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"An Investigation on Potential of Decentralized Rainwater harvesting for improving Sustainability of an urban residential area"

(A Case of Samakhusi, Kathmandu)

by

Anami Bohara

A THESIS

SUBMITTED TO THE DEPARTMENT OF
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Declaration

I hereby declare that the thesis entitled **"An Investigation on Potential of Decentralized Rainwater harvesting for improving Sustainability of an urban residential area" (A case of Samakhusi, Kathmandu)** submitted to the Department of Architecture in partial fulfilment of the requirement for the degree of Master Science in Engineering in Energy for Sustainable Social Development, is a record of an original work done under the guidance of Prof. Dr. Sangeeta Singh, Institute of Engineering, Pulchowk Campus. This thesis contains only work completed by me except for the consulted material which has been duly referenced and acknowledged.

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"An Investigation on Potential of Decentralized Rainwater harvesting for improving Sustainability of an urban residential area" (A case of Samakhusi, Kathmandu)** submitted by Anami Bohara in partial fulfilment of the requirements for the degree of Master of Science in Energy for Sustainable Social Development.

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Abstract

This study aims to identify the potential of rainwater harvesting on a neighborhood scale by doing qualitative and quantitative analysis. Small neighborhood of Samakhusi was selected as a good representative of compact residential urban area. Samakhusi lies in northern belt of Kathmandu valley where there is high infiltration rate for ground water recharge but also has water logged streets during rainy days and water scarcity during dry seasons. Based on a statistical analysis of the rainfall, the amount of rainwater that might be captured from roofs and ground surfaces was calculated. The standard data from the literature was used to calculate the potable water consumption of urban residential households. In this study, potential of rainwater in compact urban area for regenerating water sensitive urban development was evaluated. And also, a possibility of minimizing waste water from rainwater harvesting was evaluated. The study also examined case studies with success stories which reflects improved urban scenario through rainwater harvesting. Moreover, social perceptive from community, government institutions and technology providers on rainwater harvesting was also analyzed. Based on these qualitative and quantitative data, direct and indirect benefits were explored that helps to improve water sustainability and water sensitive planning of an urban residential area.

Keywords: urban residential area, rainwater harvesting, ground water recharge, water sustainability, water sensitive urban development

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Abbreviations

RHS: Rainwater Harvesting System

GWR: Ground Water Recharge

GWHS: Ground Water Harvesting System

KUKL: Kathmandu Upatyaka Khanepani Ltd

MLD: Millions litres a day

MWSP: Melamchi Water Supply Project

WSUD: Water Sensitive Urban Design

CIUD: Centre for Integrated Urban Development

PID: Project Implementation Directorate

KVWSMB: Kathmandu Valley Water Supply Management Board

WAN: Water Aid Nepal

DHM: Department of Hydrology and Meteorology

DWF: Dry Weather Flow

NGD: Northern Groundwater District

CGD: Central Groundwater District

SGD: Southern Groundwater District

KMC: Kathmandu Metropolitan City

LSMC: Lalitpur Sub- Metropolitan City

SODIS: Solar Disinfection

Chapter 1: Introduction

1.1. Background

Water supply crisis is the global issue which is identified as the greatest social risk facing the planet in the next decade. One third of the world's population lives in water-scarce areas and nearly a billion people still do not have access to safe water. Therefore, since large-scale rural migration leads to urban development, one of the biggest challenges is to use the existing water supply 'fairly and effectively' (Raina, 2017).

The condition of water situation in Kathmandu, Nepal is also serious. There is extremely 'inadequate and intermittent' water supply for the urban residents. From 2003 to 2014, the utilization rate of urban tap water in Nepal dropped from 68% to 58%. Kathmandu water supply system consists of three different parts; a traditional water system that consists of water sources like stone spouts, dug wells, tanks and ponds; household and industrial private water extraction; and different types and sizes water vendors. It is said that the most traditional supplies, such as public water tanks, have stopped working. In view of this, households and businesses have responded to the shortage by investing in local personal water supply and internal storage, installing private wells to extract groundwater by them, and relying on water from vendors for water supply (Raina, 2017).

The only piped water supplier in Kathmandu, Uptyaka Khanepaani Limited (KUKL) mentioned that the daily demand for water is 360 million litres (MLD), while the supply is only 150 MLD per day monsoon seasons, and it is reduced to 60 MLD per day in the dry season (TKP, March 24, 2014). Therefore, households are only expected to supply tap water once every five days. If rainwater can be used first for different purposes, including consumption (after filtering), so it will certainly reduce the water requirement in a house that will be purchased. The investment for these systems can be easily returned for a couple of years with very short payback period. Storage, use and top-up of rainwater was an old practice that lost its importance in modern comfort. It is time to review those thoughts processes and apply them (smartpaani, 2015).

According to an investigation by the Groundwater Resources Development Committee, the groundwater level in the valley has been gradually decreasing. In the past, there was water 8 to 10 meters underground in the valley, but now it is difficult to find water when digging 40 to 50 meters. In the past, KUKL used to extract 1,000 litres per minute from deep wells which is now dropped to 700 litres per minute. Since there is no earth space to absorb water, lately the valley has been witnessing flood in every monsoon. Experts say that almost 83% of the land in Kathmandu is sealed by cement and concrete to prevent water from entering the surface which has directly affected the ground water level in the valley. According to a study conducted by JICA in 1990, if almost 150 million litres of are extracted from the valley, this will cause the water level to drop and cause a greater natural imbalance. According to the Kathmandu Valley Water Supply Management Board, approximately 35-50 % of the population in the valley depends on underground water. Private water intake by households, industries, and water sellers is also‘rampant’ in the valley (Adhikari, 2020).

This unregulated mining is depleting aquifers, especially deep ones, because the valley's black clay is impervious and therefore difficult to replenish. The total rate of groundwater withdrawal exceeds 6 times the natural recharge capacity, causing the groundwater level to drop approximately 2.5 meters per year. The direct consequence of the depletion of shallow groundwater aquifers is that well drilling, hand pumps and traditional stone pipes can no longer supply water as before. Groundwater quality is also an issue: Chemical contaminants such as arsenic, ammonia, and nitrate have been detected in deep aquifers in many areas of the valley (Shrestha R. R., Rainwater Harvesting and Groundwater Recharge for Water Storage in the Kathmandu Valley, 2009).

Along with the excess groundwater extraction, haphazard building constructions, roads and paved surfaces and the subsequent sealing of the natural recharge areas have led to the depletion of the groundwater table, thus creating acute water shortage during dry periods. Groundwater recharge is done mainly to store surface runoff during the monsoon. This water is then extracted through community wells, dug wells, boring and through stone sprouts and spring outlets. Thus groundwater recharge helps in maintaining groundwater table and revive community wells, stone sprouts and spring sources (Recharging Kathmandu Valley).As rainwater is a free, relatively clean source of water. Harvesting rainwater can save high-quality drinking water sources by reducing flooding, soil erosion and replenishing groundwater levels, and reducing pressure on sewers and the environment (Nolde).

1.2. Rational of the study

The rationale of the thesis which defines favor of implementing the project in the proposed area is summarized below in terms of need and importance.

Need

Water is the foundation of human well-being and a limited and irreplaceable resource, which is only renewable when managed properly. The sustainability of water resources and energy is one of the two major factors that challenge the world in the 21st century (Jin, 2013). Comparing to other areas, urban centres are currently facing an ironic situation. As, on the one hand, there is a serious shortage of water resources. On the other hand, the streets are often flooded during the rainy season. Although these cities have plenty of rainfall (rainwaterharvesting.org).

The direct benefit of (Rainwater Harvesting System) RWHS in urban areas is to reduce urban flooding and in same way, RWHS improves the quality & quantity of groundwater, thereby also indirectly benefiting. Recharge wells are ideal for recharging groundwater and minimizing water logging (Lasshmi, 2018). The extraction of rainwater and the artificial enrichment of shallow and deep aquifers provide a promising method for reversing the trend of water resources development and groundwater depletion. According to the source, the average rainfall in the Kathmandu Valley is about 1,900 mm, more than twice the world average. Approximately 1.2 billion cubic meters per year or 3.353 billion litres (MLD) of rainwater falls into the 640 square kilometers valley. This is approximately 12 times the current water demand (Shrestha R. R., Rainwater Harvesting and Groundwater Recharge for Water Storage in the Kathmandu Valley, 2009).Groundwater recharging also helps to protect public open spaces and community ponds as these areas are considered ideal for the groundwater recharging. Moreover, the groundwater recharging also helps minimize monsoon floods and possibly minimizes the risk of collapsing of the lands of the valley due to the excess groundwater extraction (Recharging Kathmandu Valley).

Importance

Most of the government and individual projects on Rainwater harvesting are more focused on potable water consumption where only excess water gets recharged to the ground which is disturbing to the hydrological cycle. With a better understanding, it will help municipal decision makers in different sectors to rethink on decentralized ground water recharging from rainwater harvesting and develop policies to improve the residential urban scenario in terms of water sensitive urban planning.

In communities, rainwater harvesting is simply understood as an alternative to water sources rather than an important component of ground water recharging. So the study will throw light on benefits of ground water recharging from RWH and raise the awareness of water sustainability right from the academic level.

1.3. Problem Statement

The steady expansion of urban areas has put increasing pressure on the supply of water resources. With the rapid development of social economy, the contradiction between increasing water demand and limited water resources has become increasingly prominent. Due to the lack of sufficient advanced technology and adequate coordination between the government and the public, there are more and more problems with drinking opportunities nowadays. Climate change leads to shortages of drinking water in cities (Gautam).

Taking example of Kathmandu, due to the lack of adequate vision and structural design, the valley is facing serious problems with drinking water facilities, and the water supply is very poor compared to the current water demand. In recent years, despite heavy rainfall during the rainy season the winter is still relatively dry (Gautam). KUKL's supply only meets 25% of demand. Similarly, 35% of KUKL's total supply is wasted due to leaks. Although a person needs 135 litres of water a day, the per capita daily water supply in the Kathmandu Valley is only about 34 litres. According to KUKL data, the average daily demand for drinking water in the Kathmandu Valley is 375 million litres per day. But KUKL only supplied about 119 million litres (Per capita water supply in Kathmandu Valley at just 34 liters a day, 2017).

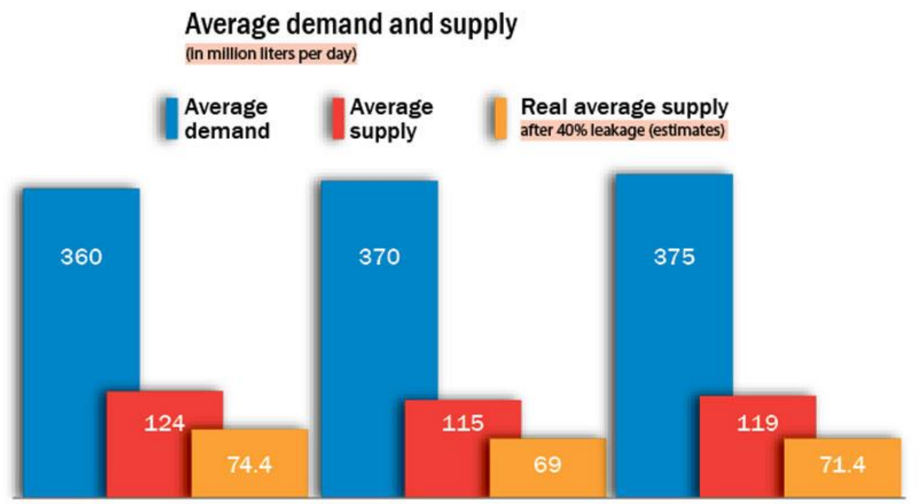


Fig.1-1: Average demand and supply of Kathmandu (Per capita water supply in Kathmandu Valley at just 34 liters a day, 2017)

However, on March 6, 2021, the water from the Melamchi River in Sindhupalchowk finally reached Kathmandu. The project aims to divert approximately 170 MLD of fresh water from the Melamchi River in Sindhupalchowk District to the Kathmandu Valley. The water in Melamchi is not enough to quench the thirst of the residents of Kathmandu. However, it will alleviate the water problem to a great extent. The government is preparing another phase of the project: transferring water from the Rak and Yangli rivers to Kathmandu. The total water supply of these two rivers is 340 million liters per day, 170 MLD each. After this phase is completed, Kathmandu will receive 510 million litres of water from Sindhupalchowk, which will solve Kathmandu's water problem (Maharjan, 2021).

But for now, to fulfil the water demand, households and businesses invest in individual local supplies and in-house storage, installing private wells to extract ground water on their own, and relying on water being delivered by tankers (Raina, 2017). The pie chart below shows that the main sources of water supply are part of the Municipality and part of the private water tanks in Ward 6, Kathmandu. Only 10% of HH has few of shallow tubes and nobody has deep tube wells. Similarly, no one has adequate RWHSs, but occasionally water collects only using large containers such as informal or non-systematic RWHSs. The result of the survey also revealed that the dependence of the municipal water supply system was low and other types of sources comply with the demand (Gautam).

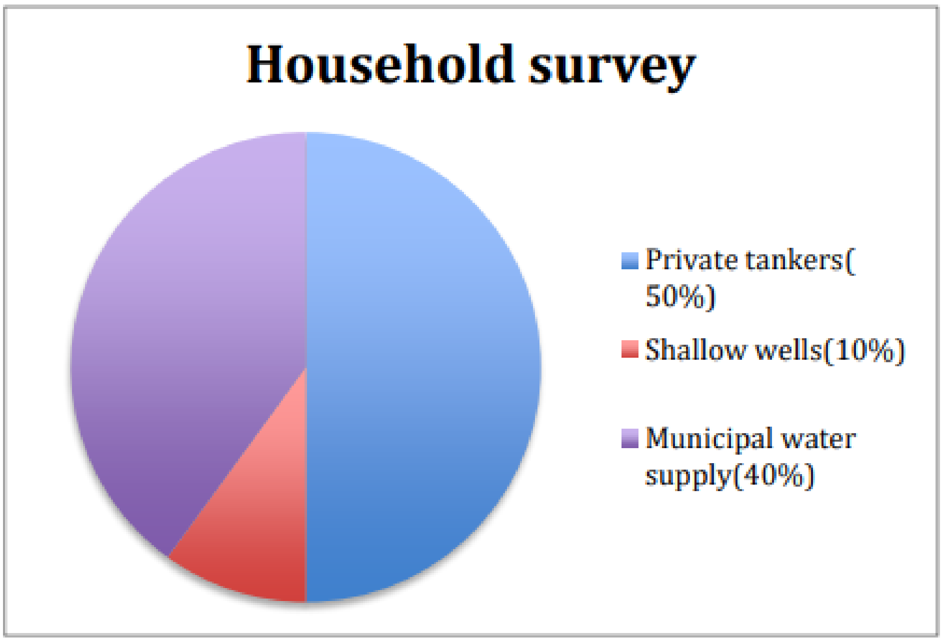
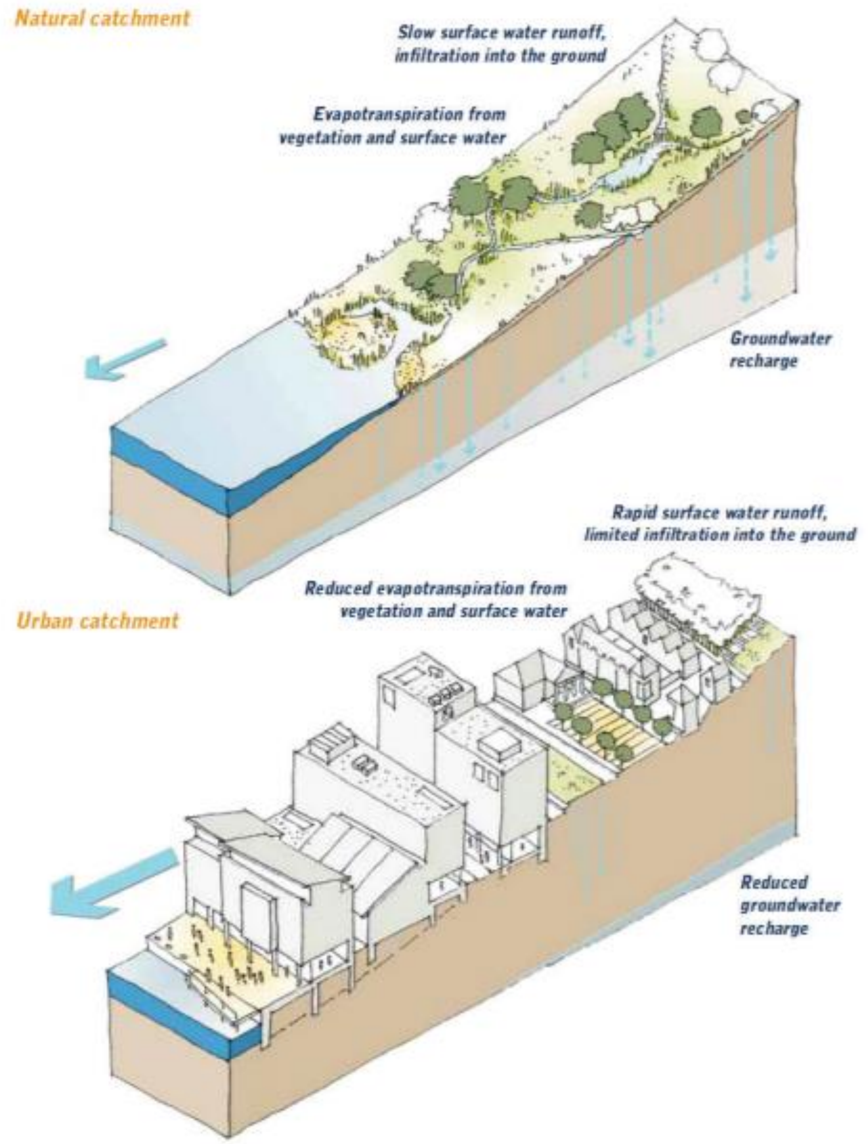


Fig.1-2: HH survey on different water supply sources of ward 6, Kathmandu (Gautam)

In the name of reaching possible alternative water sources, people who could afford RWH technologies are attracted towards rainwater harvesting for consumption that helps in water savings to some extent but it is hampering to the natural water cycle.

Another issue is that with the growing urbanization, the land surface of the Kathmandu valley is sealed by cement and concrete that blocked the water to enter the earth's surface. As a result, the ancient water sources of the valley, which were reliable water sources, now is drying. Almost more than half of the stone tubes inside the valley has already dried and the amount of water recovered from the ground underlying has increased the collector due to the lack of water in the valley. (Adhikari, 2020). Experts say that almost 83% of the land in Kathmandu is sealed with cement and concrete, which prevents water from penetrating the surface. This has a direct effect on the groundwater level in the valley.

The water provided by KUKL makes up almost 50% of the groundwater that is pumped through deep boreholes. According to KMC, this is also the cause of the drop in water levels in Kathmandu (The Himalayan, 2019). KUKL itself takes around 80 million liters of water every day from 80 deep boreholes to supply water in the valley, which is twice as much as the valley water replenishment (Adhikari, 2020).



Source: Dickie, S., McKay, G., Ions, L. and Shaffer, P., 2010. Planning for SuDS–making it happen. CIRIA Publication C, 687.

Fig.1-3: Difference between natural and urban catchment

The above figure depicts the natural and urban catchment area where there is reduced ground water recharging due to decrease in vegetation. Also, increased urban wastewater generation is another negative impact of urbanization which could be minimized by harvesting rainwater through rainwater harvesting.

The figure below clearly shows the case reflecting urban water cycle where there is low groundwater flow with more run off water as there is increase in construction of buildings and paved areas.

