and Analysis

- Action plan areas 'Re-1' and 'Re-2' falling in the urbanized zone 'F' and urban extension zone 'J' in Delhi are most water stressed and support artificial recharge of groundwater. All other action plan areas which fall in the peri-urban and rural MPD 2021 zonal classification support surface water storage through natural depressions and can be potentially used for storing large quantities of water for local use and even redistribution to other water stressed areas. Action plan area 'Re-5' can also undertake natural or artificial recharge to groundwater to improve the quality of groundwater in this area which is saline at all levels.
- If all the water bodies of Delhi are fully utilized for storing and recharging rainwater with proper watershed management approximately 12 MCM of rainwater can be harvested annually which can be maximized to 19 MCM with desilting and deepening them further by 1 m. They must therefore be augmented and integrated with the green space network of the city.

Rainwater Harvesting Potential in Public Green Spaces

- The study shows that rainwater harvesting alternatives in public green spaces in Delhi are both technically and financially feasible as they can help in harvesting substantial amount of water and the cost of construction can be amortized within three years when equating the total water yield with the current price paid by the Delhi Government to procure additional water from private sources. It is therefore, imperative that these alternatives be put into practice.
- The harvested rainwater can also be successfully stored locally through small underground water tanks to meet part irrigation needs of the perennially maintained green spaces before recharging (as demonstrated by Scenarios 2 & 4). The study finds that the cost of these storage structures can also be fully amortized within 3 years when equated with the current cost borne by the government to pump underground water [for irrigation] from depths of upto 40 mts.
- There are direct financial and environmental benefits to the neighbourhood residents and

therefore they can be involved in financing, constructing and maintaining the neighbourhood green spaces with the rainwater harvesting systems.

- If all the public green spaces in the Urban Zones are utilized for rainwater harvesting with minimum intervention, approximately 5 MCM of rainwater can be harvested annually at a cost of approximately 10 million $ (Cdn.) and it would help bridging the current water demand-supply gap by 1.5 percent (Fig. 7.1).
- If all the public green spaces in the Urban Zones are utilized for rainwater harvesting with maximum intervention, approximately 21 MCM of rainwater can be harvested annually at a cost of approximately 80 million $ (Cdn.) and it would help bridging the current water demand-supply gap by 6.5 percent (Fig. 7.1). This option also serves to improve the overall environment and usability of these green spaces for long term beneficial use.

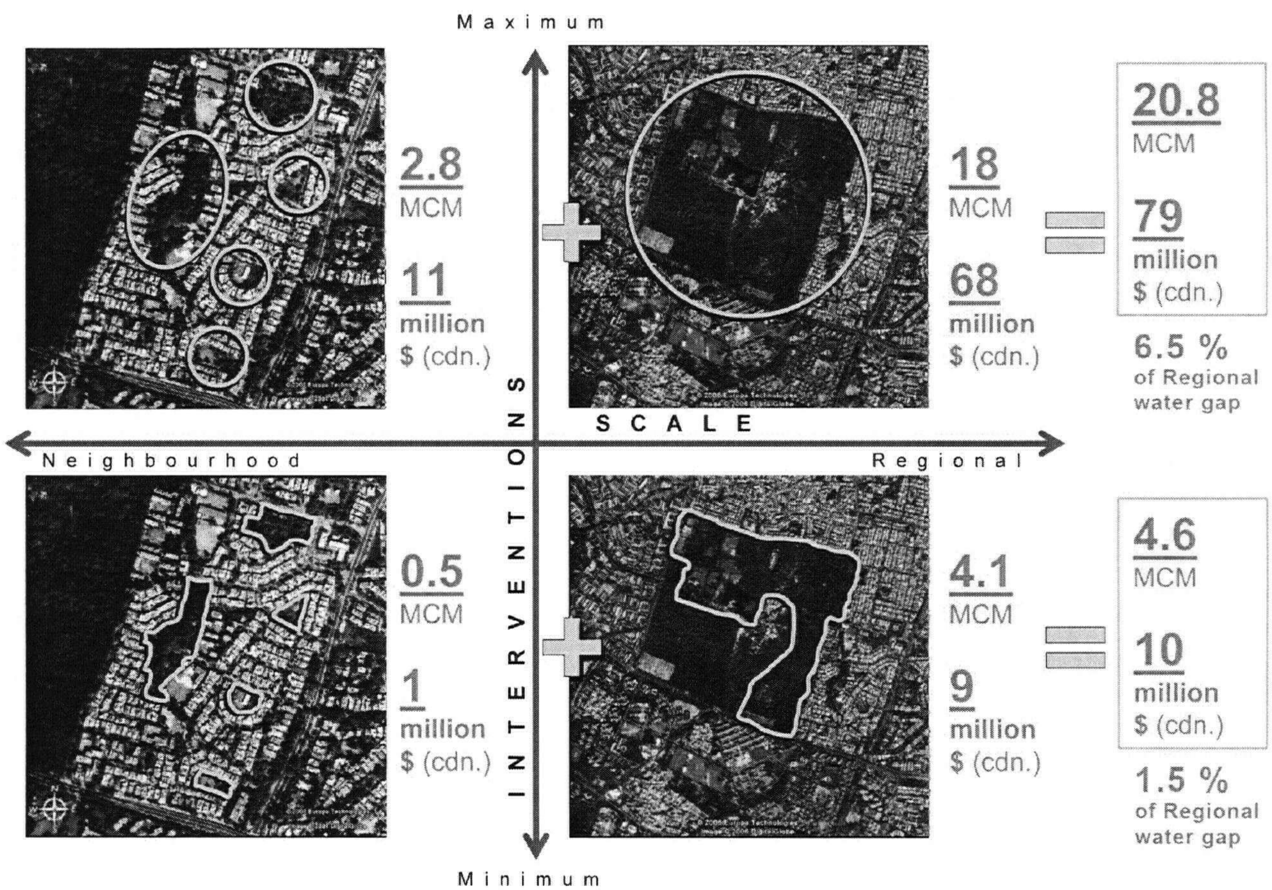


Figure 7.1: Percentage of water Gap bridged by different scenarios

- If the total water yield thorough the public green spaces is combined with the potential water harvesting capacity of the water bodies [with improvements], majority of which are currently in the newly formed rural MPD 2021 Zones with yet unclassified and undeveloped Public green spaces, approximately 40 MCM of rainwater can be harvested annually and it would help bridging the current water demand-supply gap by 12.5 percent.

This study focusses only on public green spaces and not on private and government building sites which also have large green spaces and therefore potential for rainwater harvesting.

Strategy for adopting rainwater harvesting alternatives

As demonstrated by the study, any action plan for adopting rainwater harvesting alternatives in public open green spaces must follow certain steps as mentioned below to ensure their long term success:

- Identifying the data gaps in base information and carry out necessary investigations using the various investigation techniques.
- Identifying the methods which may be suitable including consideration for traditional rainwater harvesting systems using base data on topography, rainfall, hydro-geology, aquifer situation and land source water availability.
- Identifying the most appropriate techniques of artificial recharge suitable at various sites/ locations with reference to the local conditions of the area.
- Determining the number of each type of artificial recharge structure needed to achieve the quantitative targets.
- Finalizing the design specifications for individual structures at different locations.
- Designing and modifying the catchment areas to bring the source water to the recharge site while maximizing the runoff.
- Evaluating the economic feasibility of the Artificial Recharge Project.

7.2 Recommendations

Recommendations for Immediate Future

- A pilot project must be undertaken as demonstrated in the study and monitored for water quality, quantity and maintenance issues.
- Post construction evaluation must be done to improve the design and/or the process.
- The Policies and Master Plan must aim at protecting and upgrading the green spaces, integrating them with the surface water bodies based upon a sound hydrological network.
- Keeping in view the acute water crisis in Delhi, it is necessary to promote the scheme of Rainwater Harvesting in a big way through various electronic/mass media measures.
- In order to make the proposed methods effective, the concerned authorities in Delhi (viz MCD, NDMC, DDA etc) should be made responsible for implementing the schemes by making a RWH structure compulsory in the public green spaces and also monitoring the implementation of the same by concerned agencies.
- Local residents must be involved in financing, constructing and maintaining these systems in green spaces of their neighbourhoods.