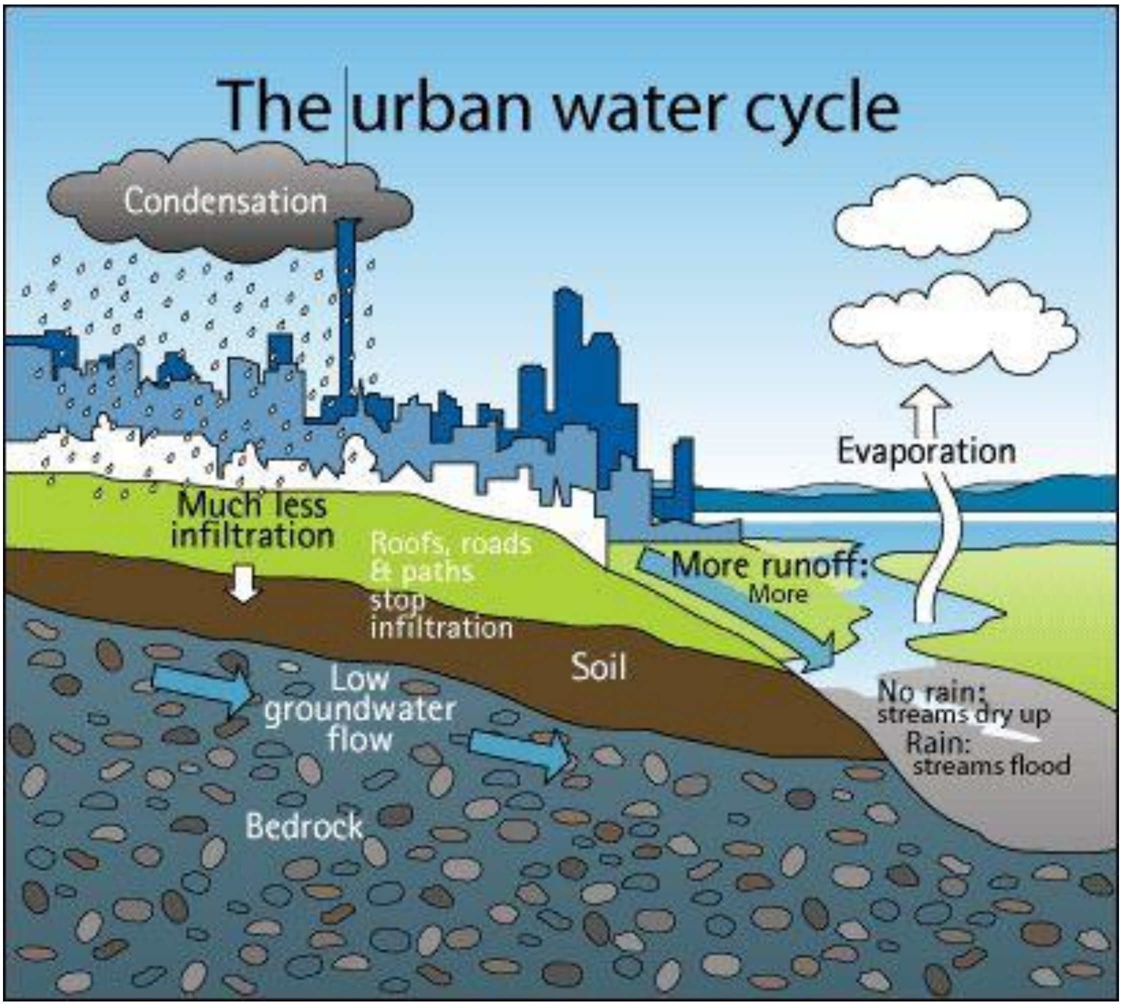


Fig.1-4: The Urban water cycle (Urban Water Cycle)

The Kathmandu Valley is the most densely populated city in Nepal.. The groundwater system in the Kathmandu Valley is being affected by the increased extraction rate and low ground water recharging. Groundwater is a source of drinking and for other purposes for household use. Increased water extraction rates coupled with increasing impermeable surfaces associated with urban areas can ultimately pressurize groundwater systems (K.C., 2011)

According to Suman Shakya, Managing Director at Smart Paani Pvt Ltd, “Nowadays, as people have started depending on groundwater for fulfilling their daily water needs; there is a double negative effect on the environment – First, people extract groundwater which is limited and second, they do not put water back to the ground, which causes water tables to further decrease. This should be changed and everyone should take measures to conserve water as it starts from an individual leading to societal change" (PPP to promote innovative solutions for water recharge, 2018).

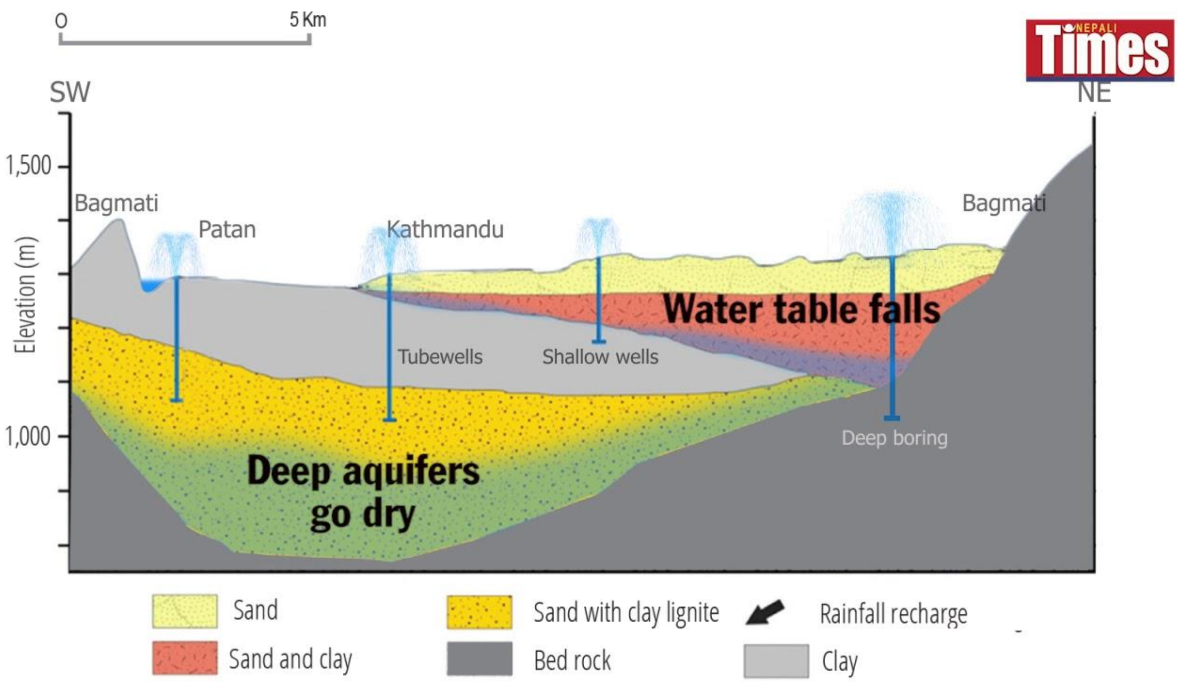


Fig.1-5: Kathmandu's lowering water table (Awale, 2017)

The figure above shows the condition of water level of Kathmandu Valley. Due to overexploitation, the groundwater level drops as much as 1 m per year. The valley used to be the lake bed, and the only source of water here was rainwater seeping into the ground. The ground under our feet is a huge sponge, which is drying out, because the pumped water is more than the natural replenishment. The 3.5 million people in Kathmandu need around 360 million litres of water every day: half of this is obtained by pumping groundwater. This causes the groundwater level to drop by an average of 80 cm per year, exposing the valley to hazards such as sinkholes, dying forests and pollution. Users must also drill deeper every year and require more energy to pump water. The remaining groundwater will also contain higher concentrations of ammonia, nitrate, iron, and even arsenic, making it unsuitable for human consumption.

"We are extracting excessively from the ground, and human activity has reduced natural recharge. The solution is to replenish groundwater: it is foolish to let rainwater drain away," explains Padma Sundar Joshi of UN Habitat. So, groundwater has to be maintained as it is vital part of valley's ecology (Awale, 2017).

1.4. Research Objective

General Objective

The overall objective of the thesis work is to investigate the role of decentralized rainwater harvesting for improving scenario of urban residential area in terms of sustainability.

Specific Objective

The specific objectives of the project are summarized as follows:

- To explore the water demand met by decentralized rainwater harvesting
- To explore the contribution of decentralized ground water recharging to improve the water infiltration in an urban residential area.
- To explore the contribution of decentralized rainwater harvesting to minimize waste water of an urban residential area.
- To explore the people's perception towards rainwater harvesting.

Research Question

What is the major component of rainwater harvesting for improving urban residential scenario in terms of sustainability?

1.5. Limitations

For this study, I will be only looking at potential of rainwater harvesting in case of urban residential buildings only. The study does not include the detail study of maintenance and treatment components of the Rainwater harvesting technology. The research will not include the laboratory tests on water quality or water quality itself. This study does not account for economic aspect of the rainwater harvesting technology. The study will also not focus on exact quantitative data on rise of water table from ground water recharging.

Chapter 2: Literature Review

2.1. Relation between population and water problem of Kathmandu

The rapid urbanization of the Kathmandu Valley began in the early 1950s, when the political situation changed drastically. Since the 1940s, the valley has also developed into the center of the country. The development of infrastructure started to begin. At the time of rapid development, infrastructure such as water supply and roads were not properly designed for the future. Due to the lack of proper pre planning, the valley is facing major problems with the supply of drinking water. Compared with the current water demand, the water supply is very low. In recent years, although the rainy season has abundant rainfall, winters have become increasingly dry. In 2009, the country experienced more droughts due to less rainfall during the monsoon season. In some respects, the country faces more water problems due to the lack of adequate water storage facilities (Gautam). Author mentioned that every year about 4,000 new houses are built in the city of Kathmandu leading to rapid urbanization.

Kathmandu Valley has been suffering from a shortage of drinking water since the 1980s, and the situation is getting worse (Shrestha R. R., Rainwater Harvesting and Groundwater Recharge for Water Storage in the Kathmandu Valley, 2009).

According to the data of 2016, the metropolitan city of Kathmandu, the city of Lalitpur, and the municipalities of Madhyapur Thimi, Bhaktapur and Kirtipur have the highest demand for water due to their very dense populations and various changes in the lifestyle such as the use of full flushing toilets, etc. (Udmale, Ishidaira, Thapa, & Shakya, 2016).

Table 2-1: The Kathmandu Valley's estimated water demand (Udmale, Ishidaira, Thapa, & Shakya, 2016)

Year		2001	2006	2011	2016	2021
Kathmandu Valley population (in millions)		1.59	1.95	2.42	3.08	4.00
Water demand in the valley (MLD) *	Assuming 135 lpcd	214.6	262.8	327.1	415.5	540.3
	Using BIS guidelines	183.9	224.9	282.5	366.0	481.5

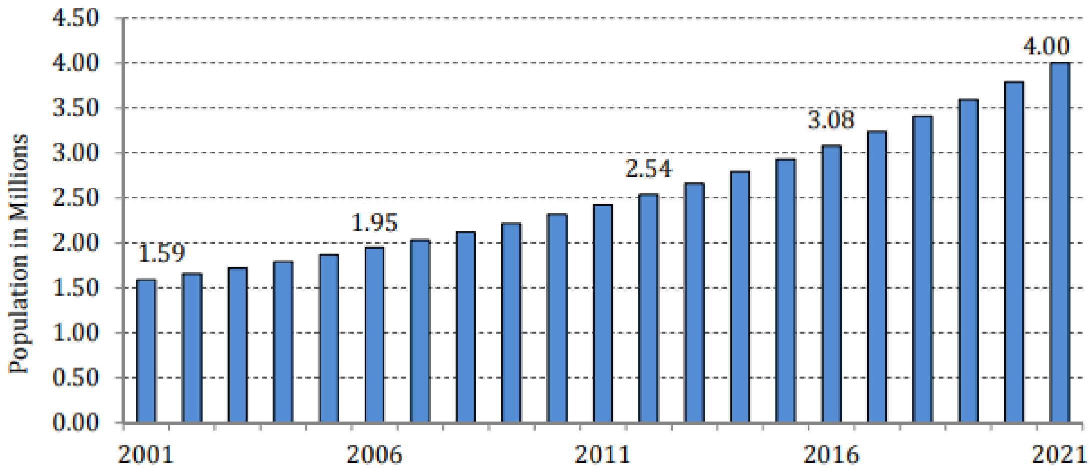


Fig.2-1: Annual population growths in Kathmandu Valley (Udmale, Ishidaira, Thapa, & Shakya, 2016)

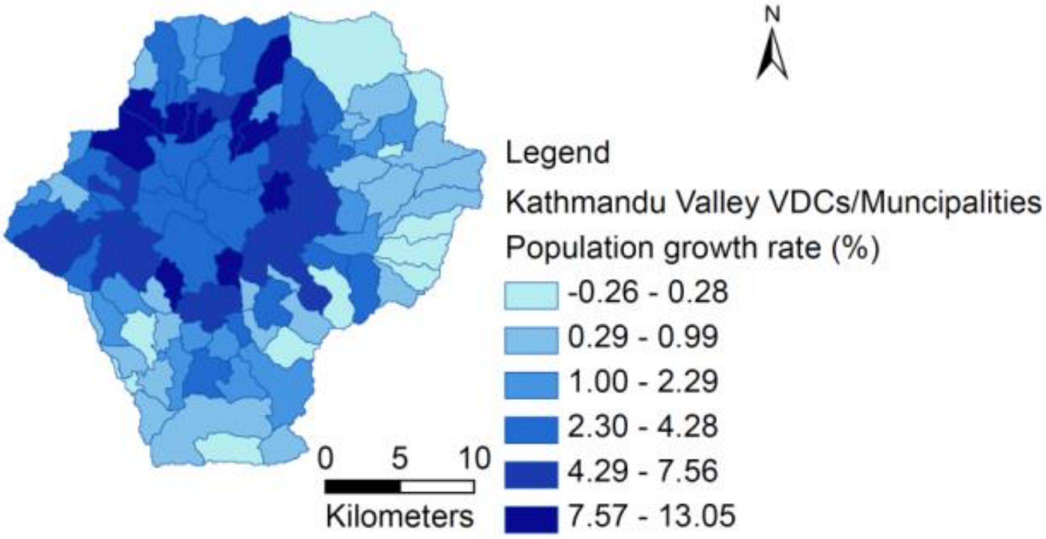


Fig.2-2: Annual population growth rates at VDC levels (Udmale, Ishidaira, Thapa, & Shakya, 2016)

Above figure shows the annual population growth rates at VDC levels. The VDC wise annual exponential population growth rates in the Kathmandu Valley were ranged from 0.26% to 13.05% over the period of 10 years (2001–2011). The population growth rates were moderate (2.4% to 4.3%) in KMC, LSMC and other 17 VDCs. However, the population growth rates were highest (4.4% to 13.1%) in VDCs located near or in the vicinity of KMC and LSMC; those can be classified as rapidly urbanizing VDCs. The high population growth rates in these VDCs may have resulted from the migration of population (due to better education, health, and other facilities) from surrounding VDCs and other parts of Nepal.

However, KUKL is the authorized agency to provide drinking water for the Kathmandu Valley. The figure below graphically shows the water supply capacity of KUKL, estimated demand, estimated deficit without MWSP and estimated deficit if MWSP first phase could be completed. This clearly depicts the gap in water demand and supply in Kathmandu.

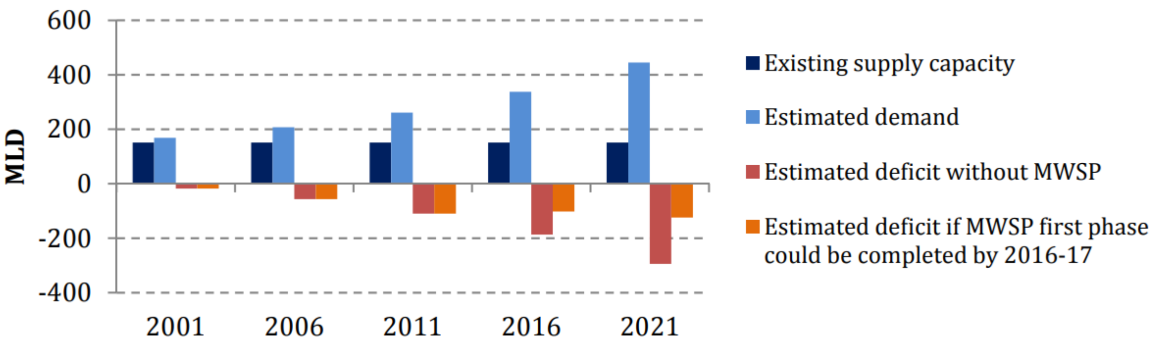


Fig.2-3: KUKL Service Area: Water Supply, Demand and Deficit (Udmale, Ishidaira, Thapa, & Shakya, 2016)

The Nepalese government has been unable to cope with the current situation, which eventually led to more and more problems that could not meet the water needs of the growing population. With the decline of the groundwater level, rapid urbanization has affected the rainwater recharge of the underground aquifer, causing serious problems with the supply of drinking water to meet current water demand. (Gautam).

2.2. Weather patterns and local rainfall data of Kathmandu

Due to geographical and topographical characteristics, Nepal's weather can be divided into four seasons: spring from March to May, summer from June to August, autumn from September to November, and winter from December to February. Summer is the monsoon season from June to September, and almost all-annual rainfall falls during this period. Whereas, the remaining October to June of the year is often referred to as the dry season (Hofer, 2014).

Annual rainfall in Kathmandu is 1,400 mm (55 in), of which 115 mm (4.5 in) fell in May (due to pre-monsoon thunderstorms) and as much as 360 mm (14.2 in) in July that is the rainy month. There was still 185 mm (7.3 in) of rainfall in September and 60 mm (2.4 in) in October, concentrated in the first half of the month before the monsoons receded. This is the average rainfall (Climate-Nepal).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Prec. (mm)	15	15	30	55	115	255	360	315	185	60	10	15	1425
Prec. (in)	0.6	0.6	1.2	2.2	4.5	10	14.2	12.4	7.3	2.4	0.4	0.6	56.1
Days	2	3	4	6	12	17	23	22	15	4	1	1	110

Fig.2-4: Average Precipitation of Kathmandu (Climate-Nepal)

The annual rainfall in Kathmandu is approx. 1600 mm (equivalent to 160,000 litres per hectare of land) (Thanju & Shrestha). Many people are not aware, of which the Kathmandu valley receives an average of 1600 mm rain every year. This is within the distance of what should bring the Melamchi water supply project (170 MLD a day). If all the houses manage to allow rainwater to filter themselves on the ground, water levels certainly increase in the valley, which will help the family take water from underground wells undergoing and using it (smartpaani, 2015).

2.3. Soil Condition of Kathmandu Valley

The parts of the North and northeast of Kathmandu have a great potential for deep aquifers. Previous studies and research recommend excavators, shallow pipes and recharge wells to recharge the shallow aquifers. The restoration of the pond and the canalization of rainwater in the ponds also supports the refill of underground aquifiers (Shrestha R. R., Rainwater Harvesting and Groundwater Recharge for Water Storage in the Kathmandu Valley, 2009).

Talking about the groundwater system of the valley, it is supposed to have closed and isolated groundwater basin having irregular and discontinuous aquifers. The principal aquifers of the Kathmandu Valley are sand and gravel beds i.e. with fluvio lacustrine sediments. These are mainly at northern and north eastern parts of the valley with alluvial type. Whereas at central parts, there is thick sequence of lacustrine clay. And at the southern and south western parts, there are sand and gravel beds with silt and clay layers. A general cross-sectional view of subsurface geology and hydrogeological system of the Kathmandu Valley is presented in figure below (Shrestha S.).

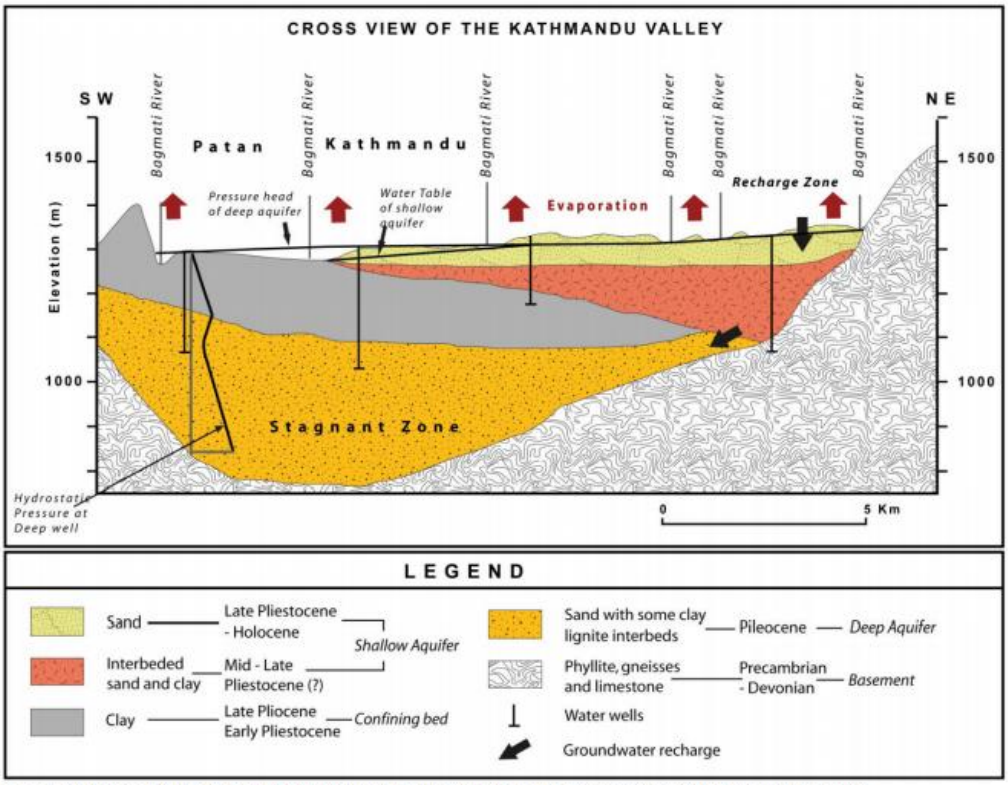


Figure 3.2 Cross-sectional view of subsurface geology and hydrogeological system of the Kathmandu Valley (modified from GWRDB, 2009)

Fig.2-5: Cross sectional view of Kathmandu Valley (Shrestha S.)

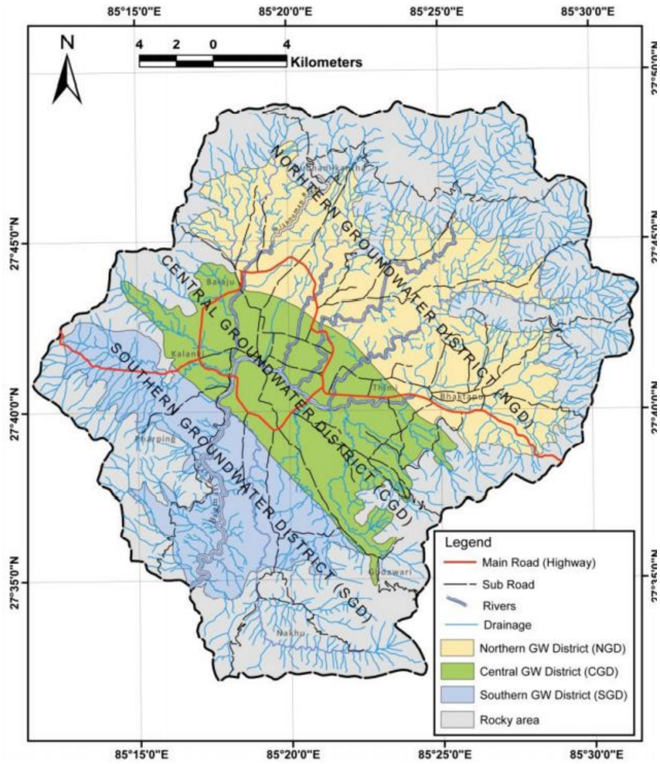


Fig.2-6: Hydrological Districts in Kathmandu Valley (JICA,1990) (Shrestha S.)

The figure above shows the hydrological districts of Kathmandu Valley. JICA (1990) divided the deep part of the Kathmandu Basin into three groundwater areas based on the physical and chemical properties of groundwater and geological conditions. They are the Northern Groundwater District (NGD), the Central Groundwater District (CGD), and the Southern Groundwater District (SGD). The NGD sediments consist of loose, highly permeable mica sand and gravel materials. The loose coarse sediment is up to 60 m thick. CGD consists of very thick, impermeable (approximately 200 m) black Kalimati clay, with some lignite and peat. The SGD has an aquifer, which has not been well developed except along the Bagmati River between Chobhar and Pharping. Like CGD, this area is characterized by a low T basement gravel covered with a thick impermeable clay formation (Shrestha S.).

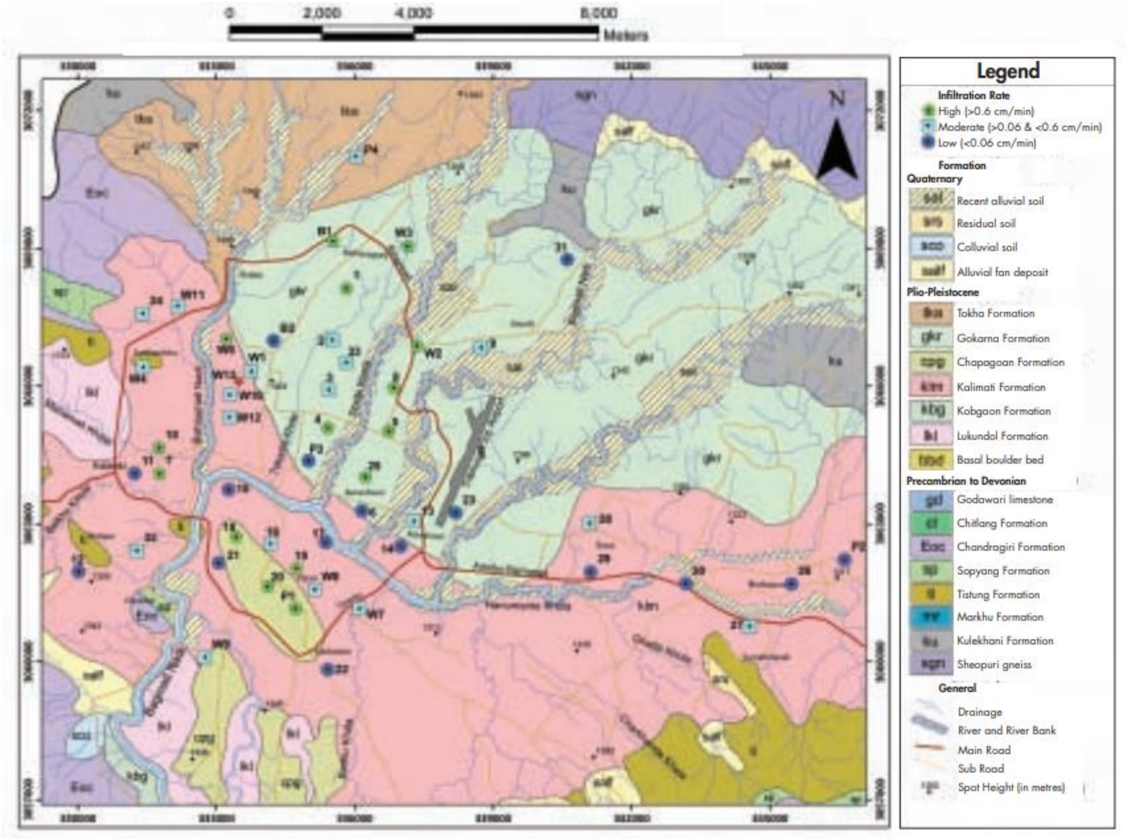


Fig.2-7: The rate of infiltration during the monsoon season in a potential recharging zone in Kathmandu Valley (Shrestha R. R., Rainwater Harvesting and Groundwater Recharge for Water Storage in the Kathmandu Valley, 2009)

The figure above depicts the geological setting of the Kathmandu Valley.

2.4. Water and sustainable development

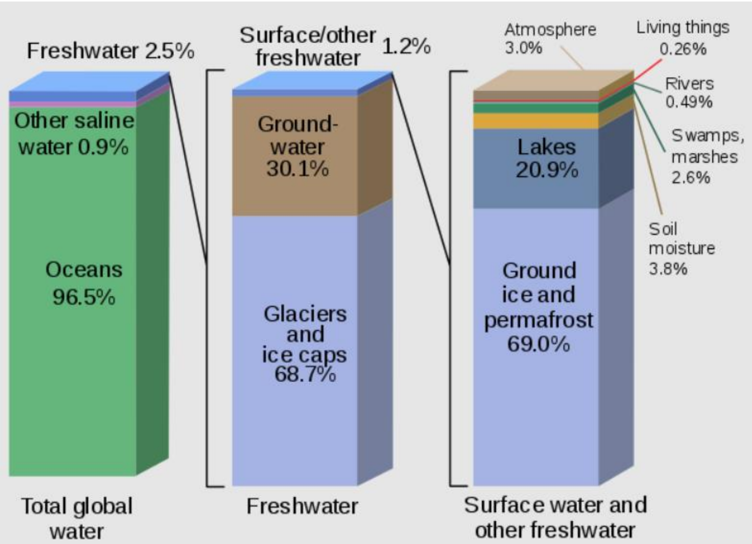


Fig.2-8: Earth's Water Distribution (Wikipedia)

Most water in Earth's atmosphere and crust comes from saline seawater, while fresh water accounts for nearly 1% of the total (Wikipedia) as depicted in figure above.

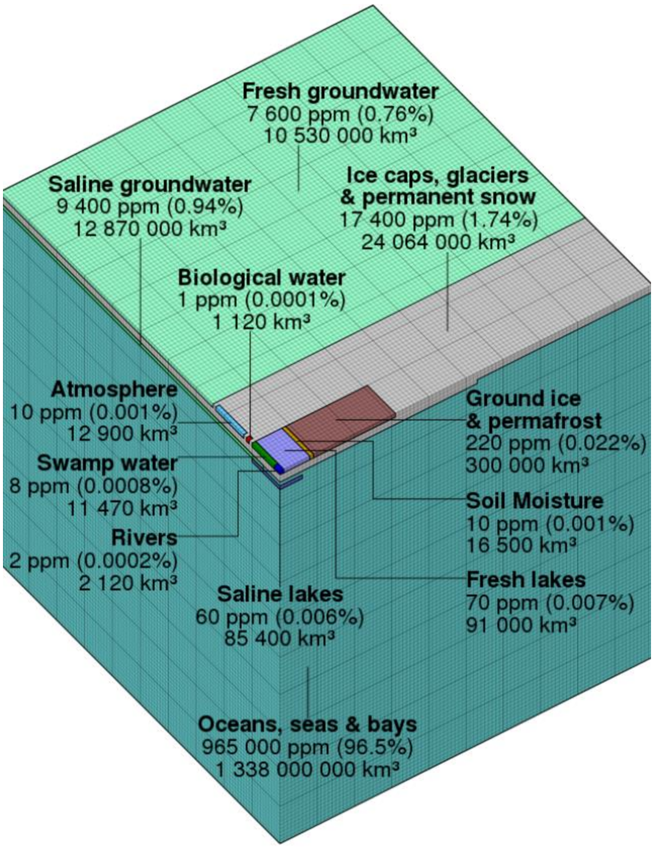


Fig.2-9: A map depicting the locations of water on the planet (Wikipedia)

Water is at the core of sustainable development and is very essential to social and economic development and healthy ecosystems. Water is also a finite and irreplaceable resource that is essential to human wellbeing. Only when properly managed can it regenerate. It is essential to reduce the global burden of disease and improve the health, well-being and productivity of the population. Water is also at the heart of adaptation to climate change and an important link between the climate system, human society and the environment. Today, more than 1.7 billion people live in river basins that have been depleted through use and exceed natural reconstruction. By 2025, two thirds of the world's population will live in countries with water scarcity. This trend is becoming a serious challenge for sustainable development. But it can be managed effectively. To be fair, in the face of rapid and unpredictable changes, water can play a vital role in strengthening the resilience of social, economic and ecological systems (UNDESAI, 2015).

2.5. Water sustainability

‘Water sustainability also means effective and holistic management of water resources.’ Today’s demand for water resources is diverse and requires sustainable, integrated and comprehensive water resources management (Aqua Tech, 2019).

The managed cities understand and face their water in a sustainable way. This means that effectively provides safe, reliable and easily accessible water, as well as reliable sanitary and a protected river stretch from pollution. Sustainability also means being resistant and adaptable to extreme weather events that can contribute to problems such as floods and water scarcity (Hill, 2016).

Fig.2-10: Three elements of a sustainable water future (Hill, 2016)

2.6. Hydrological Cycle

As shown by the water cycle, all water will eventually be recycled in the ecosystem. The water cycle refers to the continuous transportation of water in the environment, evaporating from the surface of biota, land and water bodies connected to clouds, moving through the climate system, and then precipitation in the form of rain or snow. Humans have learned to intervene in this cycle by developing water storage tanks and network systems to promote water use, subsequent treatment for reuse and/or return to the environment (Radcliffe). The components of the hydrological cycle are shown in the following figures by different sources.

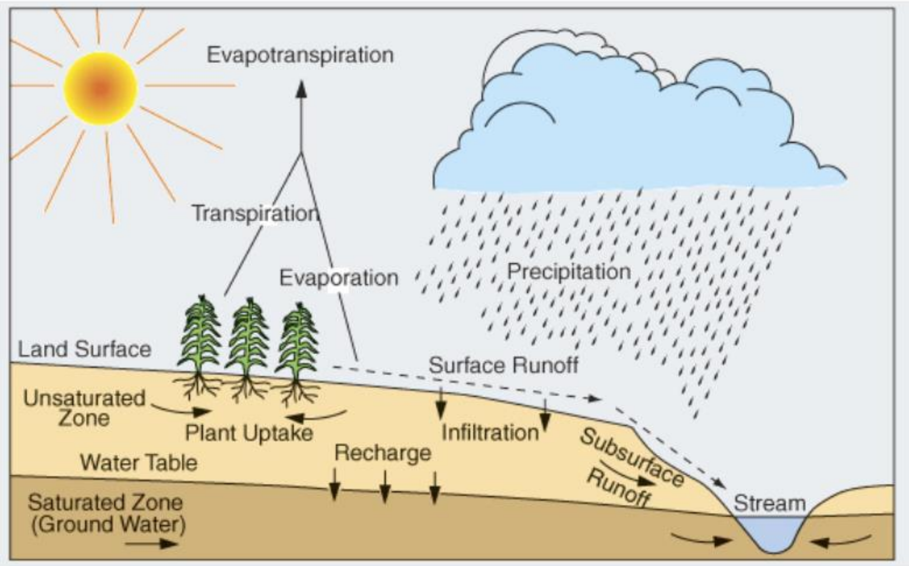


Fig.2-11: Hydrological cycle (Adhikari, 2020)

The figure below shows the ecological cycle of the forested and the urban area. As shown in figure, in case of nature, most rainwater evaporates and is absorbed by plants or seeps into the ground. The urban development has drastically changed these processes by removing vegetation from the land and covering it with a "hard" or impermeable surface that no water can pass through. As a result, rainwater flows off these surfaces, passes rainwater drains and quickly reaches our bodies of water as contaminated rainwater. This changes the time, speed and volume of the water flow and thus affects the river basins (Melbourne Water, 2017).

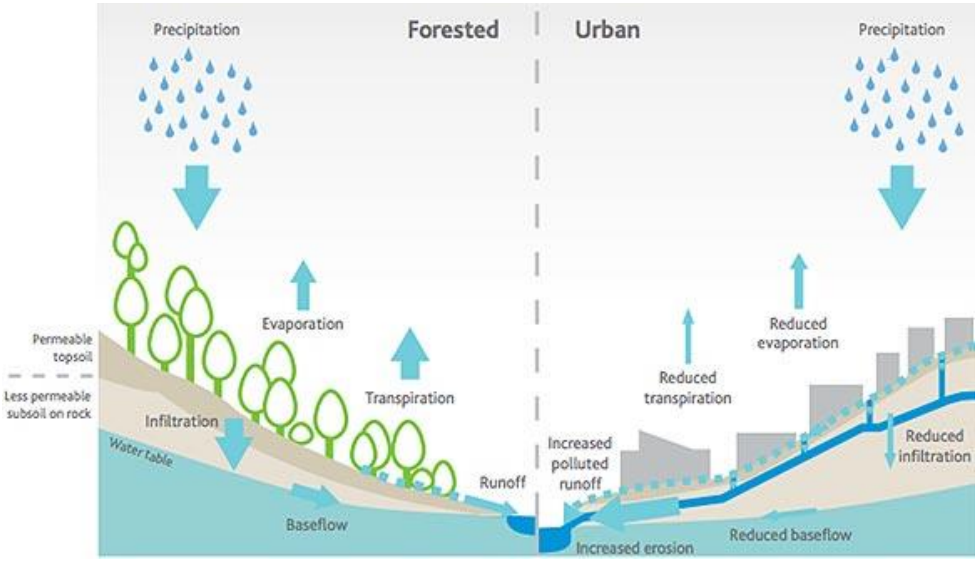


Fig.2-12: Rainwater runoffs in forested and urban area (Melbourne Water, 2017)

Due to the constant further development of building construction and urban development, the natural terrain is being replaced by compact soil, for example the roofs of buildings, road, parking lots, etc. When rainwater reaches these surfaces, almost 80% flows of the water in sewage treatment plants or rivers and only 20% seep away on the surface. Floor. This leads to ecological damage such as floods, heavy rain, lower underground water levels, local soil desiccation and endangerment of sensitive ecosystems. It is not only important to build and develop urban planning, but also to build and develop the artificial regulation of the water cycle in nature, which helps to maintain the ecological stability of the selected location.

Drainage of excess volumes of rainwater from large areas of roofs and paved areas is also a problem technically. The design of the infiltration or the recharge structures reduces the initial flow of the first volume of influential rainwater and reduces the overload of sewerage systems and reduces the risk of floods (G. Markovič, M. Zeleňáková, D Káposztásová , & G. Hu, 2014)

2.7. Rainwater Harvesting

Rain is the first known form of water in the water cycle and is therefore our main source of water i.e. primary source. Whereas, rivers, lakes and groundwater are secondary sources. Now, we are completely dependent on these secondary water sources, rather than using rainwater, which is ultimate source of supplying all of these secondary water sources. The collected rainwater can be stored and used directly or fed back into the groundwater (Gautam).

Rainwater collection is rainwater deposition for re-installations on site, instead of flow that also helps reduce overloads to water treatment plants, as well as avoiding outflow from going to the drainage system. Similarly, it helps to recharge water in aquifers and improves groundwater quality through dilution (Parajuli, 2018). Therefore, the two main methods can be defined for rainwater harvesting (RWH). It either collects onshore runoff in any type of storage tanks or reservoirs or directly penetrates into the ground to supplement the groundwater level, or it collects rainwater directly from the roof.

Fig.2-13: Common Rainwater Harvesting System's components (rainwaterharvesting.org)

The common components of a rainwater harvesting system are:

- Catchments.
- Coarse mesh.
- Gutters.
- Conduits.
- First flush.
- Filters.
- Storage tanks and
- Recharge structures (rainwaterharvesting.org).

2.7.1. Rainwater harvesting for immediate or household use

During a period of precipitation, rainwater is falling on the surface, towards the ground or on the roofs, and from there it is driven directly in the storage tanks (Hofer, 2014) for different purposes like irrigating fields, to bathing or washing laundry and, if several precautions are made, even can be used for drinking. The following figures depict the various kinds of rainwater catchments.

The most common and well-known system is to use the roof of a house or shed as a catchment area and store the collected water in a nearby water tank as shown in figure below.

Fig.2-14: Roof dependent RWH-system

The second technology is the “Land surface catchments” (Hofer, 2014) where rainwater is collected as surface and surface runoff by improving the runoff and directing it to the water reservoir, as shown in the figure below. This can be achieved by introducing drainage pipes in selected areas or manipulating existing vegetation to increase drainage capacity. In addition, streams and streams can also be used to fill storage tanks.

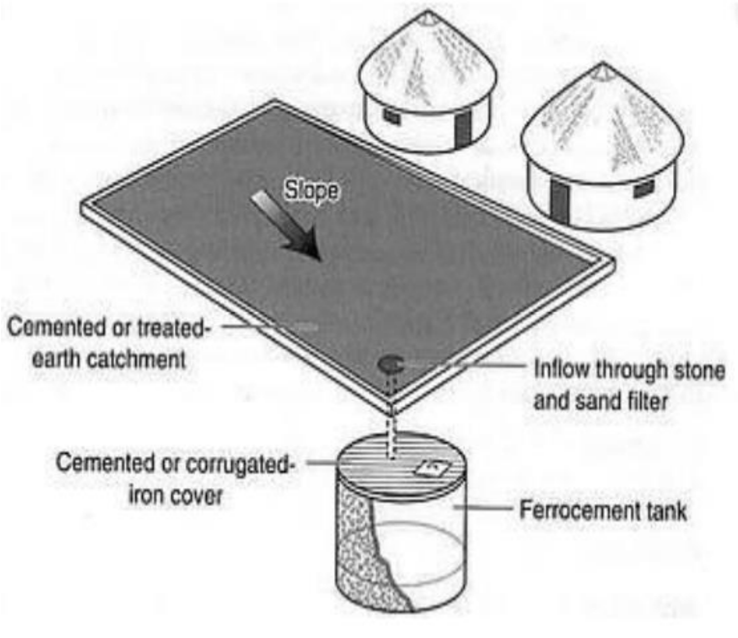


Fig.2-15: Land surface catchment (Hofer, 2014)

As a third, method the “Rain Saucers” design can be mentioned as a third technology where an alternative capture area is used i.e. "saucer" which captures the rain. This approach aims at an independent home solution, which allows a greater flexibility of the actual position in which water is necessary and preferably collected (Hofer, 2014) as shown in the following figure.