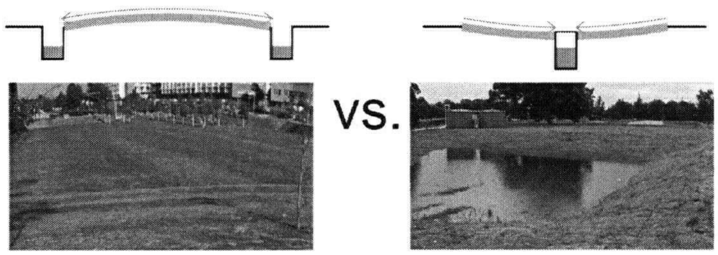
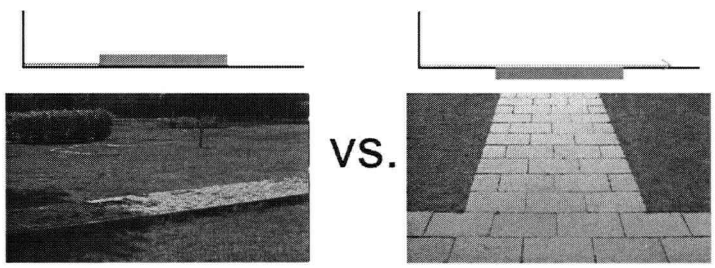
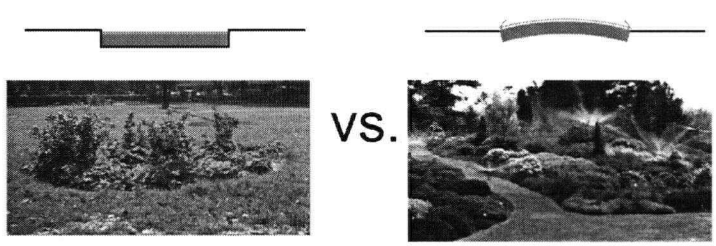
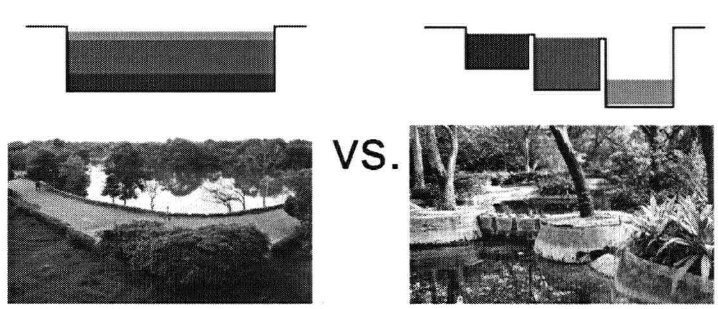
Recommendations for long term sustainable gain.

- Rainwater harvesting from roof tops, streets and large private parcels of land must be fully integrated with the public green spaces to better serve the objectives of the study.
- Gray water from various land uses must also be integrated with rainwater harvesting through the green spaces with natural water treatment systems.
- The rainwater harvesting systems must be maintained regularly and properly to ensure good quality of the harvested rainwater.
- For successful implementation of the strategies, a committed environment is necessary. This can be put in place through formulation of a categorical regulation dealing with all the green spaces in Delhi. Some of the provision under the regulation could be:

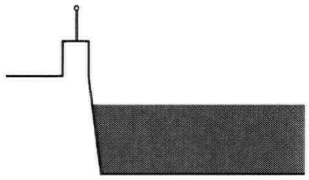
- An exhaustive, scientific study of status and potentials of each Green Space be carried out as per the parameters suggested in the study.
- Expert committee with representation of all stakeholders from:
  - CENTRE namely MOEF, CGWA, CSWBA;
  - STATE namely DDA, DJB;
  - LOCAL GOVT. namely MCD, NDMC,;
  - COMMUNITY namely RWA's, CBO's;
  - PRESSURE GROUP namely NGO's, ACADEMECIANS, MLA's
- Responsibilities of the expert group can be to,
  - Review & approve proposed plans for development.
  - Revise bye laws.
  - Conduct EIA of planned activities in the catchment.
  - Monitoring, management and maintenance.

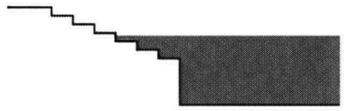
For achieving satisfactory results with the methods and procedures mentioned in this study for long term sustainable benefits, there must also be emphasis on water conservation through appropriate design, planning, planting designs and irrigation methods. Parks will become sustainable for their water requirement only if the landscaping changes to less water intensive ones through models such as **"xeriscaping"**. [72] Some of these recommendations [in the context of the study] are tabulated below with a comparison of existing practices to the preferred ones.

[72] According to the definition by wikipedia the word Xeriscaping was coined by combining xeros (Greek for "dry") with landscape. Plants whose natural requirements are appropriate to the local climate are emphasized, and care is taken to avoid losing water to evaporation and run-off.

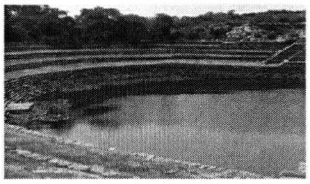
Design & Planning options (maximum intervention)		**Principles / Advantages**
Park Profile:	Convex vs. Concave,	**Draining vs. storing.** Convex profile drains water into the street stormwater drains and contributes to urban flooding, whereas concave profile collects water within the park for infiltration or storage for irrigation.
		
Pathways:	Raised vs. Flushed	**Blocking vs. free flowing** Raised pathways tend to block flow of water and create unwanted pockets for surface water storage leading to runoff inefficiency. Raised pathways must be only used to demarcate the catchment areas.
		
Planters:	Sunken vs. mounded	**Holding vs. Draining** Sunken planter areas act as surface depressions holding water and leading to water losses., whereas planters designed as mounds would drain water into the park adding to the water yield.
		
Water Bodies:	Large, Single vs. smaller, multiple	**Spreading water vs. distributing rationally** Large water bodies lead to excessive evaporation due to large surface area and therefore dry up faster, whereas a series of smaller water bodies distribute water rationally depending upon the volume of water, have less evaporation losses and can be possibly used in parts for longer periods of time without drying.
		

Water Edge: | Sharp, detached vs. gradual, stepped





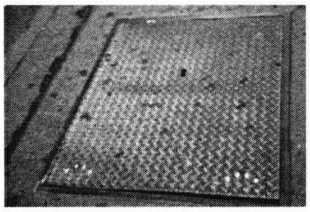
VS.



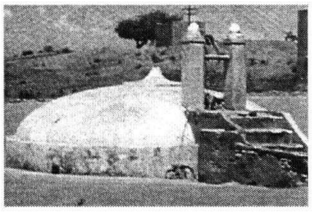
Separation vs. Celebration

Having a sharp protected edge to a water body alienated the water from people whereas a stepped or gradual edge leading to water invites people to celebrate water and enjoy it thus encouraging a sense of ownership and joy , ultimately leading them to take care of it.

Recharge Structures: | Standard, mundane vs. Unique



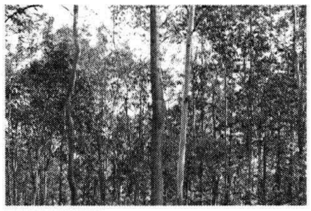
VS.



Unnoticeable vs. revelatory

A standard mundane design resembles a manhole on surface and leaves no impression on the viewer, whereas a universal special design would reveal and educate people of its presence and purpose, spreading awareness and recognition.

Plantation Types: | Exotic vs. native



EUCALYPTUS

VS.

ACACIA (BABUL)

Water demanding vs. Drought resistant.

Appropriate choice and grouping of plants according to their water requirements creates little stress on the soil moisture, helps in conserving water and are easy to maintain.

Native plants are well acclimatized to the local climate, demand less water and can tolerate water stress.

Irrigation Methods: | Flooding vs. sprinkling

VS.

Efficient application of water. Water wasting vs. conserving

Current practice of irrigating parks manually using rubber/ PVC pipes with no shower heads by flooding the area leads to excessive water wastage as opposed to more efficient sprinkler systems or drip irrigation systems.

7.3 Concluding Statement

Delhi is going through acute water crisis in recent years. It is currently not a matter of when and where alternatives to water sources and supply, such as rainwater harvesting, are considered rather it is absolutely essential that such alternatives be put into practice now and everywhere, where it is possible. Any amount of water that can be saved, is water produced and every drop of water counts for Delhi, not only owing to the current water situation but for a long term sustainable approach. Such alternative systems have been used throughout India , traditionally and continue to be used even today in different parts of the country. Unfortunately, the urban areas have alienated themselves from this vast repertoire of knowledge and become dependent on the state for centralized water supply which has evidently failed to fulfill the demand in recent years.

The thesis brings forward several methods of rainwater harvesting that can be implemented in the public green spaces of Delhi as one of the potential areas which are currently under utilized for this purpose. It is demonstrated through the study that rainwater harvesting in these areas is not only technically and financially feasible for public stakeholders but also for the local residents and can have additional environmental benefits. The study finds that the public green spaces can collectively bridge only about 12.5 percent of water demand-supply gap in the best case scenario which might appear little but owing to the area under the green spaces it is significant and as mentioned earlier it is a crisis situation for Delhi where no area must be left unused for harvesting the rainwater. Considering the rainwater endowment for Delhi, if all the areas are used for harvesting rainwater, the water-demand supply gap can be successfully bridged. The main challenges being political will, breaking the myths surrounding rainwater harvesting and ensuring a proper management and maintenance strategy. It is time, when Delhi government and its citizen must take a leadership role and try to fight the water crisis collectively for the current and future generations. This study is one of such efforts that provides some insight to help in moving towards this cause.

Bibliography

1. Aggarwal, Anil and Sunita Narain (ed): Dying Wisdom; Rise, Fall and Potential of India's Traditional Water Harvesting Systems: A Citizens' Report. Centre for Science and Environment, Delhi, 1997.
2. Agarwal, A.; Narain, S.; Khurana, I. (Eds.), Making Water Everybody's Business : Practice and Policy of Water Harvesting. Centre for Science and Environment, New Delhi, 2001.
3. Athavale, R. N., Water harvesting and sustainable supply in India, Ahmedabad : Centre for Environment Education ; Jaipur : Rawat Publications, c2003.
4. Blueprint for Water Augmentation in Delhi. India National Trust for Architectural and Cultural Heritage (INTACH), New Delhi. 1998
5. Brooks, David B., Water: Local Level management, International Development Research Centre, Canada 2002
6. Brooks, Kenneth N., Ffolliott Peter F., Gregersen, Hans M., Debano, Leonard F., Hydrology and the management of watershed, Iowa state University press, 1997
7. Ferguson, Bruce K., Debo, Thomas N., On-site stormwater management : applications for landscape and engineering, New York : Van Nostrand Reinhold, 1990.
8. Gould, John, Nissen-Petersen, Erik, Rainwater catchment systems for domestic supply : design, construction and implementation, London : Intermediate Technology Publications, 1999.
9. Guide on Artificial Recharge to Groundwater, Central Ground Water Board, Ministry of Water Resources. New Delhi. May 2000
10. Gupta, Kokil; Dissertation: Mainstreaming Urban Water Bodies. Dept. of Environmental Planning; School of Planning and Architecture. New Delhi. 2004
11. Izembart, Helene; Bertrand Le Boudec, Waterscapes: Using Plant Systems to treat Wastewater. Impression Printing, Barcelona, 2003.
12. Krishen, P. Trees of Delhi: A Field Guide, Dorling Kindersley (India) pvt. ltd. India 2006
13. Loucks, Daniel P., Gladwell, John S. (editors), Sustainable Criteria for Water Resource Systems. International Hydrology Series. Cambridge University Press & UNESCO, 1999.

14. Master Plan for Artificial Recharge to Groundwater in India, Central Ground Water Board, Ministry of Water Resources. Delhi. India. 2002

15. Mohiddin, S.K., Shashank Shekhar, Uma Kapoor & P.N. Singh; Enhancing the Recharge Capabilities of Aravalli Ridge in NCT and parts of NCR Region of Delhi, Central Ground Water Board. New Delhi, India. January 2006.

16. Rainwater Harvesting and Artificial Recharge to Groundwater - A Guide to Follow, Central Ground Water Board, UNESCO, International Hydrological Programme. Delhi, November 2000.

17. Rainwater Harvesting Techniques To Augment Groundwater, Central Ground Water Board, Ministry of Water Resources. Faridabad. India. 2003

18. Rainwater Harvesting and Utilization. Blue Drop Series, Book 2: Beneficiaries and capacity builders. United Nations Human Settlements Programme (UN-HABITAT). 2005.

19. Rohilla, S. Water Augmentation in Delhi: Techno-feasibility Study on Urban Water Harvesting. Conference on Market Development of Water & Waste Technologies. Paris, May 2004.

20. Sakthivadivel, R.; Artificial Recharging of Groundwater Aquifers and Groundwater Modelling in the Context of Basin Water Management; Modelling in Hydrogeology, Eds: L. Elango and R. Jayakumar, UNESCO-IHP, Allied Publishers, 2001, pp.25-38

21. Start at the Source – residential Site Planning & Design Guidance Manual for Stormwater Quality protection, Bay Area Stormwater management Agencies Association (BASMAA), 1997

22. Subramanya, K., Engineering Hydrology: Second Edition, Tata McGraw Hill publishing company limited, New Delhi, 2000.

23. Waller, D. H., J.D. Mooers, A. Samostie and B. Sahely. Innovative residential water and wastewater management; Centre for Water Resources Studies, DalTech, Dalhousie University in collaboration with totten sims hubicki associates, Blue Heron Environmental Technology, Canadian Water and Wastewater Association. Publisher: Canada Mortgage and Housing Corporation, 1998.

Electronic Sources

1. http://www.cseindia.org/ - Centre for Science and Environment (CSE), Delhi. India
2. http://www.waterbalance.ca/waterbalance/home/wbnIndex.asp
3. www.ddadelhi.com - Delhi Development Authority
4. www.delhijalboard.nic.in - Delhi jal Board
5. http://cgwb.gov.in/ - Central Ground Water Board
6. www.iwmi.org - The International Water Management Institute
7. http://www.rainwaterclub.org/ - Rainwater Club
8. http://www.idrc.ca/water/ - International Development Research Centre
9. http://www.unep.or.jp/ - United Nations Environment Program
10. http://www.eng.warwick.ac.uk/DTU/index.htm - University of Warwick

Appendix A : Techniques and Design of Artificial Recharge to Groundwater

Check Dams, Cement Plug, nala bunds (stream weirs)

Check dams are constructed across small streams having gentle slope and are feasible both in hard rock as well as alluvial formation. The site selected for check dam should have sufficient thickness of permeable bed or weathered formation to facilitate recharge of stored water within short span of time. The water stored in these structures is mostly confined to stream course and the height is normally less than 2 m (Figure A.1). These are designed based on stream width and excess water is allowed to flow over the wall. In order to avoid scouring from excess run off, water cushions are provided at downstream side. To harness the maximum run off in the stream, series of such check dams can be constructed to have recharge on regional scale.