Fig.2-16: Example of Rain Saucer design (Hofer, 2014)

2.7.1.1. Factors affecting evaluation and design of RWH

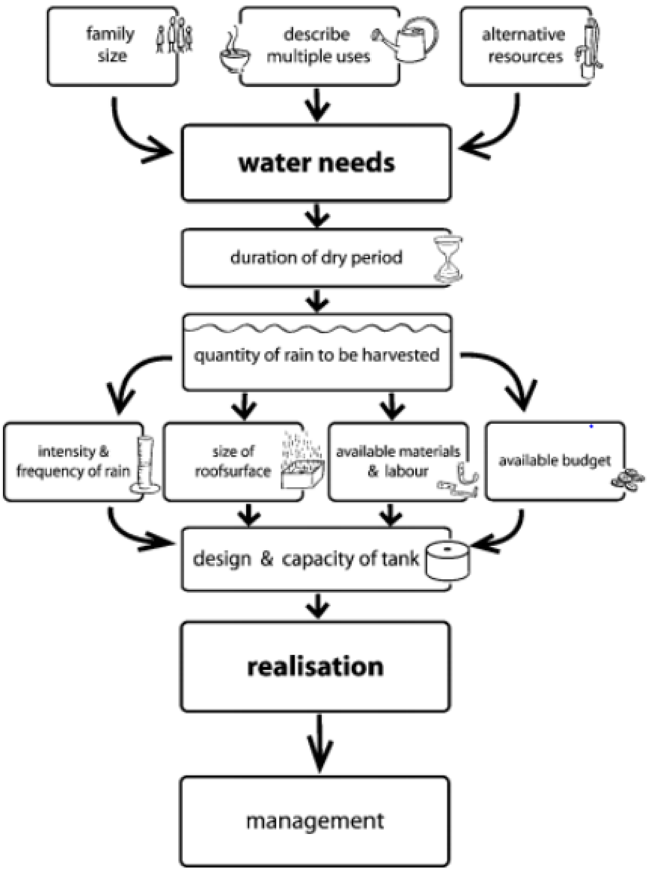


Fig.2-17: Approach of evaluating and designing RWH-systems (Hofer, 2014)

To perform a reliable evaluation of the profitability of RWH techniques, various factors are to be considered (Hofer, 2014). The figure above shows a basic description of all the key aspects.

2.7.1.2. Components of a rainwater harvesting system

The components that are needed in RWH can be easily installed in a new building with relatively little effort, but retrofitting in an existing building is more difficult. The typical process diagram below clearly shows the flow of the system for drinking water purpose.

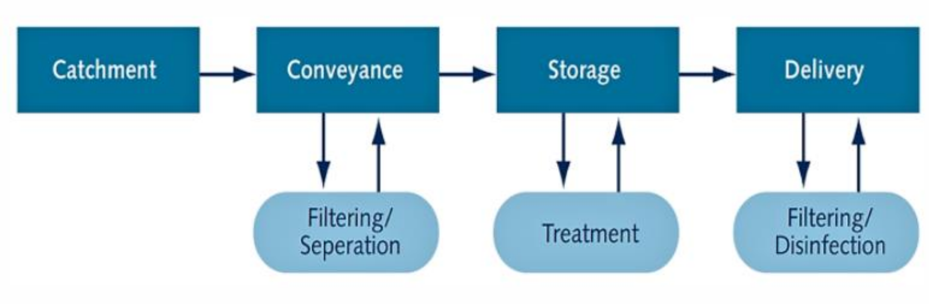


Fig.2-18: Process diagram of a drinking water RWH system (Gur & Spuhler)

The major components of a rainwater harvesting system are shown in figure below along with the list.

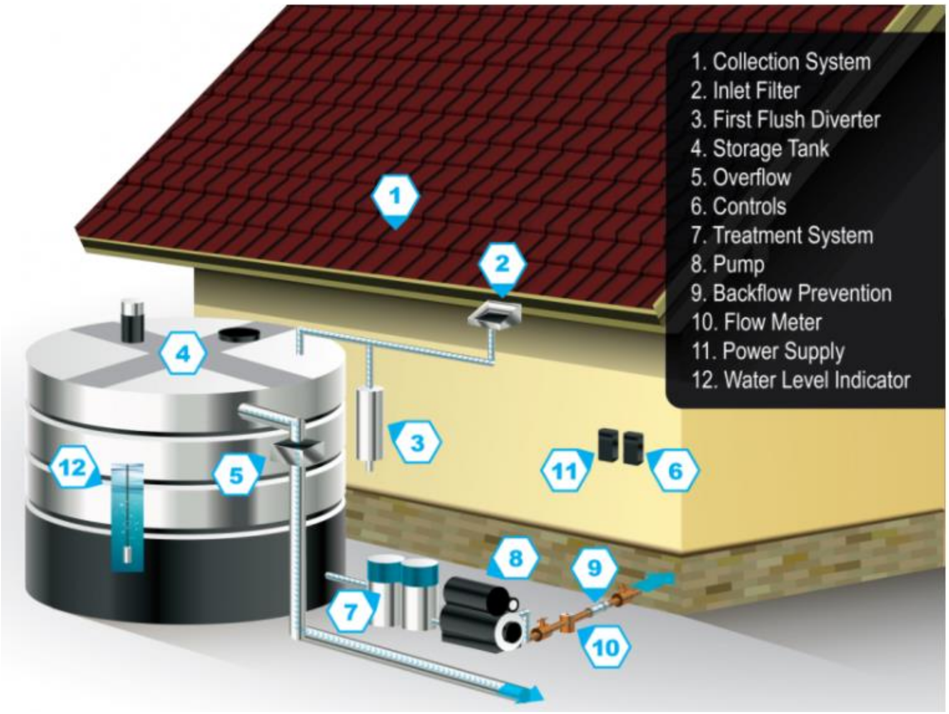


Fig.2-19: A typical rainwater harvesting system components (Energy)

2.7.1.3. Catchment area

Calculating the size of the area of a flat roof is as follows:

$$\text{Area} = \text{length X width}$$

Whereas for the pitched roof,

$$\text{Area} = l \text{ X } (f + g/2)$$

With:

l= Length of the roof

f= Width of the roof till the pitch

g= Height of the roof (Hofer, 2014).

2.7.1.4. Water harvesting Potential

Water harvesting Potential = Rainfall (mm) X Area of Catchment X Runoff coefficient

2.7.1.5. Demand

The most important aspect of the tank is that its capacity corresponds to the needs throughout the dry season. For this, two simple calculations can be made.

For drinking water

Required demand:

Demand = (Water Use X Household Members X 365days)/ 12 months

With: Demand (l/month) Water Use (l) (Hofer, 2014)

For irrigation water

Required storage capacity: (Water demand – precipitation) X field size

With: Storage capacity (m^3)

Water demand (m^3/m^2) for total growing period

Precipitation (m^3/m^2) of total shortage period

Field size (m^2)

2.7.1.6. System Sizing

The following are the basic steps to correctly determine the size of the rainwater collection system storage tank.

1. Calculate the amount of rainwater that is available for collection.

2. Determine the monthly demand for the application throughout the year.

3. Compare the amount of monthly rainfall that can be harvested to the monthly water demand over the year.

4. Determine an optimal size of the storage tank that provides sufficient volume to store adequate rainfall to meet the demand.

If there are great rain variations throughout the year, a larger tank can be needed to store rainwater during the wet months for use during drier months (Energy).

2.7.1.7. Storage tank

There are many ways to determine the size of the tank, some of which may be region-specific. One criterion is that the water tank should be large enough to meet the average demand for 18 days or 5% of annual production, whichever is lower (Peacock Irrigation, 2011). Another criterion is that the water tank can store enough water to cover the average demand during the longest period of drought (according to 30-year climate data statistics). The return can be calculated using the following simple formula:

S = (R/1000) x A x RC		
S	Annual supply	m^3
R	Annual rainfall	mm
A	Plan area draining into collection pipes	m^2
RC	Run-off coefficient	0 – 1

Fig. 2-20: Calculation of storage tank

Annual precipitation varies greatly between and within countries and through years. Annual average annual precipitation data must be obtained from the nearest weather station. The area shows the area of the floor, which will differ from the roof area for inclined roof surfaces (Styles, Schönberger, & Martos, 2013). While calculating the rainwater, run off coefficients are also to be considered which is different for different surfaces. Some of them are tabulated below.

Table 2-2: Coefficients of runoff for varied catchment surfaces

Type of Catchment	Coefficients
Roof Catchments	
- Tiles	0.8- 0.9
- Corrugated metal sheets	0.7- 0.9
Ground surface coverings	
- Concrete	0.6- 0.8
- Brick pavement	0.5- 0.6
Untreated ground catchments	
- Soil on slopes less than 10 per cent	0.0 - 0.3
- Rocky natural catchments	0.2 - 0.5
Untreated ground catchments	
- Soil on slopes less than 10 per cent	1.0 - 0.3
- Rocky natural catchments	0.2 - 0.5

Source : Pacey, Arnold and Cullis, Adrian 1989, Rainwater Harvesting: The collection of rainfall and runoff in rural areas, Intermediate Technology Publications, London

Type of catchment	Runoff coefficient
Roof top	0.75 - 0.95
Paved area	0.50 - 0.85
Bare ground	0.10 - 0.20
Green area	0.05 - 0.10

Fig.2-21: Run-off Coefficients (Rainwater Harvesting and Utilization)

2.7.1.8. Technology Considerations

The following are important considerations when planning rainwater harvesting projects.

End Use: The intended end use of the collected rainwater will determine the type of treatment equipment required by the system.

Site location: Choose a location with sufficient rainfall for the application.

Applications: Choose a location with multiple applications that can use rainwater like Vehicle washing, landscape irrigation, and dust control.

Size of catchment area: A larger roof area can collect a lot of rainfall even in areas with less rainfall.

Rainwater storage capacity: In areas with less rainfall, larger tanks may be required to provide greater storage capacity.

Roof pitch and type: Roof material and slope will affect the amount of water that can be collected. Lower pitched roofs tend to collect more water than pitched roofs. A smoother roof texture is better for run off than a rough roof.

Water rates: Areas with higher water rates will make rainwater harvesting projects more economical.

Permits: A rainwater use permit may be required. Please consult your local or state government (Energy).

2.7.2. Rainwater Harvesting for Ground Water Recharging

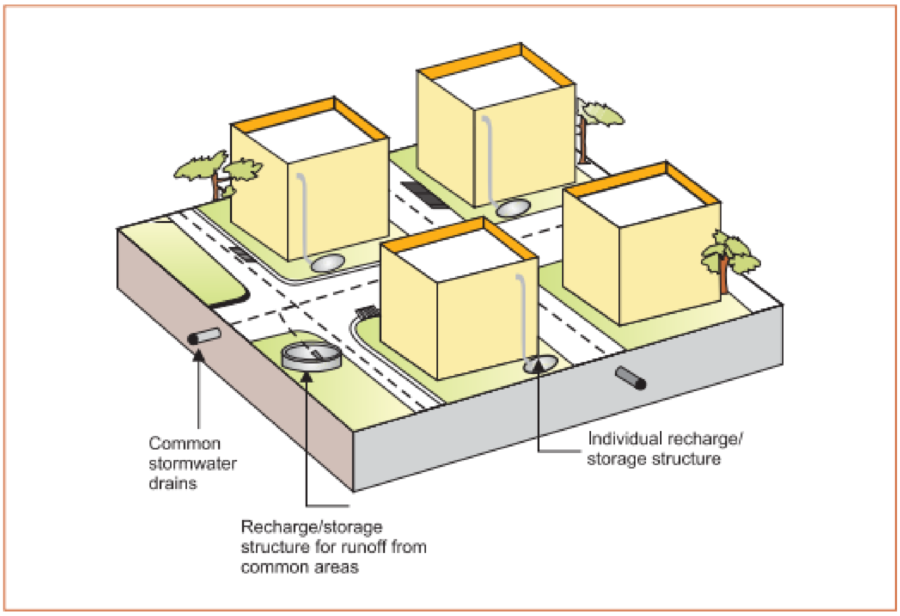


Fig. 2-22: Buildings with individual recharge pits

Shallow Groundwater Recharging

Simply, groundwater recharging is the diversion of the surface rainwater runoff into underground soil surface after the filtration. It takes place naturally when water is allowed percolate through the soil or is collected in the ponds. The groundwater can be recharged artificially when surface runoff is allowed to move into the ground through the simple techniques like construction of recharge wells with filter chambers. This may need some improvements in the surface drainage system including surface levelling (Recharging Kathmandu Valley).

GWHS is a natural collection system in which rainwater falls on the surface moves together with the rock and soil, settles in the aquifer area, and finally collects at a certain point underground in the aquifer. A certain area should be sufficient to absorb precipitation and penetrate into the soil for groundwater collection (Gautam).

Similarly, artificial ground water recharging is a planned human activity, through efforts to increase the natural replenishment or penetration of surface water to aquifers, thereby increasing the amount of groundwater available, and thereby increasing the amount of groundwater that can be extracted accordingly.

During precipitation, rainwater falls on the ground, whether on land or on the roof, and then directly enters the charging pit from there for groundwater replenishment. Several methods are currently available for assisted groundwater recharge. These measures include recharge pits and permeable walkways, which encourage water to infiltrate through shallower soil layers; and charging wells, which allow rainwater to infiltrate deeper into the soil (Shrestha R. R., Rainwater Harvesting and Groundwater Recharge for Water Storage in the Kathmandu Valley, 2009).

2.7.2.1. Recharge Structures

1. Recharge Pit

Soil surveys will determine the best location for regeneration pits to infiltrate rainwater into the soil. In alluvial areas where permeable rocks are exposed on the land surface or are located at very shallow depth, rainwater harvesting can be done through recharge pits. The technique is suitable for buildings having a roof area of 100sq.m. These are constructed for recharging the shallow aquifers.

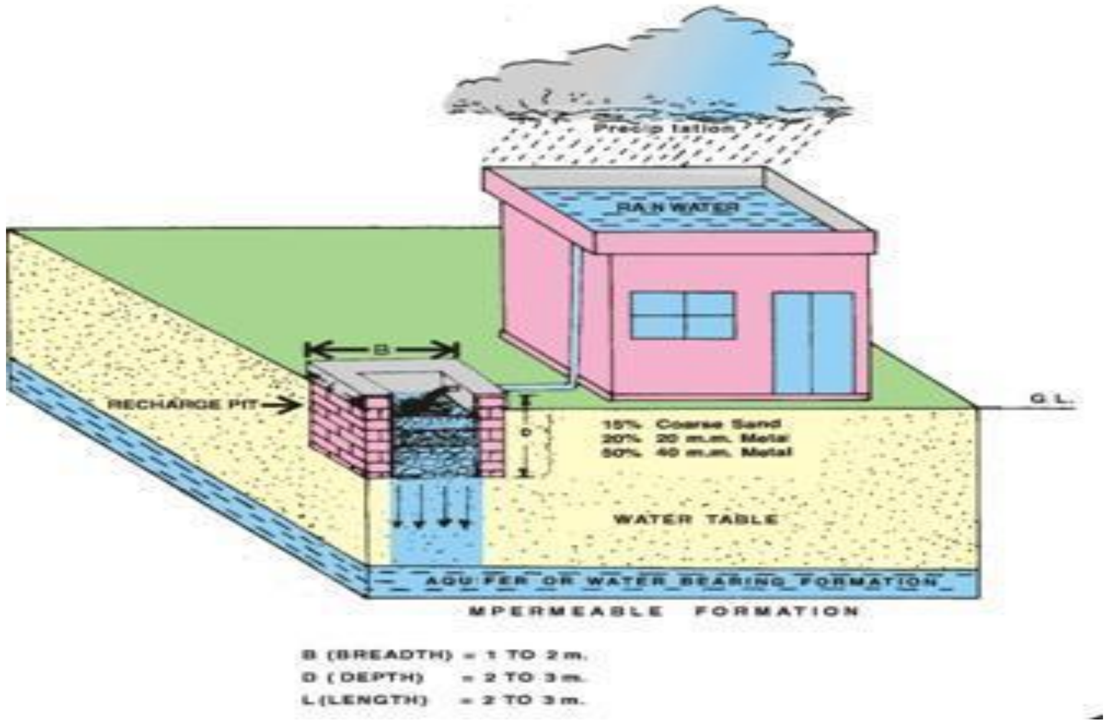


Fig. 2-23: Recharge pit in an individual house

Recharge Pits may be of any shape and size that are generally constructed 1 to 2 m. wide and 2 to 3 m deep. The pits are filled with boulders (5-20 cm), gravels (5-10mm) and coarse sand (1.5- 2mm) in graded form. Boulders at the bottom, gravels in between and coarse sand at the top so that the silt content that will come with runoff water will be deposited on the top of the coarse sand layer and can easily be removed. For smaller roof area, pit may be filled with broken bricks/ cobbles.

A mesh should be provided at the roof so that leaves or any other solid waste / debris is prevented from entering the pit. A desilting /collection chamber may also be provided at the ground to arrest the flow of finer particles to the recharge pit. The top layer of sand should be cleaned periodically to maintain the recharge rate. By-pass arrangement is to be provided before the collection chamber to reject the first flows (Vikaspedia).

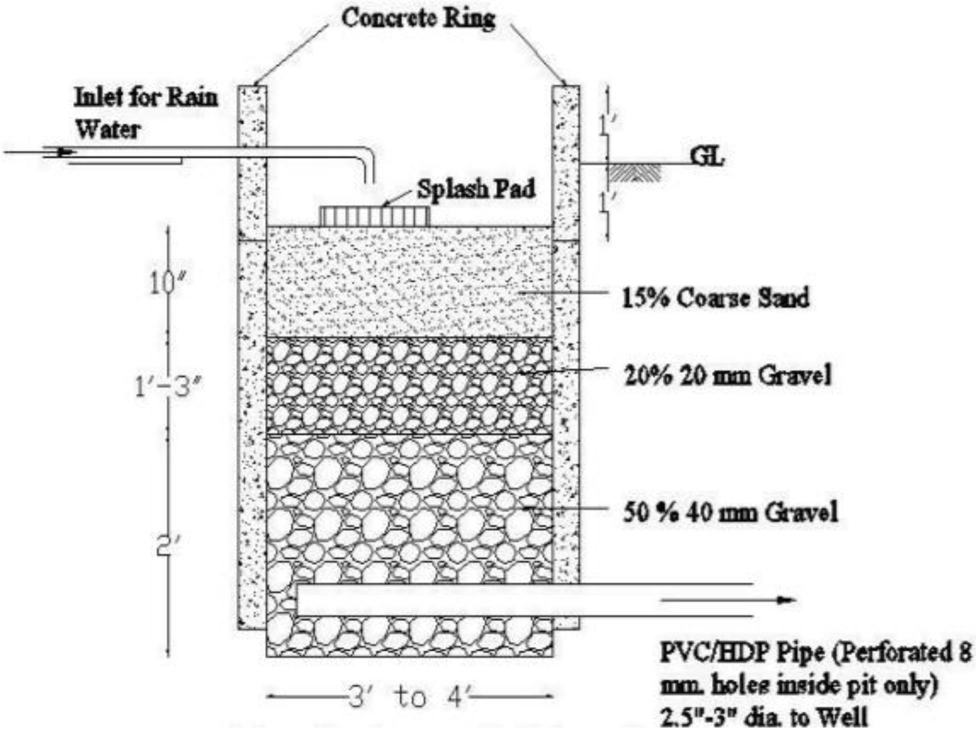


Fig.2-24: Sample of Recharge Pit/ Trench Section

2. Recharge well

Rainwater is first collected, deposited and filtered through sand and gravel. Households or institutions can use water: The overflowing water reaches a well lined with perforated concrete rings so that the water can slowly seep away from both sides.

3. Boring recharge

The same pipeline that is used to withdraw the groundwater can also be used to divert collected rainwater and surface runoff back into the ground after some basic filtering (Awale, 2017).

2.8. Water Sensitive Urban Design (WSUD)

Water sensitive urban design (WSUD) is an important component of water cycle management. “It is an approach that integrates whole of water cycle management into urban planning and design” (Urban Water). Water-sensitive urban design is an integral part of nature-based solutions that use the natural environment to respond to various ecological, economic, social and climatic challenges (Development Asia, 2020).

The common types of WSUD are rain garden, hollow, constructed wetland, porous walkway, rainwater and rainwater collection, green infrastructure (green roof, green exterior wall and tree pit), infiltration trenches (Urban Water).

The National Water Initiative defines water sensitive urban design as "the integration of urban planning with the management, protection and conservation of the urban water cycle that insures urban water management is sensitive to natural hydrological and ecological cycles" (New Water Ways, 2021).

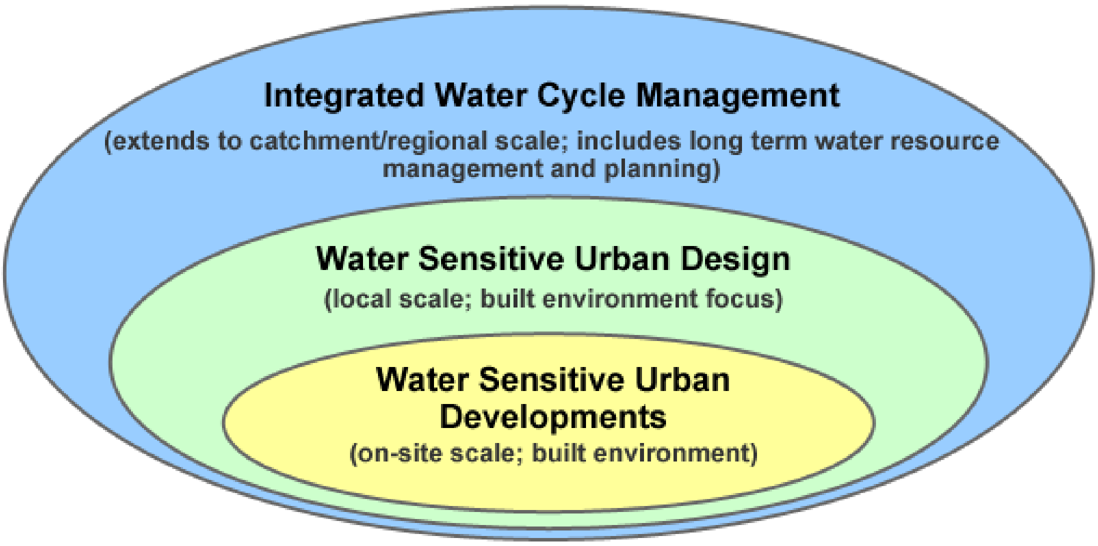


Fig.2-25: Water Sensitive Urban Design(New Water Ways, 2021)

WSUD can be implemented on any scale, from unique projects in individual lots to interconnected projects at regional level. Therefore, it can also be implemented in a household building also, which could reflect WSUD in an individual scale.

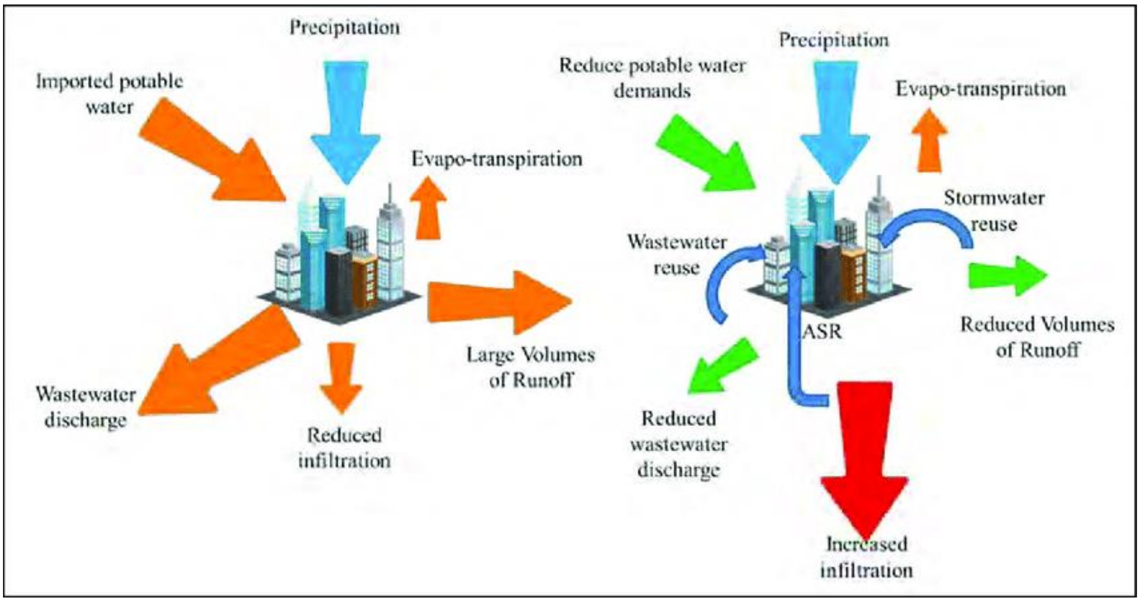


Fig.2-26: Before and after water sensitive urban design water balance

(Development Asia, 2020)

In figure above, urban water balance is shown in left figure and water sensitive water balance is shown in right figure. Comparing the both figures water sensitive urban design has benefits of reduction in potable water demands, reduction in wastewater discharge and reduction in volumes of runoff along with increased infiltration.

The many advantages to implement WSUDs include:

- Reduced volume of rainwater coming into river basins, leading to an improved aquatic environment.
- Improving the quality of rainwater and thus improving the water quality of rivers and bays.
- Reduced reliance on fresh potable water to irrigate green space.
- Mitigation of floods
- Improve in overall biodiversity as a result of wetlands and rains gardens.
- Decreased the effect of the urban heat island due to the increase in green space and the increase in irrigation capacity.
- Higher levels of permeable terrain or sealant and soil moisture (Urban Water).

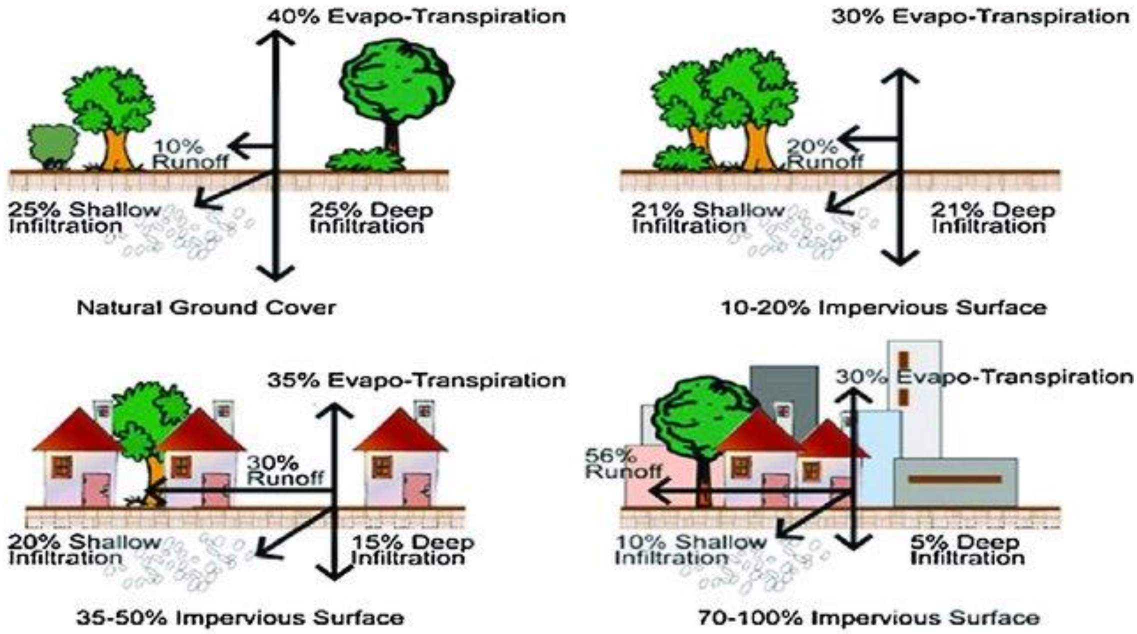


Fig.2-27: Evapo-transpiration, runoff and infiltration of different surfaces in % (Source: Saraswat, Kumar, & Kumar Mis, 2016)

The figure above shows the decrease in infiltration with the increase in impervious surface. Here, more the hard surface less is the infiltration of water into the ground. For eg. Urban area having 70 to 100% impervious surfaces has only total infiltration of 15%.

2.9. Benefits of Rainwater harvesting in an urban context

The advantages of rainwater harvesting can be summarized as follows:

- Water harvesting systems provide water to near points of use, which reduces delivery and pumping costs as well as other operating expenses.
- Independent systems that do not rely on the water distribution network and are suitable for construction in areas that are not supplied by the network.
- Rainwater is considered to be relatively clean and of acceptable quality for various purposes, even without treatment, if the required hygiene precautions are taken.
- The existence of the water harvesting systems along with the water supply network can serve as an additional water supply that can be used in dry seasons and periods of water shortages and thus reducing the gap between supply and demand.

- Reducing in the water consumption rate and as a result reducing the water bill.
- Protecting the soil from the accumulation of salts if the collected water is used for irrigation purposes.
- Agricultural expansion within arid and semiarid areas.
- Economic benefits where the value of a property or facility can rise if it includes a rainwater harvesting system.
- Rainwater harvesting reduces flood and surface runoff especially in urban areas and reduces soil erosion and water contamination.
- Reducing the over-pumping from groundwater aquifers and the preserving natural resources

The indirect benefits of water harvesting can be summed up as follows:

- Decreasing the amount of water flowing into the sewer network and thus prolonging the lifespan of networks and avoiding possible flooding.
- Reducing diseases caused by water scarcity and obtaining a better health status in the society.
- Reducing social problems and conflicts between members of the same family and neighbouring families.
- Increasing property's price if rainwater harvesting technique is applied.
- Increasing agricultural production and green spaces if collected water to be used for irrigation purposes, thus reducing carbon dioxide concentrations and improving the aesthetic view.
- Contribute to the use of main water sources and prevent wastewater from entering sewer pipes, thereby reducing the burden of treatment (rainwaterharvesting.org).
- Adding water to the aquifer can help improve the quality of the existing groundwater quality through dilution (rainwaterharvesting.org).

2.10. Case Studies

2.10.1. Panchsheel Park Colony, Delhi, India

Fig.2-28: Panchsheel Park Colony (rainwaterharvesting.org)

Panchsheel Park Colony is a water-rich colony in southern Delhi which collects every drop of rainwater. The project was implemented in June 2002 where the cost of the entire rainwater harvesting system was Rs 8 lakh. Here, average annual rainfall in Delhi wad taken as 611 millimetres (mm). It has total catchment area including rooftop and surface area is 3,57,150 sq.m. and the total volume of rainwater harvested is 1,74,575 cubic metre (m3), or 174,575,000 litres (2002). This represents 80 percent of the total potential of the water harvest. The water supply mainly provided by six bore wells where the remaining water requirement is covered by separate boreholes (rainwaterharvesting.org).

For the rainwater collection, a storm water drainage network is used throughout the residential area for the rainwater collection and the outflow of the surface. About 36 recharge wells of 1m x 1m x 2 m are built in the drainage of the storm water to facilitate the top-up of groundwater. The quality of the runoff passing through 15 m borehole is passed through the filter bed (rainwaterharvesting.org).

Before implementing rainwater-harvesting project, the water level was around 28.6 m below ground level. The water level in July 2003 after the monsoon was 27.3 m, representing a total rise of 0.7 m, or 2.29 feet. According to the source, the area depends largely on tube wells (Rainwater Harvesting and Utilization).

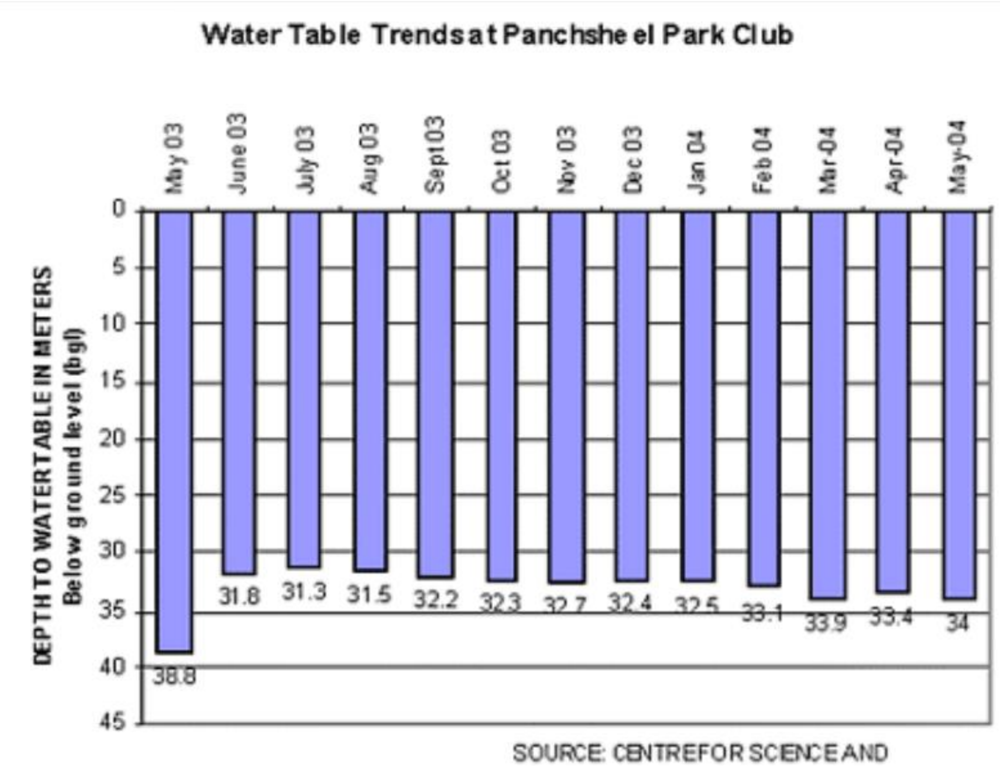


Fig.2-29: Water Table 2003-2004(rainwaterharvesting.org)

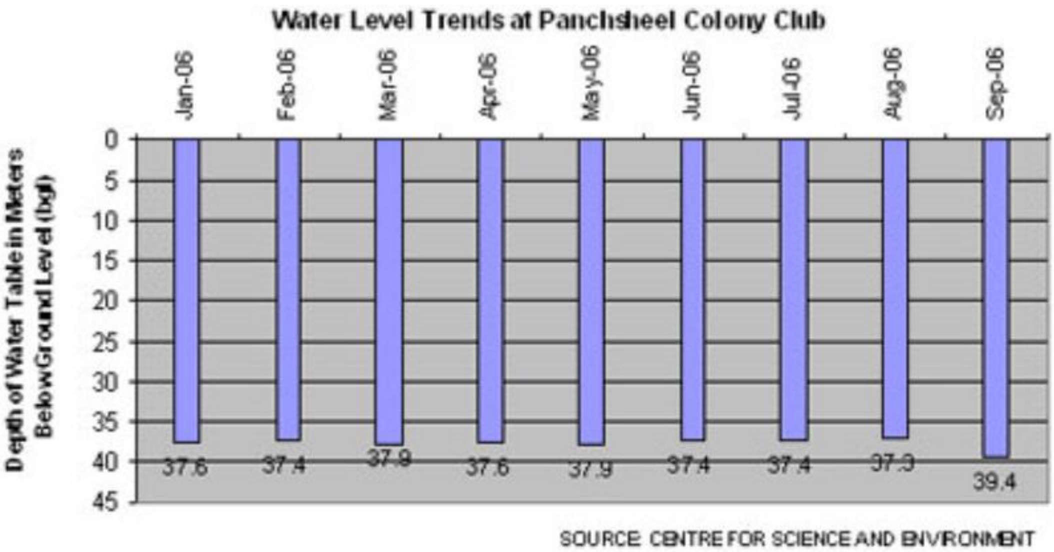


Fig.2-30: Water Level 2006 (rainwaterharvesting.org)

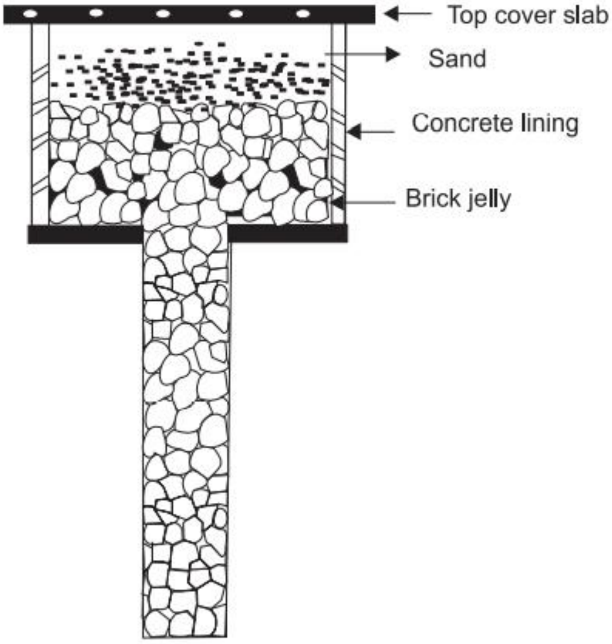


Fig.2-31: Cross-Section of Percolation Pit (Rainwater Harvesting and Utilization)

2.10.2. Eco Home, Dallu, Kathamndu (Residence of Dr. Roshan Raj Shrestha)

Fig.2-32: Eco home (Residence of Dr. Roshan Raj Shrestha)

Dr Roshan Raj Shrestha has eco-friendly features in his new home of area 135 sq. m. (1453.127 sq.ft./ 0R-4A-0P-3.93D) that was built in November 2002 (DEWATS for Private House). The house is located in the city of Kathmandu which uses a variety of sustainable water management methods.

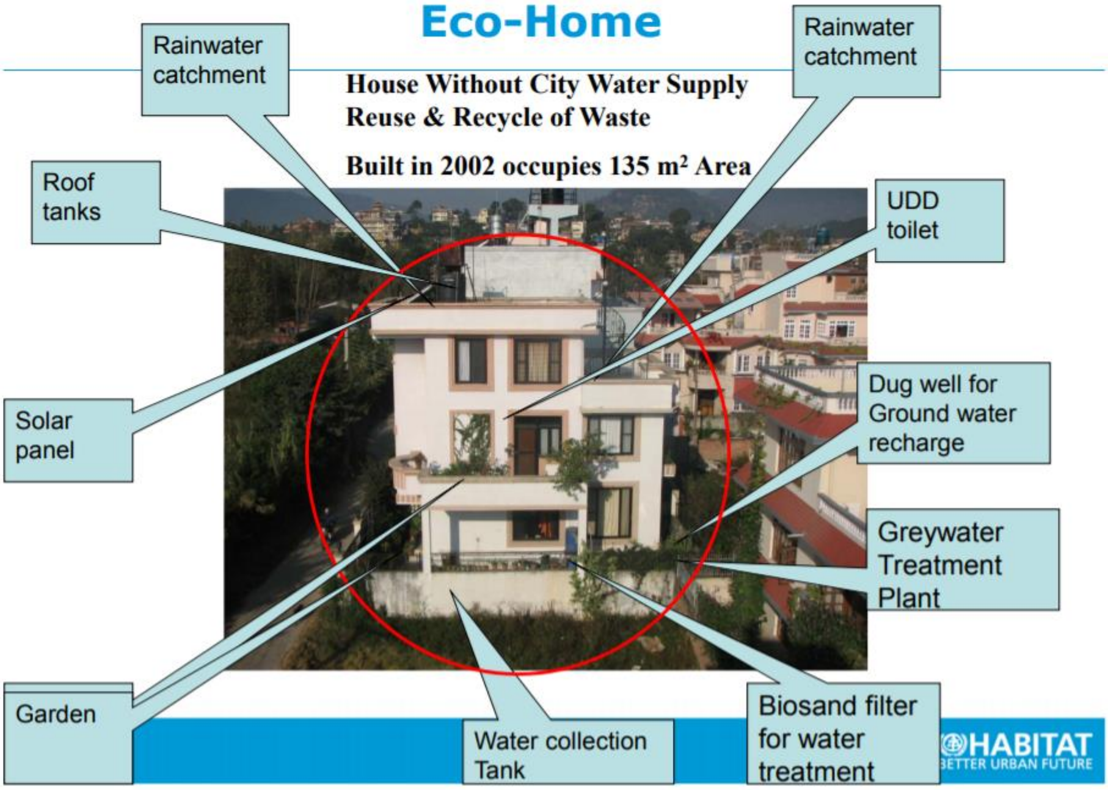


Fig.2-33: Eco Home (Shrestha R. R., Eco-Approach to Manage Wastewater, 2010)

The house has rainwater harvesting system that is used for domestic purposes and for groundwater recharging through dugwells (DEWATS for Private House). The author started measuring the precipitation data at this point in 2005. The three-year average rainfall (2005-2007) was 2576 mm where almost 90% of the rainfall fell in just 6 months (April-September). The roof area of Eco home is 90.4 m2, which can collect more than 180 m3 of rainwater per year as shown in the table below with the assumption of 69 average rainy days (Shrestha R. R., International Conference on Sustainable Sanitation: Food and Water Security for Latin America", 2007).