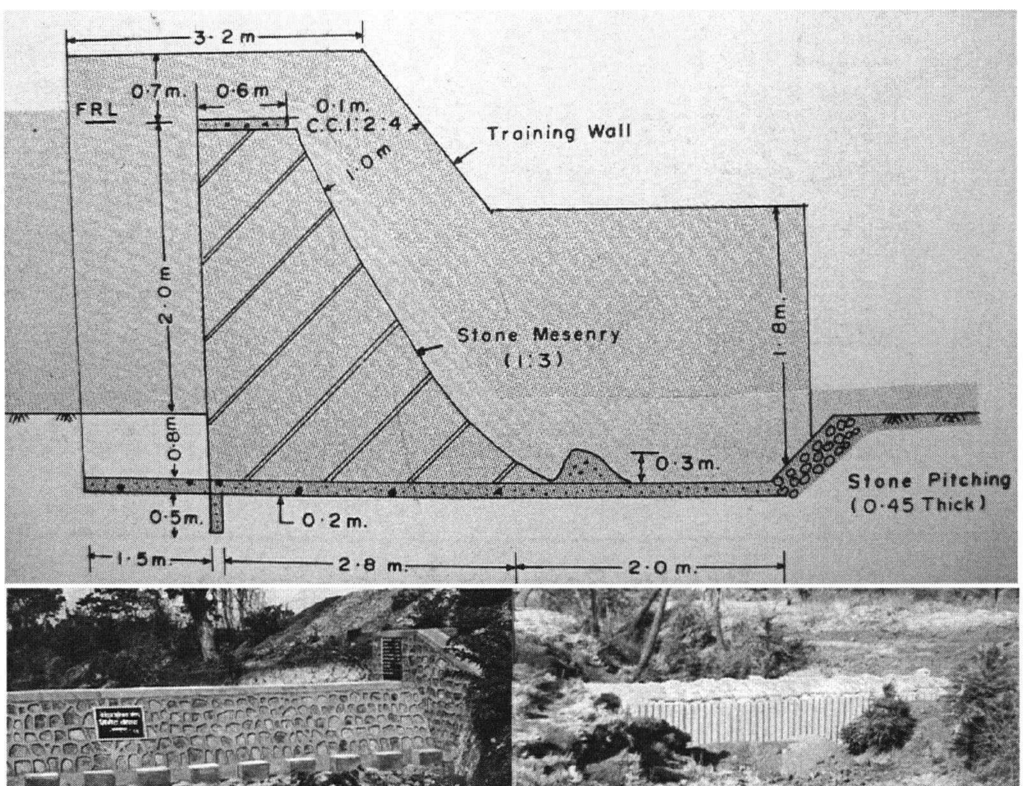


Figure A.1: Details of a typical check Dam structure

Source: Rainwater Harvesting & Artificial Recharge to Groundwater, UNESCO, CGWB. New Delhi. 2000

Gabion Structure

This is a kind of check dam being commonly constructed across small stream to conserve stream flows with practically no submergence beyond stream course. The boulders locally available are stored in a steel wire. This is put up across the stream's mesh to make it as a small dam by anchoring it to the stream side. The height of such structures is around 0.5 m and is normally used in the streams with width of about 10 to 15 m. The excess water overflows this structure storing some water to serve as source of recharge. The silt content of stream water in due course is deposited in the interstices of the boulders to make it more impermeable.

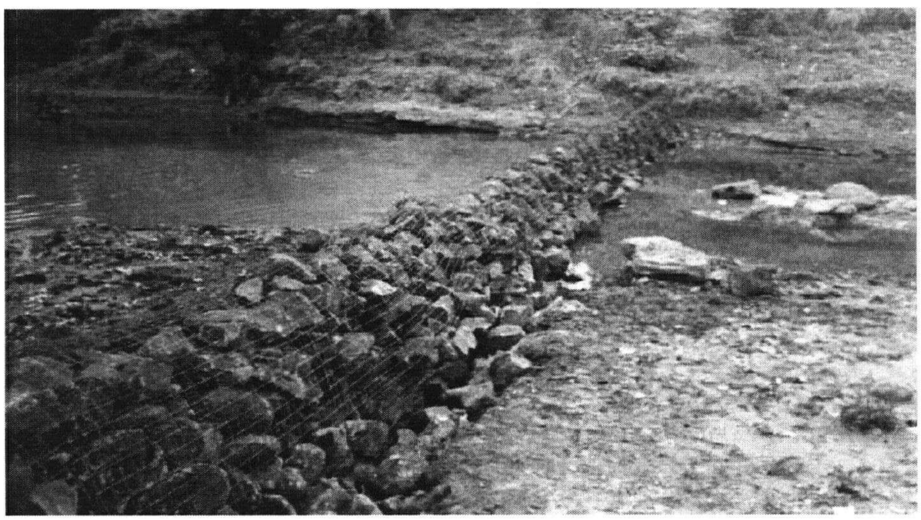


Figure A.2: Typical Gabion Structure

Source: Rainwater Harvesting Techniques To Augment Groundwater, Central Ground Water Board, Ministry of Water Resources. Faridabad. India. 2003

Dug Well Recharge

In alluvial as well as hard rock areas, there are thousands of dug wells which have either gone dry or the water levels have declined considerably. These dug wells can be used as structures to recharge. The groundwater reservoir, stormwater, tank water, canal water etc. can be diverted into these structures to directly recharge the dried aquifer. By doing so the soil moisture losses during the normal process of artificial recharge, are reduced. The recharge water is guided through a pipe to the bottom of well, below the water level to avoid scoring of bottom and entrapment of air bubbles in the aquifer. The quality of source water including the silt content should be such that the quality of groundwater reservoir is not deteriorated. Schematic diagrams of dug well recharge are given in figures A.3 & A.4.

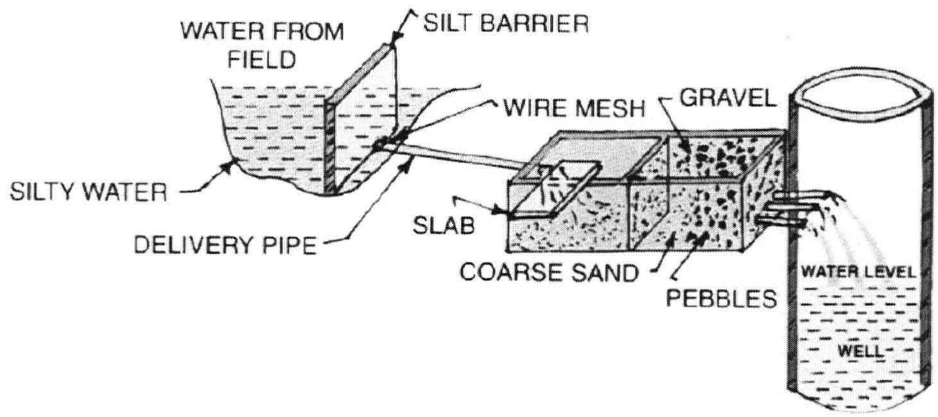


Figure A.3: Dugwell recharge system schematic diagram

Source: Rainwater Harvesting Techniques To Augment Groundwater, Central Ground Water Board, Ministry of Water Resources. Faridabad. India. 2003

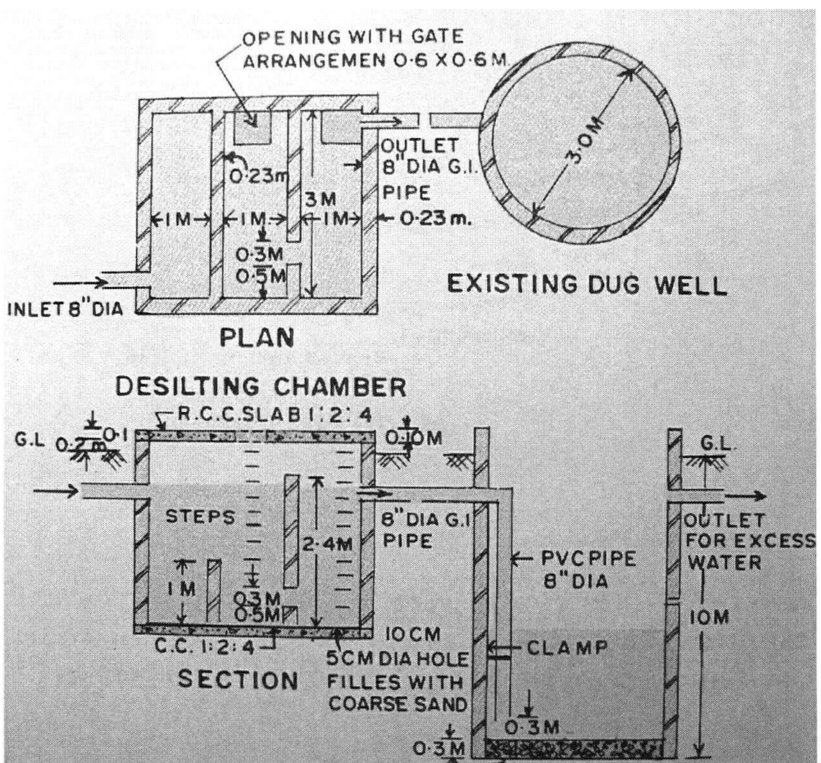


Figure A.4: Plan and Section showing Dugwell recharge system

Source: Rainwater Harvesting & Artificial Recharge to Groundwater, UNESCO, CGWB. New Delhi. 2000