Table 2-3: Rainfall and rainwater collection (2005 to 2007)(Shrestha R. R., International Conference on Sustainable Sanitation: Food and Water Security for Latin America", 2007)

	Rainfall mm						
Month	2005	2006	2007	Average	Rainwater collection m3	Water Demand m3	Deficit and Surplus m3
Jan	45			15	1.1	8.4	-7.3
Feb	20		125	48	3.5	8.4	-4.9
Mar	53	51	76	60	4.3	8.4	-4.1
Apr	90	144	184	139	10.1	8.4	1.7
May	87	313	265	222	16.0	8.4	7.6
Jun	403	437	535	458	33.1	8.4	24.7
Jul	449	487	561	499	36.1	8.4	27.7
Aug	458	720	444	541	39.1	8.4	30.7
Sep	240	401	674	438	31.7	8.4	23.3
Oct	216	205	0	140	10.1	8.4	1.7
Nov	0	44		15	1.1	8.4	-7.3
Dec	0	0		0	0	8.4	-8.4
Total	**2061**	**2802**	**2864**	**2576**	**186.3**	**100.8**	**85.5**

Through the rainwater utilization system, the continuous water supply of the ecological house can be realized. The house depends on rain for nearly nine to ten months for which rainwater is stored in an 8,000-liter underground storage tank, and excess water is replenished in wells dug of capacity nearly 10,000 litres to provide water for the remaining months. The water of dug well also promotes groundwater recharging.

Fig.2-34: Dug well before and after rain (Shrestha R. R., Eco-Approach to Manage Wastewater, 2010)

The figure above shows the dug well before and after rein, where there is increase in water level in case of after rain.

Rainwater that is collected for drinking is treated with SODIS (Solar Disinfection) technique. Prior to which, the water in the dug well is treated with bio sand filter (NGO Forum for Urban Water & Sanitation, 2009). According to the author, the replenishment of groundwater also improves the water quality of the well dug, especially by reducing the nitrate content (Shrestha R. R., International Conference on Sustainable Sanitation: Food and Water Security for Latin America", 2007).

Fig.2-35: Water Disinfection (SODIS)(Shrestha R. R., Eco-Approach to Manage Wastewater, 2010)

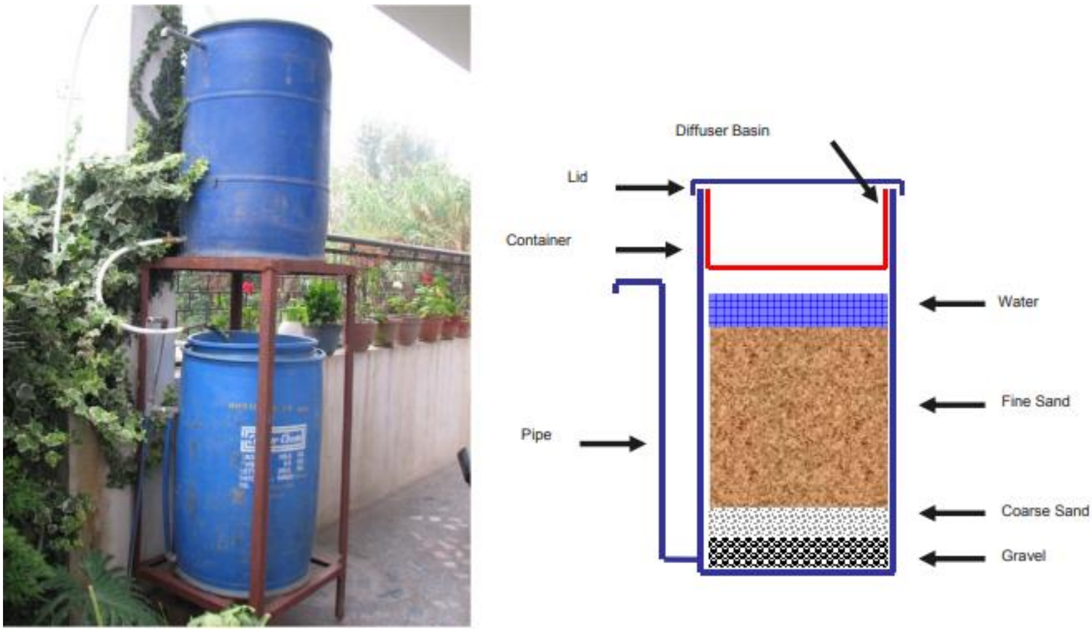


Fig.2-36: Treatment of water for Drinking- Bio Sand Filter (Shrestha R. R., Eco-Approach to Manage Wastewater, 2010)

Chapter 3: Research Paradigm and Methodology

3.1. Research Design

In this research, the potential of decentralized ground water recharge through rainwater harvesting of the urban residential buildings was reviewed using research paradigm like post positivism and constructivism which focuses both on objective and subjective reality. The research Strategy will be correlation and Phenomenology. And the research approach will be inductive research approach as it starts with the observations and theories that are proposed towards the end of the research process as a result of observations and analysis. Hence, this study employs a descriptive and exploratory research design to agree on improving urban residential scenario by ground water recharging from rainwater and ultimately reinforcing the concept of water sensitive urban design. This research will offer a profile of described relevant aspects of the phenomena of interest from an individual and organizational oriented perspective. Therefore, this research design will enable to gather data from a wide range of respondents on the topic. The research overall design and flow process are depicted in figure below.

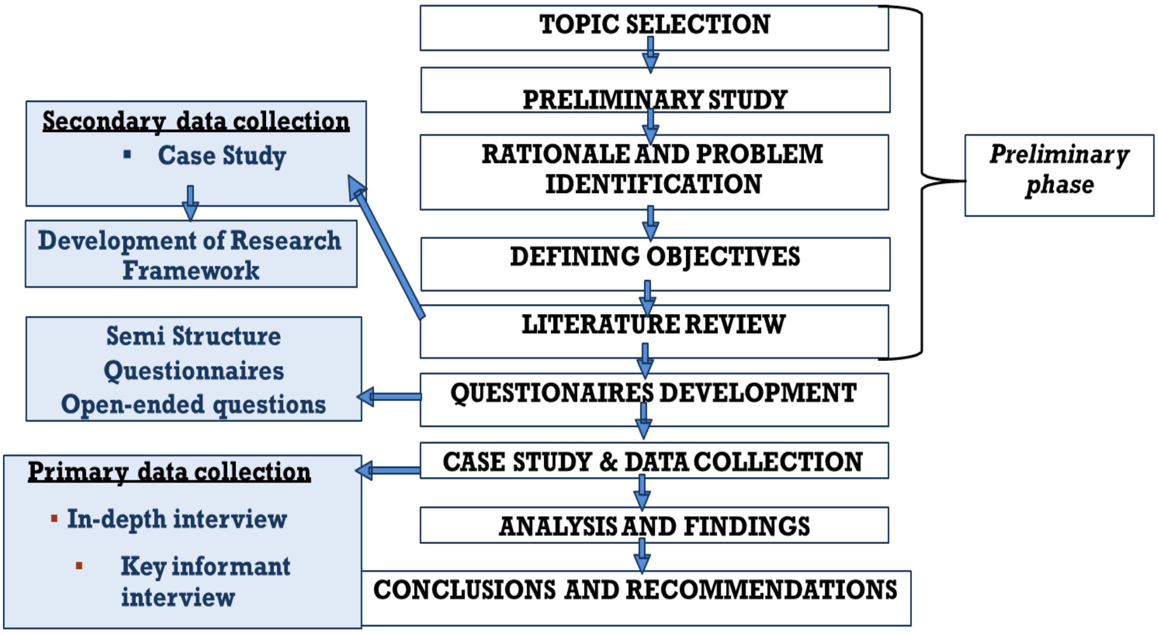


Fig.3-1: Methodology

ONTOLOGY:

Due to a rapid urbanization and high water demand in cities, people are facing water shortage and stress on existing water sources(Kurunthachalam, 2014).So, as an alternative source of water, people are choosing rainwater harvesting as an alternative source of water for consumption along with private tankers, jars and deep wells.

Although rainwater harvesting for immediate/household use can result in significant water and cost savings, also in minimizing the waste water generation (Zavala, Vega, & Miranda, 2016), it breaks the natural cycle and lead to ecological imbalance. Whereas ground water recharging through rainwater harvesting help to increase the infiltration which would be instrumental in regenerating and promoting water sensitive urban development.

However, rainwater harvesting for consumption help in water sustainability and rainwater harvesting for ground water recharge help in water sensitive urban development, there is concern about the most important component of rainwater harvesting in developing countries like Nepal.

EPISTOMOLGY:

The literature would guide to gather established factors and these could be analyzed in the case study area. To understand the issue the epistemological areas would be information from residents, published articles, scientific publications, interview with stakeholders and observations.

3.2. Research Methodology

To address the key research objectives, this research used both qualitative and quantitative methods and combination of primary and secondary sources. The qualitative data supports the quantitative data analysis and results. The study includes a site survey of residential buildings of small neighborhood of Samakhusi, Kathmandu which lies on ward number 26 of Kathmandu Metropolitan City. The study also measures the public perception from individual and organizational level on the concept of rainwater harvesting. The survey was based on direct observations and using questionnaires/ in-depth interviews. The result obtained would be triangulated since there is utilization of the qualitative and quantitative data types in the data analysis.

DATA SOURCES:

Primary data sources

Primary data sources were obtained from the original source of information i.e. real time data. The primary data are more reliable and have more confidence level of decision-making with the trusted analysis having direct intact. The primary data sources are case areas' environment (through observation, pictures, photographs, questionnaires) and from employees in government and private institutional sector (interviews and discussions).

Secondary data

Past data were collected from various second-hand resources. This includes reports and project files related to water efficiency, reuse of grey water, rainwater harvesting, water sustainability. In addition, secondary data were obtained from literatures manuals and reports. Magazines, books, various articles, magazines, meeting records, periodicals, newsletters, newspapers, websites and other sources were viewed. In fact, The review considered data in existing working documents, manuals, procedures, reports, statistics, guidelines, regulations and standards.

3.3. Research Framework

As per the methodology, literature review, case study, direct observations and interviews support the study i.e. by using primary and secondary data sources.

The parameters are change in volume of infiltration by ground water recharging, change in volume of potable water consumption, change in volume of infiltration by groundwater recharging through rainwater, change in volume of wastewater generation by rainwater harvesting, behavioural and psychological study about the concept of rainwater harvesting. By measuring the parameters followed by the indicators, the study fulfils the objectives.

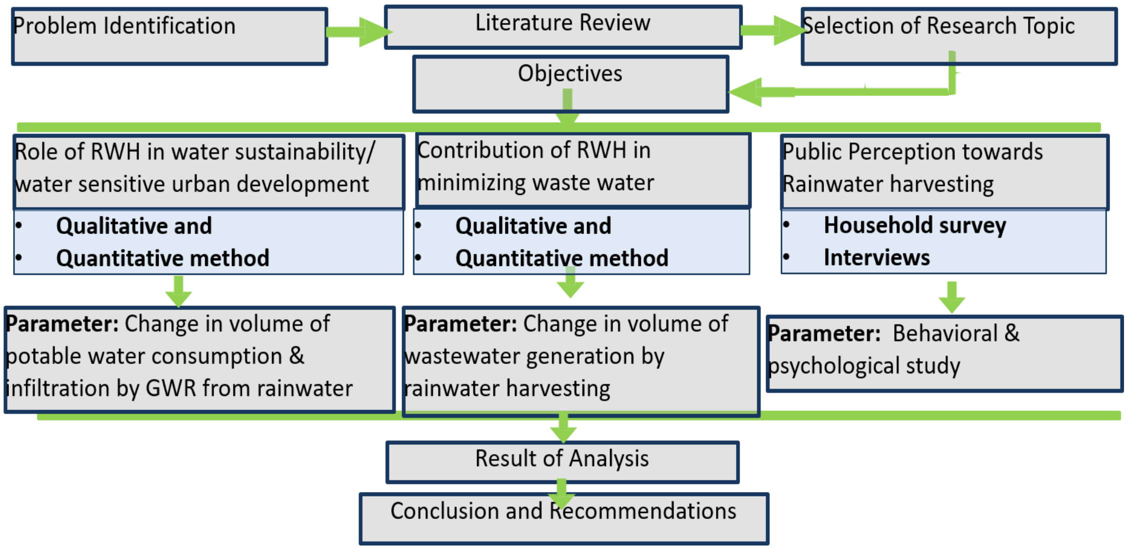


Fig.3-2: Research Framework

The indicators for parameter - change in volume of potable water consumption, change in volume of infiltration by groundwater recharging through rainwater are like:

- Total rainwater from the plots is ground recharged
- Total rainwater from the land surface is ground recharged
- Total rainwater from the roof top is ground recharged

The indicators for parameters - change in volume of wastewater generation by rain water harvesting are like:

- Reduction in high volume of wastewater after household/immediate use or recharging all rainwater from the plot into the ground.

The indicators for parameter - behavioural and psychological study about the concept of rainwater harvesting are like:

- Separate pipe system for rainwater and its ejection
- Familiarity with the concept of RWH for consumption and ground water recharge.
- Idea about the cause of water logged streets during rainy seasons
- Idea about the cause of dry wells in near past

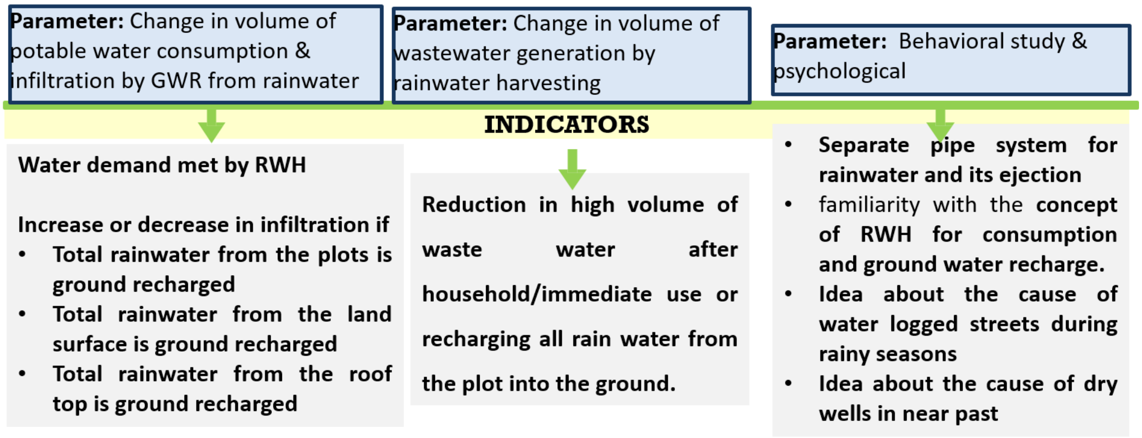


Fig.3-3: Parameters and indicators of Research Framework

Chapter 4: Case Area

4.1. Neighborhood of Samakhusi, Kathmandu

The case area selected for the thesis is small neighborhood of Samakhusi which lies in Ward number 26 of Kathmandu Metropolitan City. Samakhushi is one of the urban cities of Nepal, which is within Kathmandu. Samakhushi is one of the cities within Kathmandu who looks like a quiet area. Samahkusi borders Ranibari to the east, Gangabu to the north, Balaju to the west, and Golkopakha to the south.

4.1.1. Building Typology

Most of the buildings in the case area are modern with fat roof type where most used finishing material was concrete with some cases of tiles. The average height of the buildings is 2.5 storey.

4.1.2. Settlement pattern

The area has compact kind of settlement with no open or common open or green spaces. The settlement has few narrow streets in between.

4.1.3. Road or street networks

The case area has wide black topped or asphalt road of 21’ width at three sides at north, south and west. Whereas, at the eastern part, it has narrow stone paved road of around 6’ width and small streets of 3’ width at some areas in between the plots at southern side.

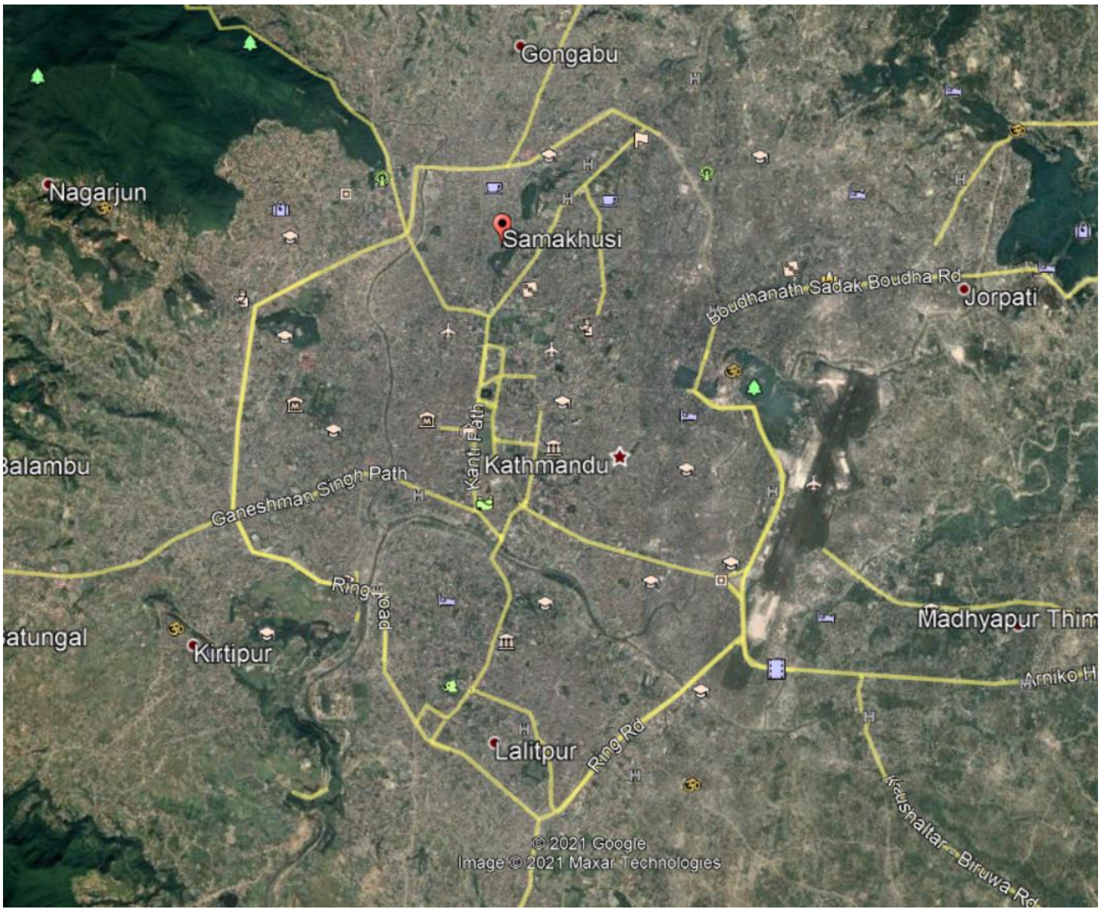


Fig.4-1: Map of Kathmandu with along with the location of Samakhusi

4.2. Settlement growth of Case Area

2003

2007

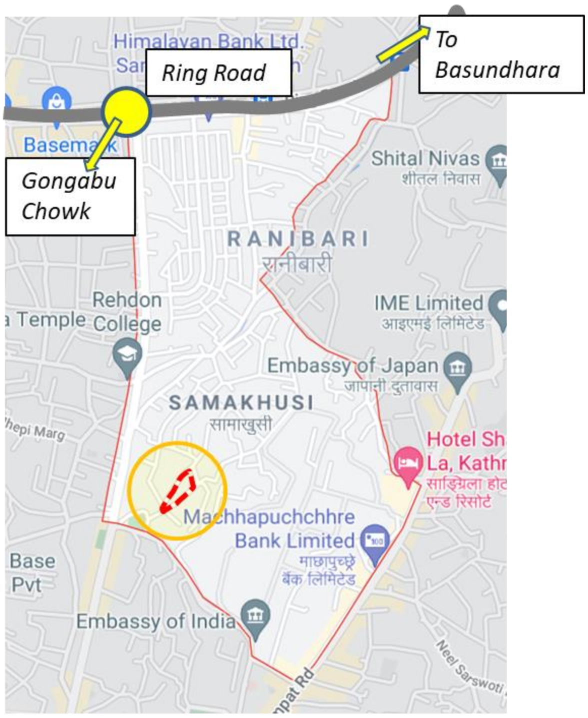
2011

2016

2020

4.3. Site Justification

It is good representative of compact urban area. It lies in highest belt -northern belt of Kathmandu Valley and has sandy soil, which is best portion for the ground water recharge.