Recharge Shaft

These are the most efficient and cost effective structures to recharge the aquifer directly. In the areas where source of water is available either for some time or perennially e.g. base flow, springs etc. the recharge shaft can be constructed (Figure A.5).

The main advantages of this technique are as follows:

1. Disused or even operational dugwells can be converted into recharge shafts, which does not involve additional investment for recharge structure.
2. Technology and design of the recharge shaft is simple and can be applied even where baseflow is available for a limited period.
3. The recharge is fast and immediately delivers the benefit.

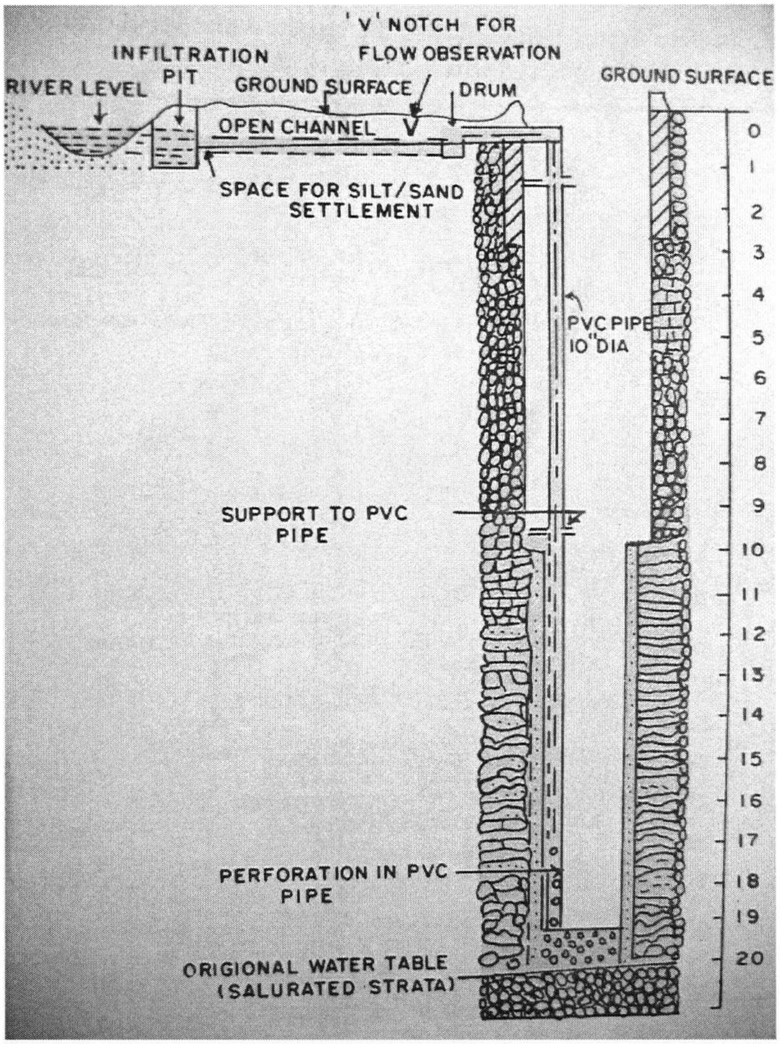


Figure A.5:
Cross Section through a recharge shaft.

Source: Rainwater Harvesting & Artificial Recharge to Groundwater, UNESCO, CGWB. New Delhi. 2000

The recharge shafts can be constructed in two different ways viz. Vertical and lateral. The details of each is given in the following paragraphs.

Vertical Recharge Shaft

1. WITHOUT INJECTION WELL (Figure A.6)

- Ideally suited for water levels less than 15 m.
- Presence of clay is encountered within 15 m.
- Effective in the areas of less vertical natural recharge.
- Copious water available can be effectively recharged.
- Effective with silt water also (using inverted filter consisting of layers of sand, gravel and boulder)
- Depth and diameter depends upon the depth of aquifer and volume of water to be recharged.
- The rate of recharge depends on the aquifer material and silt content in the water.

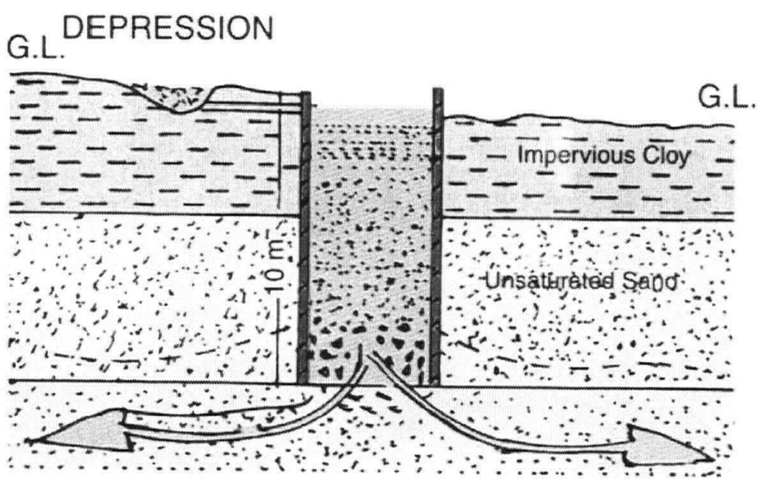


Figure A.6: Vertical Recharge Shaft without injection well

Source: Rainwater Harvesting Techniques To Augment Groundwater, Central Ground Water Board, Ministry of Water Resources. Faridabad. India. 2003

2. WITH INJECTION WELL

In this technique at the bottom of recharge shaft a injection well of 100 - 150 mm diameter is constructed piercing through the layers of impermeable horizon to the potential aquifers to be reached about 3 to 5 meter below the water level.

- Ideally suitable for very deep water levels (more than 15 meters)
- Aquifer is over lain by impervious thick clay beds
- Injection well can be with or without assembly
- The injection well with assembly should have screen in the potential aquifer at least 3 – 5 meter below the water level.
- The injection well without assembly is filled with gravel to provide hydraulic continuity so that water is directly recharged into the aquifer
- The injection well without assembly is very cost effective.
- Depending upon volume of water to be injected, number of injection wells, can be increased to enhance the recharge rate.

Lateral Recharge Shaft

- Ideally suited for areas where permeable sandy horizon is within 3 meter below ground level and continues upto the water level - under unconfined conditions
- Copious water available can be easily recharged due to large storage and recharge potential.
- Silt water can be easily recharged
- 2 to 3 meter wide and 2 to 3 meter deep trench is excavated, length of which depends on the volume of water to be handled.