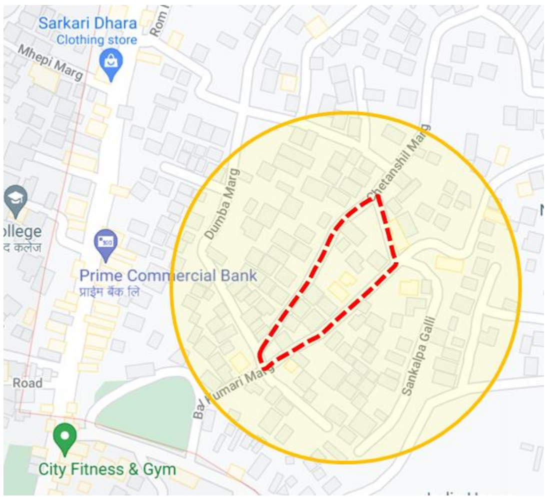


Fig.4-2: Site Location

Chapter 5: Findings and Discussion

5.1. Existing Scenario

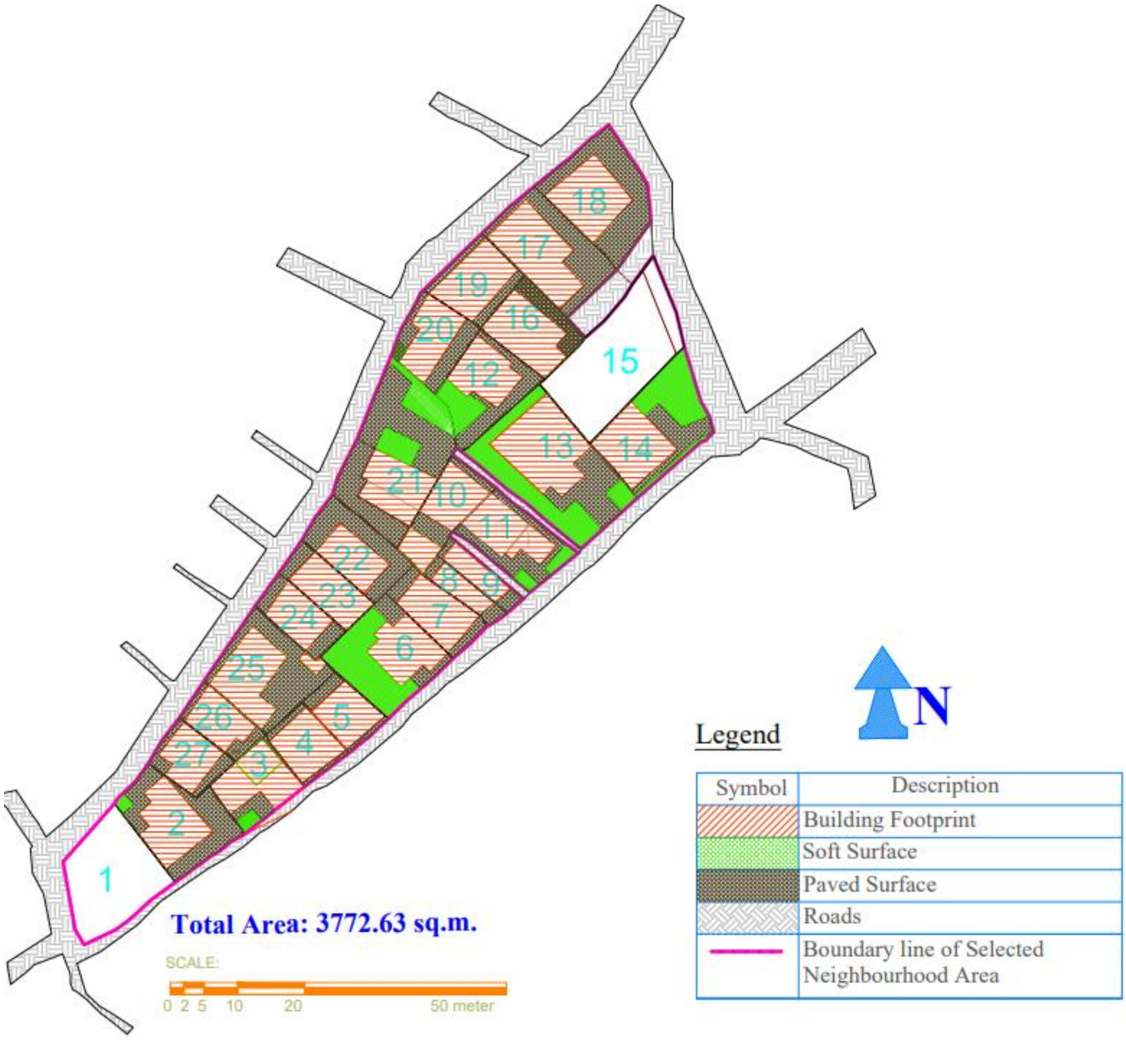


Fig.5-1: Existing Scenario of Case Area

There are 27 plots in the selected neighbourhood area where 2 plots are vacant with the total number of 25 households. Total area of the case area is 3772.63sq.m. The figure above shows the type of land distribution. The chart below also clearly depicts the land distribution. As shown in legend on figure above the map shows the building footprints, paved surfaces, green spaces and the area covered by roads.

Table 5-1: Land type of case area

Unit	Total Neighbourhood Area excluding road (sq.m.)	Total Roof Top	Total Paved Area	Total Green Area	Total Bare Ground	Others
Area (sq.m.)	3772.63	1802.08	1014.62	361.21	548.64	46.08
Area (R-A-P-D)	7R-6A-2P-2.41D	3R-8A-2P-2.82D	1R-15A-3P-2.56D	0R-11A-1P-1.76D	1R-1A-1P-0.08D	0R-1A-1P-3.19D
Land Coverage (%)	100.00	47.77	26.89	9.57	14.54	1.22

The area in covered by roof top, paved area, green area, bare land and others are shown in table above. It is also expressed in percentage in the table above and figure below.

The percentage of land type i.e. distributed on the case area is shown in figure below.

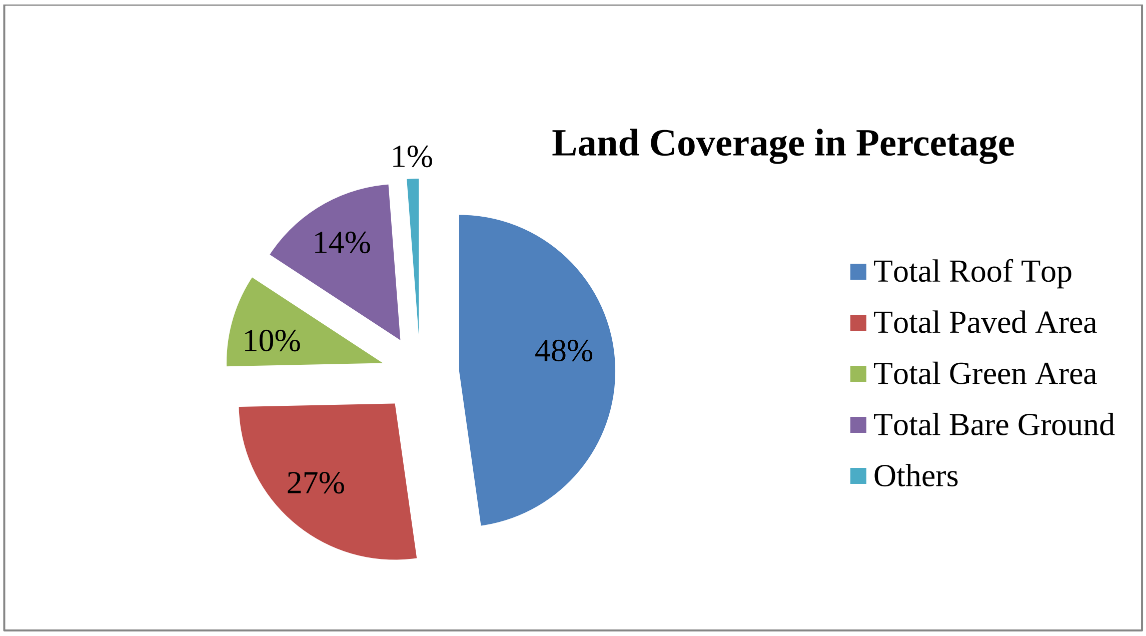


Fig.5-2: Land Coverage in percentage of the case area

The percentage of land covered by rooftop is 48%, which is the more in comparison to others. The area covered by paved area is 27%, area covered by green area is 10%, bare land is 14% and the area covered by others is 1%. This is the existing scenario of the case area.

Therefore, in total as per the calculation, the hard surface is about 76% and soft surface is about 24%. It has clearly shown in chart below.

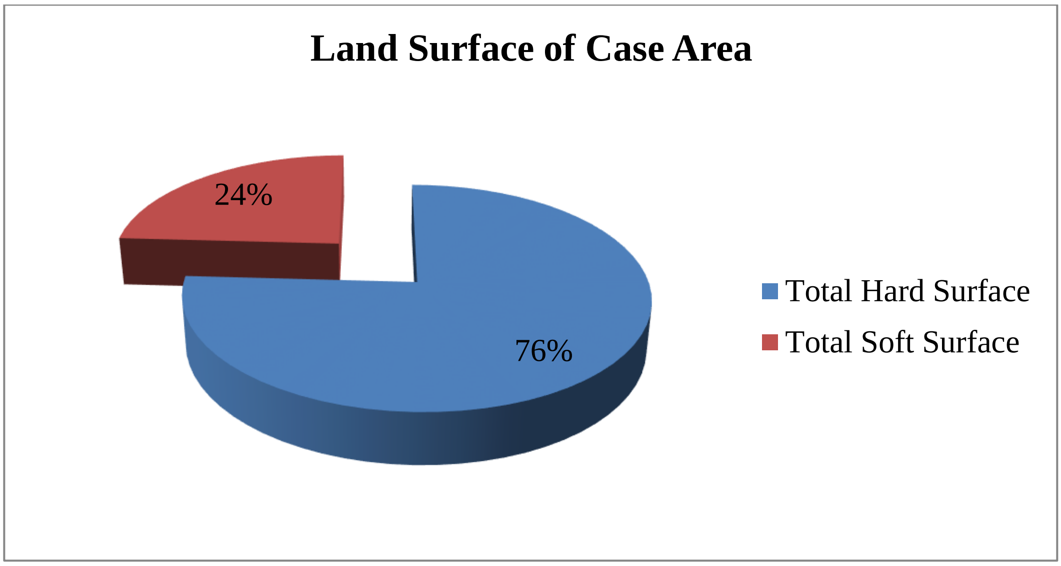


Fig.5-3: Land Distribution of Case Area in Pie Chart

The selected neighbourhood area has different sizes of plots where the largest number of plots are under 3 Anna i.e. 95.388 sq.m. The chart below shows the plot distribution of case area under four categories. They are one Anna to three Anna, three Anna one Daam to five Anna, Five Anna one Daam to eight Anna, eight Anna one Daam to ten Anna.

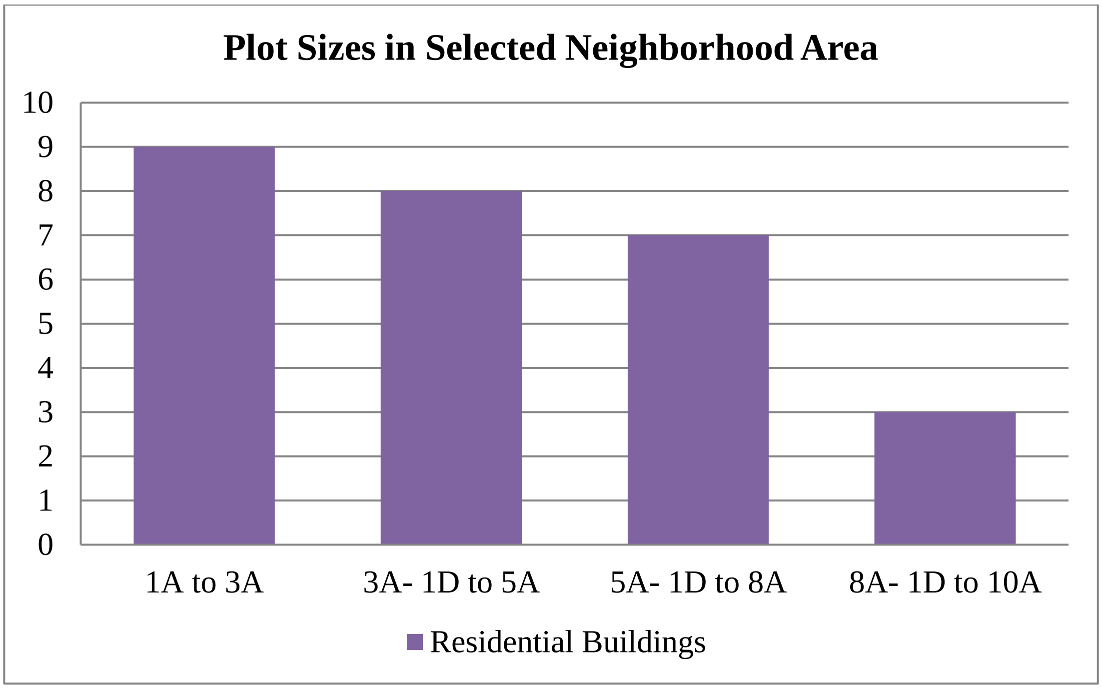


Fig.5-4: Plot sizes distribution in case area

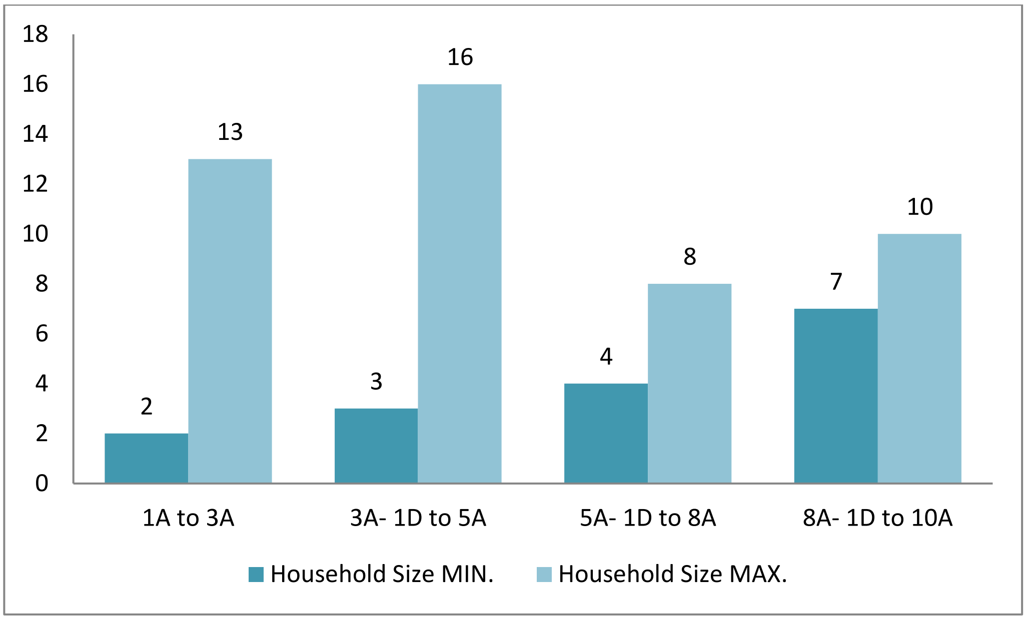


Fig.5-5: Household sizes in the case area

The chart above shows the household sizes of the case area in plots of different sizes. The maximum number of people are seemed to be on the plots of 3 to 5 anna of land area. The above chart clearly shows the minimum and maximum number of household sizes in different plot area that are under four categories up to 10 anna of land area.

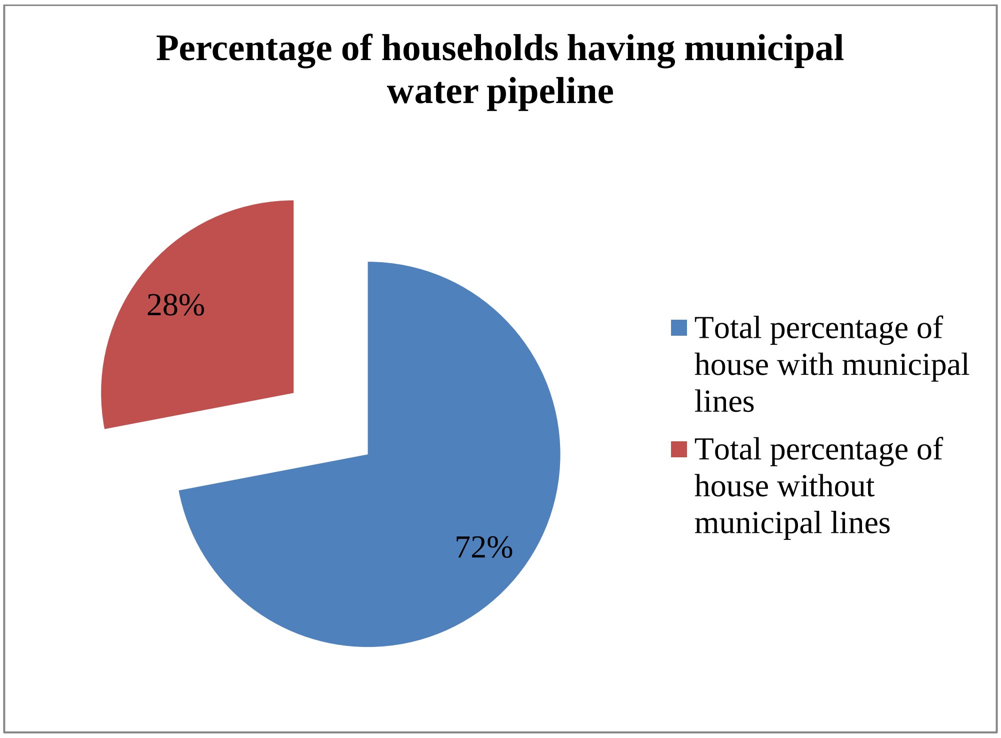


Fig.5-6: Percentage of household having municipal water pipeline

From the site study, it was known that almost 1/4th houses do not have municipal pipeline that is about 72% of the residences have municipal water supply lines and 28% do not have installed the municipal water pipe system.