This structure has been constructed at following places in Delhi

- Shram Shakti Bhawan, New Delhi - (3 lateral shafts with 2 injection wells in each. Fig.A.7)
- Lodhi Garden, New Delhi - with injection wells

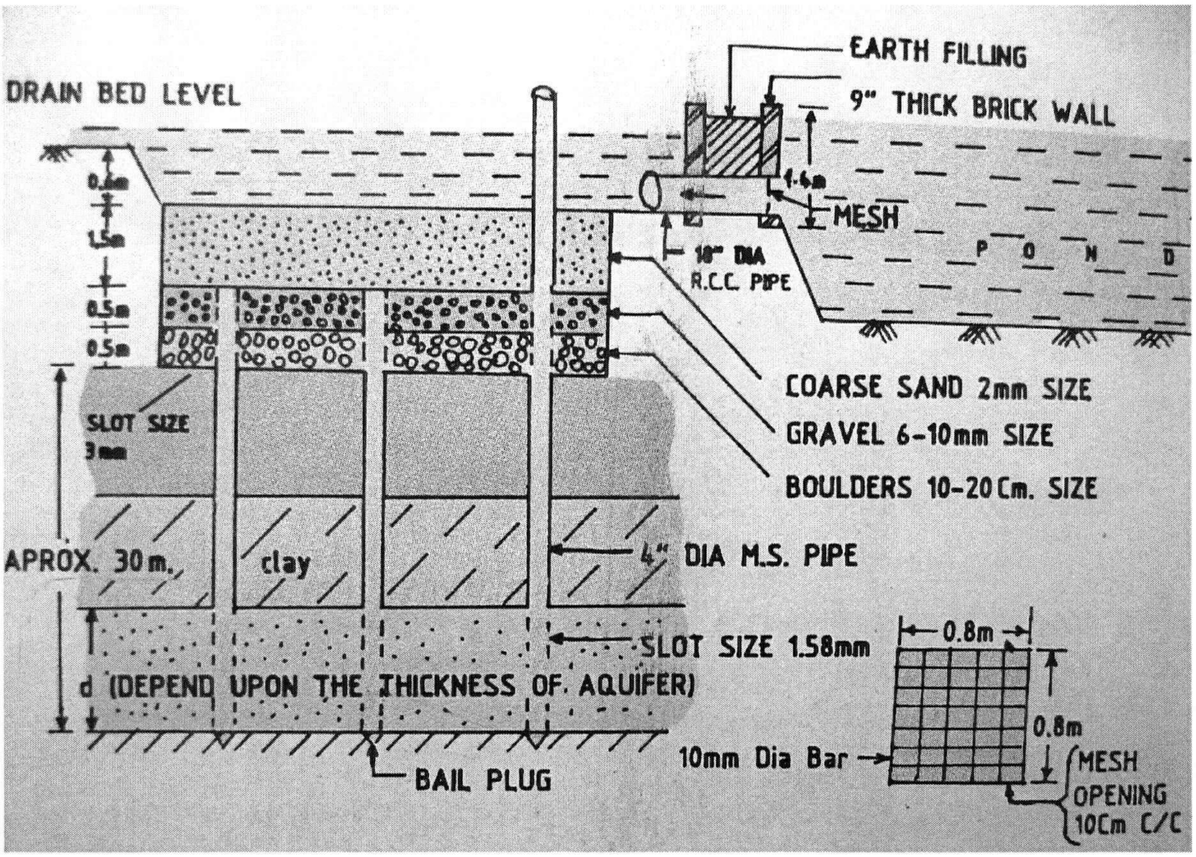


Figure A.7: Lateral Recharge Shaft with injection wells

Source: Rainwater Harvesting & Artificial Recharge to Groundwater, UNESCO, CGWB. New Delhi. 2000

Appendix B: Runoff calculations

Scenario 1

Neighbourhood green space A

	0.425 x 1552 x 0.85 = 560.7 m^3
	0.425 x 10365 x 0.3 = 1321.5 m^3
	0.425 x 19092 x 0.35 = 2839.9 m^3
	0.425 x 8674 x 0.45 = 1658.9 m^3
	0.425 x 396 x 0.9 = 151.5 m^3

Assumptions:

Total monsoon rainfall available for runoff - 500 mm

Interception loss - 15 %
Depression storage loss - nil

Neighbourhood green space B

	0.450 x 1750 x 0.85 = 669.4 m^3
	0.450 x 9562 x 0.3 = 1290.9 m^3
	0.450 x 1807 x 0.35 = 284.6 m^3
	0.450 x 866 x 0.45 = 175.4 m^3
	0.450 x 2356 x 0.1 = 106.0 m^3
	0.450 x 144 x 0.9 = 58.3 m^3

Assumptions:

Total monsoon rainfall available for runoff - 500 mm

Interception loss - 10 %
Depression storage loss - nil

Neighbourhood green space C

	0.475 x 619 x 0.85 = 111.0 m^3
	0.475 x 1879 x 0.3 = 119.0 m^3
	0.450 x 1485 x 0.35 = 104.0 m^3
	0.475 x 909 x 0.1 = 19.2 m^3
	0.475 x 36 x 0.9 = 6.8 m^3

Assumptions:

Total monsoon rainfall available for runoff - 500 mm

Interception loss - 5 %
Depression storage loss
in the play area (bare land) - 5 %

Neighbourhood green space D

	0.475 x 985 x 0.85 = 397.7 m^3
	0.475 x 3870 x 0.3 = 551.5 m^3
	0.475 x 1152 x 0.1 = 54.7 m^3

Assumptions:

Total monsoon rainfall available for runoff - 500 mm

Interception loss - 5 %
Depression storage loss - nil

Neighbourhood green space E

	0.475 x 684 x 0.85 = 276.2 m^3
	0.475 x 1629 x 0.3 = 232.1 m^3
	0.450 x 1030 x 0.35 = 162.2 m^3
	0.475 x 659 x 0.1 = 31.3 m^3

Assumptions:

Total monsoon rainfall available for runoff - 500 mm

Interception loss - 5 %
Depression storage loss
in the play area (bare land) - 5 %

Scenario 2

Neighbourhood green space A

	0.425 x 4511 x 0.85 = 1629.7 m^3	Assumptions:
	0.425 x 6626 x 0.34 = 985.7 m^3	Total monsoon rainfall available for runoff - 500 mm
	0.425 x 19094 x 0.4 = 3245.9 m^3	Interception loss - 15 % (only in the green space)
	0.425 x 8397 x 0.45 = 1605.9 m^3	Depression storage loss - nil
	0.425 x 1058 x 0.3 = 134.8 m^3	
	0.425 x 396 x 0.9 = 151.5 m^3	
	0.500 x 53480 x 0.85 = 22729.1 m^3	
	0.500 x 15806 x 0.75 = 5927.3 m^3	

Neighbourhood green space B

	0.45 x 4536 x 0.85 = 1735.0 m^3	Assumptions:
	0.45 x 8204 x 0.35 = 1292.1 m^3	Total monsoon rainfall available for runoff - 500 mm
	0.45 x 1006 x 0.4 = 181.0 m^3	Interception loss - 10 % (only in the green space)
	0.45 x 866 x 0.45 = 175.4 m^3	Depression storage loss - nil
	0.45 x 1730 x 0.3 = 233.6 m^3	
	0.45 x 144 x 0.9 = 58.3 m^3	
	0.50 x 12128 x 0.85 = 5154.2 m^3	
	0.50 x 6759 x 0.75 = 2534.6 m^3	

Neighbourhood green space C

	0.475 x 1157 x 0.85 = 466.9 m^3	Assumptions:
	0.475 x 1744 x 0.35 = 289.9 m^3	Total monsoon rainfall available for runoff - 500 mm
	0.45 x 1485 x 0.4 = 267.3 m^3	Interception loss - 5 %
	0.475 x 506 x 0.3 = 72.1 m^3	Depression storage loss in the play area (bare land) - 5 %
	0.475 x 36 x 0.9 = 15.4 m^3	
	0.500 x 6982 x 0.85 = 2967.2 m^3	
	0.500 x 2338 x 0.75 = 876.7 m^3	

Neighbourhood green space D

	0.475 x 1415 x 0.85 = 571.4 m^3	Assumptions:
	0.475 x 2295 x 0.35 = 381.5 m^3	Total monsoon rainfall available for runoff - 500 mm
	0.45 x 1478 x 0.4 = 266.1 m^3	Interception loss - 5 %
	0.475 x 819 x 0.3 = 116.7 m^3	Depression storage loss in the play area (bare land) - 5 %
	0.500 x 8111 x 0.85 = 3447.3 m^3	
	0.500 x 959 x 0.75 = 359.4 m^3	

Neighbourhood green space E

■	0.475 x 977 x 0.85 = 394.3 m^3	Assumptions: Total monsoon rainfall available for runoff - 500 mm Interception loss - 5 % Depression storage loss in the play area (bare land) - 5 %
■	0.475 x 1483 x 0.35 = 246.5 m^3	
■	0.45 x 1031 x 0.4 = 185.5 m^3	
■	0.475 x 513 x 0.3 = 73.1 m^3	
■	0.500 x 8249 x 0.85 = 3505.6 m^3	
■	0.500 x 4142 x 0.75 = 1553.3 m^3	

Scenario 3

Regional Green Space with Minimum Intervention

Runoff Calculations:

- 0.475 x 79340 x 0.85 = 32033.5 m3
- 0.475 x 236375 x 0.3 = 33683.4 m3
- 0.45 x 25490 x 0.35 = 4014.7 m3
- 0.4 x 534345 x 0.45 = 96182.1 m3
- 0.475 x 22055 x 0.1 = 1047.6 m3
- 0.475 x 4720 x 0.9 = 2017.8 m3
- 0.350 x 62840 x 1.0 = 21994 m3
- 0.500 x 7905 x 0.75 = 2964.4 m3

Assumptions and Data:

Total rainfall available for runoff - 500 mm

Interception losses (% of total rainfall):
Woodland/forest area (100% canopy cover) - 20%
Water bodies & streets - nil
All other areas (25% canopy coverage) - 5%

Depression storage loss **(% of total rainfall)**:
Play areas (bare land) - 5%
All other areas - nil

Evaporation loss for open reservoirs - 5 mm/day
~30% of total annual rainfall (current situation)

Rate of recharge for each borewell - 10 Litres/sec.

Scenario 4

Regional Green Space with Maximum Intervention

Runoff Calculations:

- 0.475 x 126615 x 0.85 = 51120.8 m3
- 0.475 x 189100 x 0.35 = 31437.9 m3
- 0.45 x 93830 x 0.4 = 16889.4 m3
- 0.4 x 899925 x 0.45 = 161986.5 m3
- 0.475 x 14300 x 0.3 = 2037.8 m3
- 0.475 x 23000 x 0.9 = 9832.5 m3
- 0.425 x 62840 x 1.0 = 26707.0 m3
- 0.500 x 13890 x 0.75 = 5208.8 m3

Assumptions and Data:

Total rainfall available for runoff - 500 mm

Interception losses (% of total rainfall):
Woodland/forest area (100% canopy cover) - 20%
Water bodies & streets - nil
All other areas (25% canopy coverage) - 5%

Depression storage loss **(% of total rainfall)**:
Play areas (bare land) - 5%
All other areas - nil

Evaporation loss for open reservoirs ~15% of total annual rainfall (with proper management - Table 6.3)

Rate of recharge for each borewell - 10 Litres/sec.

Appendix C: Catchment areas and Storage and Recharge structure calculations

Neighbourhood Green Spaces - Scenario 1

Space Reference	Scenario 1		
	Area (m²)	Runoff for 15 min. of peak intensity rainfall ~ 25mm (m³)	Recharge structures (LxBxD) (m)
Neighbourhood A			
Catchment 1	7664	76.6	11 x 2 x 3.5
Catchment 2	3240	32.4	5 x 2 x 3.5
Catchment 3	7706	77.1	11 x 2 x 3.5
Catchment 4	8762	87.6	22 x 2 x 2
Catchment 5	4804	48.0	4 m dia x 3.5 m deep
Catchment 6	7907	79.1	11 x 2 x 3.5
Total	40082		
Annual Runoff	6532.5		
Neighbourhood B			
Catchment 1	1879	18.8	3 x 3 x 2
Catchment 2	3449	34.5	5 x 2 x 3.5
Catchment 3	5301	53.0	8 x 2 x 3.5
Catchment 4	5857	58.6	8 x 2 x 3.5
Total area	16486		
Annual Runoff	2584.6		
Neighbourhood C			
Catchment 1	1681	16.8	4 x 2 x 2
Catchment 2	3247	32.5	4 x 2 x 3.5
Catchment 3			
Total area	4928		
Annual Runoff	810.1		
Neighbourhood D			
Catchment 1	2293	22.9	3 x 2 x 3.5
Catchment 2	3715	37.1	5 x 2 x 3.5
Total area	6008		
Annual Runoff	1003.9		
Neighbourhood E			
Catchment 1	2324	23.2	3 x 2 x 3.5
Catchment 2	1679	16.8	2.5 x 2 x 3.5
Total area	4003		
Annual Runoff	701.8		

Neighbourhood Green Spaces - Scenario 2

Scenario 2				
Area (m^2)	Runoff for 15 min. of peak intensity rainfall - 25mm (m^3)	Recharge structures (Additional or extensions)	Desilting chamber	Storage structures (Cylindrical)
22156	374.1	40 x 2 x 3.5	3 x 3 x 2.4 (21m^3)	
8989	151.7	17 x 2 x 3.5	3 x 3 x 2.4 (21m^3)	
24296	419.8	55 x 2 x 3.5	3 x 3 x 2.4 (21m^3)	
8762	87.6	22 x 2 x 2		
28211	532.6	60 x 2 x 3.5	6 x 3 x 3 (54m^3)	3 m dia, 3m depth (21m3)
16956	267.8	34 x 2 x 3.5	3 x 3 x 2.4 (21m^3)	3 m dia, 3m depth (21m3)
109368				
36409.9				
1879	18.8	3 x 3 x 2		
8741	141.8	17 x 2 x 3.5	3 x 3 x 2.4 (21m^3)	3 m dia, 3m depth (21m3)
15608	263.4	34 x 2 x 3.5	3 x 3 x 2.4 (21m^3)	3 m dia, 3m depth (21m3)
9144	125.3	14 x 2 x 3.5	3 x 3 x 2.4 (21m^3)	3 m dia, 3m depth (21m3)
35372				
11364.2				
4928	49.3	12 x 2 x 2		2.4 m dia, 3m depth (13.5m3)
3454	71.1	7 x 2 x 3.5	3 x 3 x 2.4 (21m^3)	
5866	121.1	14 x 2 x 3.5	3 x 3 x 2.4 (21m^3)	
14248				
4955.6				
6311	107.2	12 x 2 x 3.5	3 x 3 x 2.4 (21m^3)	
8766	143.2	17 x 2 x 3.5	3 x 3 x 2.4 (21m^3)	2.8 m dia, 3 m depth (18.5m3)
15077				
5142.4				
7880	138.0	16 x 2 x 3.5	3 x 3 x 2.4 (21m^3)	2.4 m dia, 3m depth (13.5m^3)
8514	155.0	19 x 2 x 3.5	3 x 3 x 2.4 (21m^3)	
16394				
5958.4				

Regional Green Space - Scenario 3

Space Reference	Scenario 3		
	Area (m^2)	Runoff for 15 min. of peak intensity rainfall ~ 25mm (m^3)	Recharge structures (LxBxD) (m)
Catchment 1	69500	695.0	30 x 2 x 3.5 (3 nos)
Catchment 2	37000	370.0	25 x 2 x 3.5 (2 nos)
Catchment 3	39100	391.0	25 x 2 x 3.5 (2 nos)
Catchment 4	98800	988.0	3 x 3 x 2 (10 nos)
Catchment 5	22350	223.5	15 x 2 x 3.5 (2 nos)
Catchment 6	42560	425.6	30 x 2 x 3.5 (2 nos)
Catchment 7	76450	764.5	30 x 2 x 3.5 (4 nos)
Catchment 8	21870	218.7	15 x 2 x 3.5 (2 nos)
Catchment 9	36970	369.7	25 x 2 x 3.5 (2 nos)
Catchment 10	57030	570.3	20 x 2 x 3.5 (4 nos)
Catchment 11	34930	349.3	25 x 2 x 3.5 (2 nos)
Catchment 12	78280	782.8	3 x 3 x 2 (8 nos)
Catchment 13	46850	468.5	25 x 2 x 3.5 (3 nos)
Catchment 14	16610	166.1	8 x 2 x 3.5 (3 nos)
Catchment 15	15200	152.0	20 x 2 x 3.5 (1 nos)
Catchment 16	44390	443.9	30 x 2 x 3.5 (2 nos)
Catchment 17	111700	1117.0	30 x 2 x 3.5 (5 nos)
Catchment 18	109800	1098.0	30 x 2 x 3.5 (5 nos)
Catchment 19	13680	136.8	4 x 2 x 3.5 (4 nos)
Catchment 20			
Catchment 21			
Catchment 22			
Catchment 23			
Catchment 24			
Catchment 23			
Total	**973070**		
Annual Runoff	**193937.5**		

Regional Green Space - Scenario 4

Space Reference	Scenario 4			
	Area (m^2)	Runoff for 15 min. of peak intensity rainfall ~ 25mm (m^3)	Recharge structures (Additional or extensions)	Storage structures (Cylindrical)
Catchment 1	69500	695.0	30 x 2 x 3.5 (3 nos)	
Catchment 2	37000	370.0	25 x 2 x 3.5 (2 nos)	3 m dia, 3m depth (21m3) - 4 nos.
Catchment 3	39100	391.0	25 x 2 x 3.5 (2 nos)	3 m dia, 3m depth (21m3) - 1 nos.
Catchment 4	98800	988.0	3 x 3 x 2 (10 nos)	
Catchment 5	22350	223.5	15 x 2 x 3.5 (2 nos)	3 m dia, 3m depth (21m3) - 1 nos.
Catchment 6	42560	425.6	30 x 2 x 3.5 (2 nos)	3 m dia, 3m depth (21m3) - 2 nos.
Catchment 7	76450	764.5	30 x 2 x 3.5 (4 nos)	3 m dia, 3m depth (21m3) - 3 nos.
Catchment 8	21870	218.7	15 x 2 x 3.5 (2 nos)	
Catchment 9	36970	369.7	25 x 2 x 3.5 (2 nos)	
Catchment 10	57030	570.3	20 x 2 x 3.5 (4 nos)	3 m dia, 3m depth (21m3) - 3 nos.
Catchment 11	34930	349.3	25 x 2 x 3.5 (2 nos)	
Catchment 12	78280	782.8	3 x 3 x 2 (8 nos)	
Catchment 13	46850	468.5	25 x 2 x 3.5 (3 nos)	3 m dia, 3m depth (21m3) - 2 nos.
Catchment 14	16610	166.1	8 x 2 x 3.5 (3 nos)	3 m dia, 3m depth (21m3) - 2 nos.
Catchment 15	15200	152.0	20 x 2 x 3.5 (1 nos)	
Catchment 16	44390	443.9	30 x 2 x 3.5 (2 nos)	
Catchment 17	111700	1117.0	30 x 2 x 3.5 (5 nos)	
Catchment 18	121930	**1219.3**	30 x 2 x 3.5 (5 nos) **20 x 2 x 3.5 (3 nos)**	
Catchment 19	13680	136.8	4 x 2 x 3.5 (4 nos)	2.4 m dia, 3m depth (13.5m3) - 4 nos.
Catchment 20	42080	420.8	**20 x 2 x 3.5 (3 nos)**	
Catchment 21	160210	1602.1	**25 x 2 x 3.5 (9 nos)**	
Catchment 22	29890	298.9	**15 x 2 x 3.5 (3 nos)**	
Catchment 23	130200	1302.0	**25 x 2 x 3.5 (7 nos)**	
Catchment 24	47350	473.5	**15 x 2 x 3.5 (4 nos)**	
Catchment 25	28570	285.7	**10 x 2 x 3.5 (4 nos)**	
Total	**1423500**			
Annual Runoff	**305220.6**			

Appendix D: Cost Details

General costs associated with the financial study

1.	Total water cost of supply for DJB (including capital costs and infrastructure maintenance costs)	- Rs 9.5/KL (kilo Litres) [73]
2.	Water cost for domestic consumers (Average consumption/HH/month - 22000 litres)	- Rs 1.0/KL
3.	Total coping cost /HH/month	- Rs 226
4.	Coping cost/KL of water consumed	- Rs 10.3
5.	Average Tanker cost	- Rs1200/tanker-12000 L or 12 KL - Rs 100/KL [74]
6.	Electricity Cost of Supply for DVB	- Rs 5.0/unit (Kwh)
7.	Electricity cost of domestic consumers	- Rs 2.5/unit (average) [75]

8. Average one time cost of maintenance for each rainwater harvesting structure – **Rs 1000** [76] if employing outside labour. If performed by on site staff, it can be negligible.

9. Maximum electricity cost savings possible annually to the government from each storage structure of 10 m^3 - **Rs 21,600**, assuming it rains every third day as the irrigation is needed one day after the rainy day and the tanks get emptied before each rainy day.

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[73] Misra, Smita; Sr. Economist, SASEI, World Bank, Delhi Water Supply & Sewerage Services : Coping Costs, Willingness to Pay and Affordability, December 2006

[74] Newspaper article. March 2007. < http://www.hinduonnet.com/2004/07/29/stories/2004072910050400.htm >

[75] Newspaper article. March 2007. < http://www.hindu.com/2004/06/11/stories/2004061115870300.htm >

[76] Delhi Development Authority. March 2007. < http://delhiplanning.nic.in/Reports/RWH.pdf>

Rough Cost Estimate for main items of work (current market prices in Indian Rupees - Rs)

S.no	Description of work	Unit	Unit Rate (Rs)
1	Recharge structures - lateral shafts / trenches with borewells which would include:		
	Shaft / Trench (including following items)	Cu.M	2500
	a - Excavation	Cu.M	90
	b - PCC (1:3:6) base 10 cm thick	Cu.M	1850
	c - Brick work with cement mortar (1:6)	Cu.M	1540
	d - Boulders 10-20 cm	Cu.M	250
	e - Gravel 5-10 mm	Cu.M	550
	f - sand	Cu.M	500
	Borewell (25 m deep including following items)	each	12000
	a - Making 200 mm dia borehole in alluvial soils	Meter	215
	b - 200 mm dia pvc pipe	Meter	310
	c - 153 mm dia pvc pipe	Meter	165
	d - 1:58 mm slotted pipe 153 mm dia	Meter	200
	e - 3mm size slotted pipe 200mm dia	Meter	385
	f - Gravel 3-6 mm	Cu.M	600
2	Ferro-cement Cylindrical underground storage tank - 21,000 L capacity - 3m dia, 3m deep (Pre-fabricated)	each	25200
	Ferro-cement Cylindrical underground storage tank - 18,500 L capacity - 2.8m dia, 3m deep (Pre-fabricated)	each	21000
	Ferro-cement Cylindrical underground storage tank - 13,500 L capacity - 2.4m dia, 3m deep (Pre-fabricated)	each	17800
	Ferro-cement Cylindrical underground storage tank - 10,000 L capacity - 2.1m dia, 3m deep (Pre-fabricated)	each	15000
	Submersible pumps (1hp) with installation in the storage tanks	each	4000
	Grading and surfacing (turf)	Sq.M	75
	Unit paver pathways with base preparation	Sq.M	225
	Reinforced cement concrete (1:2:4) including steel bars, and shuttering	Cu.M	5170
	1m wide, Shallow PCC drainage channel (pre-cast units or cast in-situ)	M	175
	Grade alterations to the open drainage channels along local streets in residential neighbourhoods	Sq.M	375
	General labour cost (daily wage)	per person	
	a - Mason	per day	250
	b - helpers	per day	120