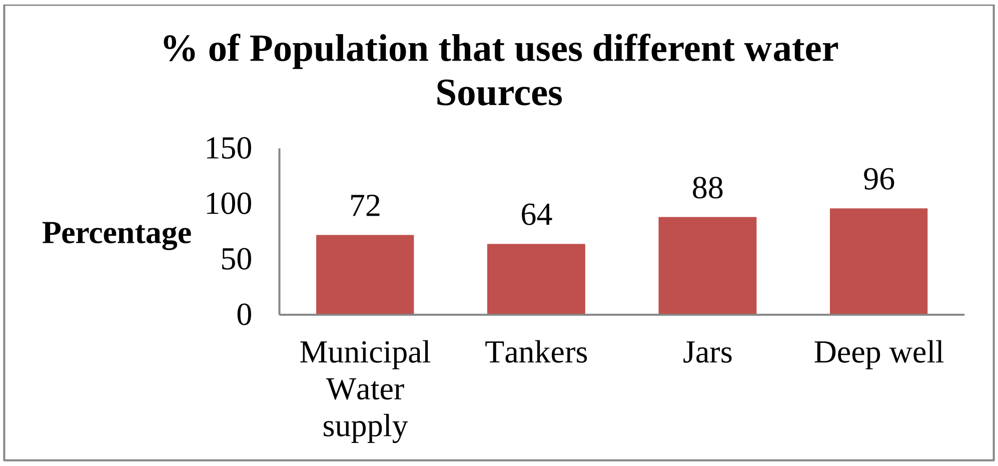


Fig.5-7: Dependency of household on different water sources to fulfill water demand

To fulfil the water demand, people rely on many alternative sources as per the site study. As shown in chart above, 72% residences use municipal water line, 64 % uses tankers for water demand, 88% totally dependent on jars for drinking water and 96% uses the water from deep well. According to the observation, people are more dependent on deep wells as 96% of the residences have installed bore wells for their water security. Even people have increased the bore well depth in past 5 to 8 years to 75' to 100' from around 35'. This clearly shows that ground water level is in decreasing state of the case area.

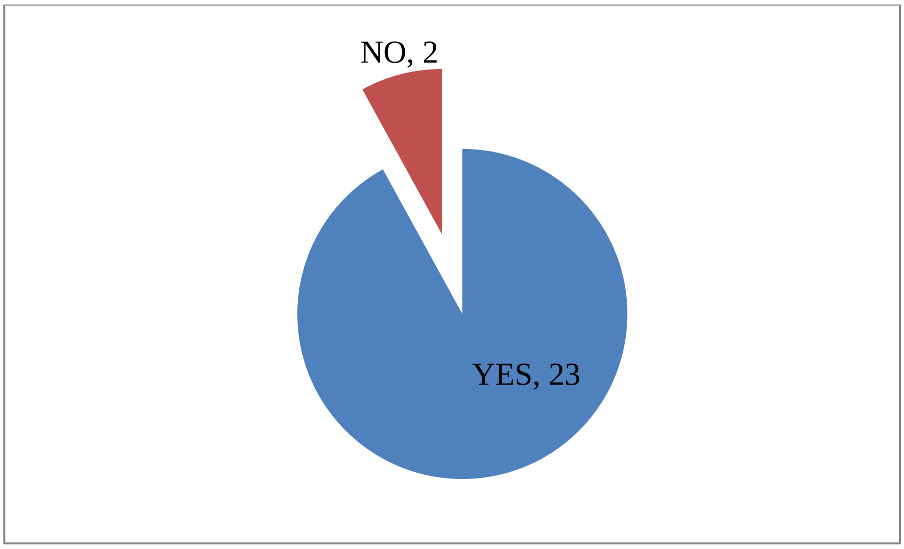


Fig.5-8: No. of household who have separate pipe system for draining roof top rainwater

Among 25 household, 23 household have separate pipe system for draining roof top rainwater as per the site study, which is 92% of the total population.

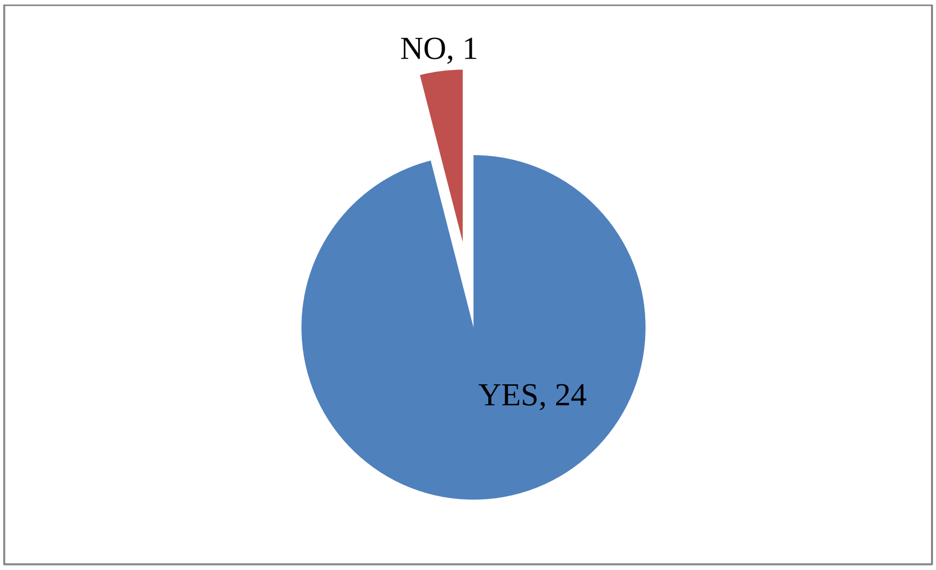


Fig.5-9: No. of household whose rainwater from roof catchment directly go to drain

Among 25 household, 24 households' rainwater from roof catchment directly goes to drain as per the site study. 1 household's rainwater from roof catchment goes to soak pit. This shows that 96% of the residences rooftop rainwater directly goes to the drain.

Boundary Wall

The research is mainly focused on rainwater harvesting which help in water sensitive urban development. There is no common space to dig common recharge pit and send the runoff to ground water recharge, so the area was selected excluding the roads. The coloured or highlighted line shows the boundary of the case area.

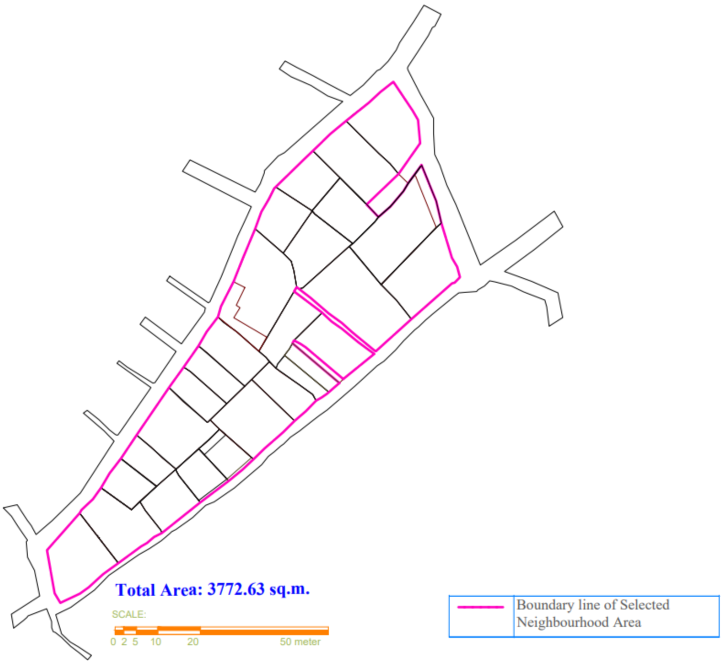


Fig.5-10: Case Area showing boundary walls

Building Footprint

As per the calculation the total land covered by building only is 1802.08 square meter which is 47.77% of the total selected area. The figure shows the position and area covered by buildings in the case area. The building footprints are highlighted in the figure below.

Fig.5-11: Case Area with building footprints only

Roads/Streets

The figure shows the position and area covered by roads or streets in the case area. Road are highlighted by a texture as shown in the legend. The road areas are excluded in the total area, as there is no open space in the case area where recharge could be dig for ground water recharging. There are different sizes of roads in the case area. North, south and west sides are surrounded by wide asphalt road, whereas the small stoned paved road lines eastern side. There are also even narrow streets in between the residents at center of the case area.

Fig.5-12: Case Area focusing streets or roads

Paved Surfaces

As per the calculation the total land covered by paved area only is 1014.62 square meter which is 26.59% of the total selected area. The figure shows the position and area covered by paved surfaces in the case area.

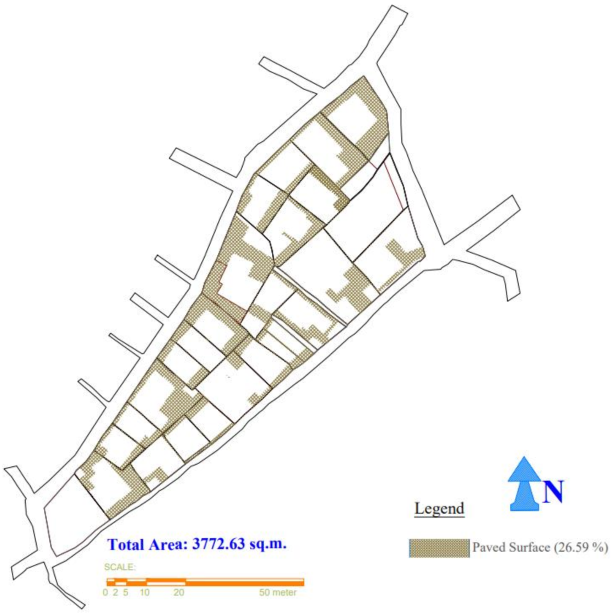


Fig.5-13: Case Area with paved surfaces only

Soft surfaces

As per the calculation the total land covered by soft surfaces only is 909.85 square meter which is 24.11% of the total selected area. The figure shows the position and area covered by buildings in the case area.

Fig.5-14: Case Area with soft surfaces only

Overall hard and soft surfaces of the case area

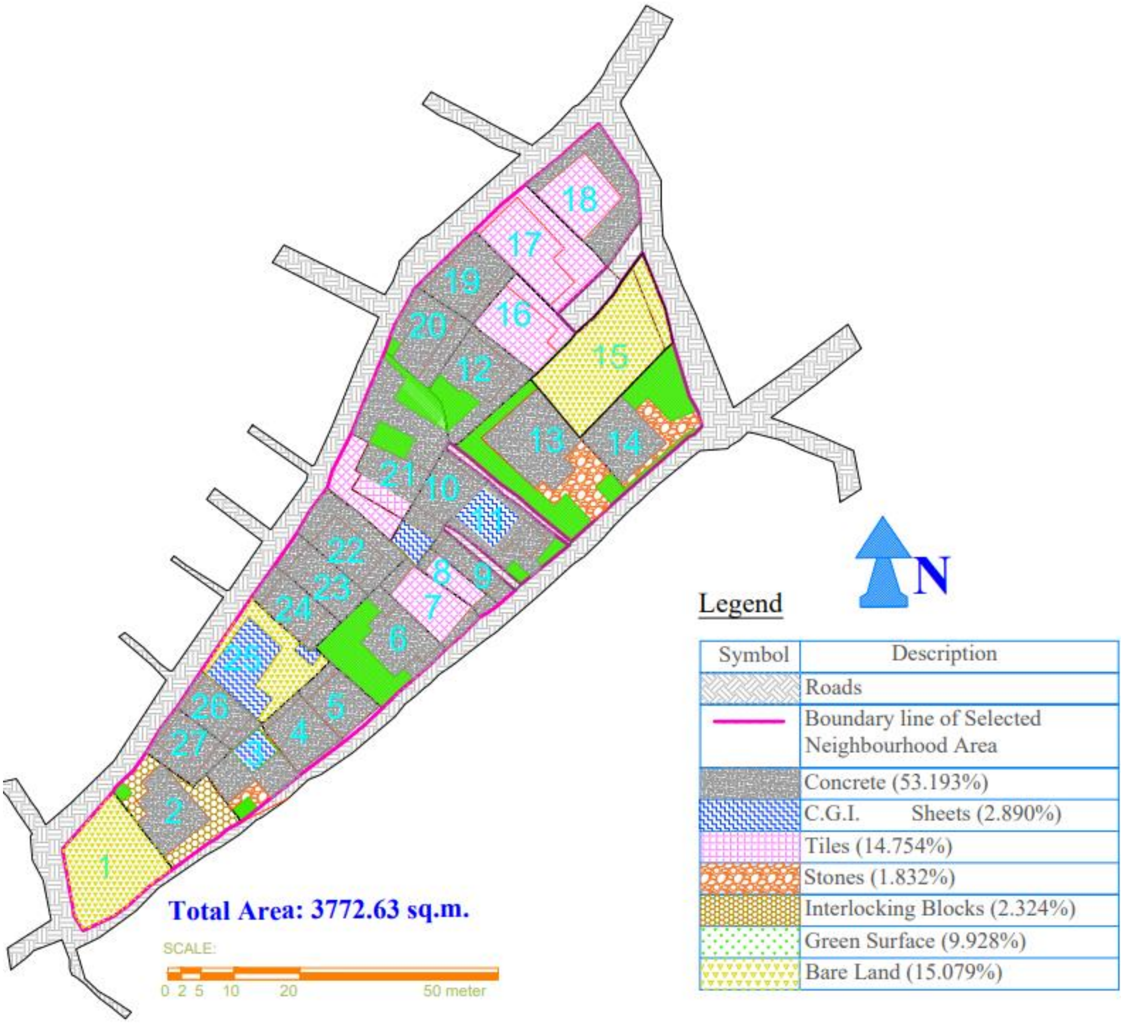


Fig.5-15: Mapping of different types of hard and soft surfaces

This map shows the different kinds of hard and soft surfaces of the case area. Hard surfaces include concrete, C.G.I., tiles, stones, interlocking blocks, etc. Whereas soft surfaces include green surfaces and the bare land. According to the site observation, the area covered by concrete is 53%, C.G.I. sheet is 3%, tiles is 15%, stones is 2%, interlocking blocks is 2%, green surfaces is 10% and bare land is 15%, which is also shown in pie chart below. Among all, the area covered by the concrete is greater in area.

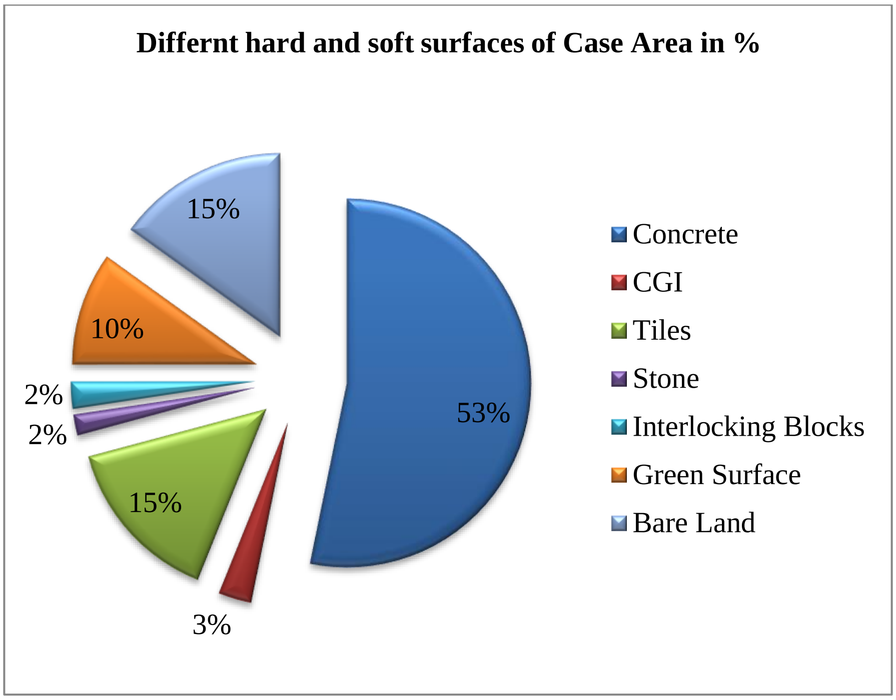


Fig.5-16: Case area with different types of hard and soft surfaces in percentage

As there are different types of hard and soft surfaces in the case as shown in figure and data above, different run off coefficients are used that were extracted from the literature. The final plotted map and area of the selected area was generated by doing tally on-site measurements, trace map provided by Survey Department, Dillibazaar and map from goggle earth. Therefore, the total volume is calculated by multiplying the total catchment area, runoff coefficient and the average rainfall data provided by DHM (Department of Hydrology and Meteorology).

Catchment Material	Runoff Coefficient	Total Area in sq.m.	Total Area in %
Concrete	0.7	1935.38	51.935
CGI	0.9	193.3	5.187
Tiles	0.9	536.81	14.405
Stone	0.6	66.67	1.789
Interlocking Blocks	0.5	84.54	2.269
Green Surface	0.1	361.21	9.693
Bare Land	0.2	548.64	14.722
Total		3726.55	100

Fig.5-17: Run off coefficient for different materials with catchment area in calculation

Rainfall data

Rainfall data was taken from DHM of 10 year frequency. As Panipokhari station is closer to the case area. The rainfall data was used of the Panipokhari Station of Kathmandu Valley.

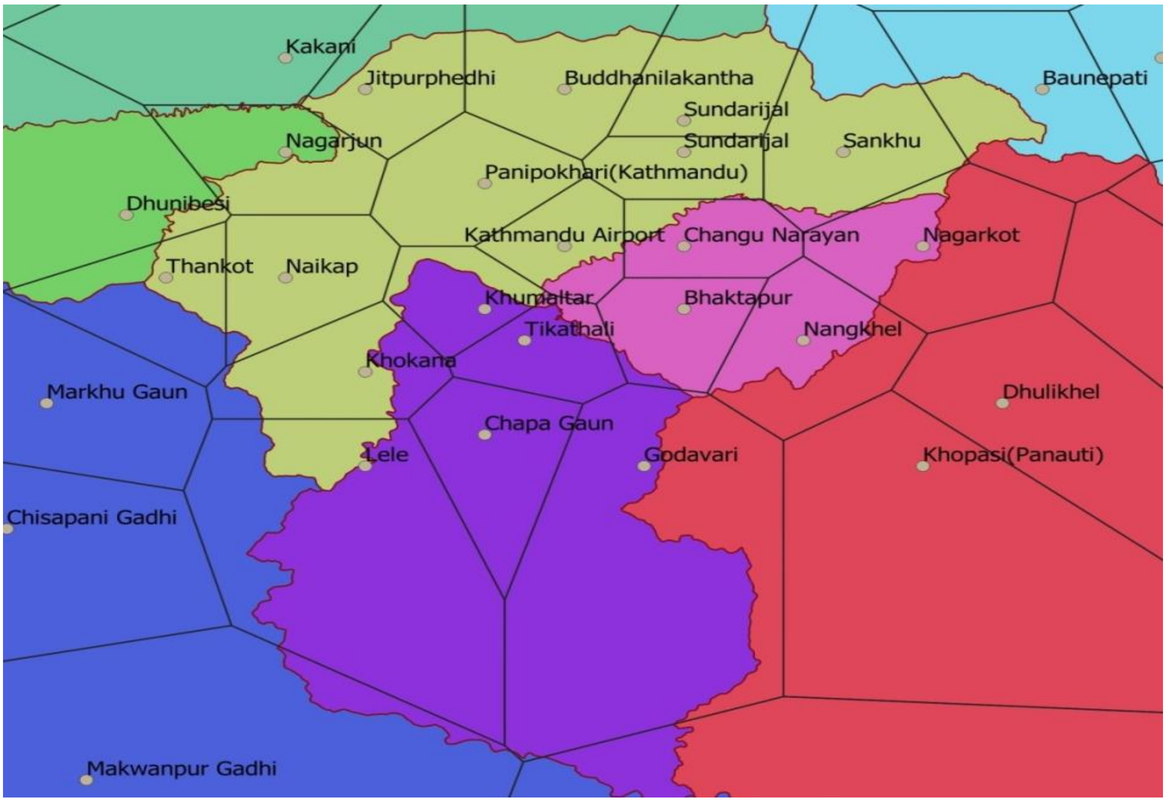


Fig.5-18: Different Rainfall Stations of Kathmandu valley (Source: KVWSMB)

Table 5-2: Average rainfall data of 10 year frequency calculated based on the data given by DHM

Month/Year	Rainfall in mm											
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total	Average
January	0	17.3	13.2	0	13.8	0	10.1	4.2	28.8	56.6	144	14.4
Febraury	17	42.3	25.5	15.4	34.2	20.2	0	2.2	93.7	15	265.5	26.55
March	13.4	12.6	0	22.8	97.1	1.7	79.6	26.2	75.7	36.8	365.9	36.59
April	111.4	87	12.2	7.3	39.6	12.8	85.9	106.3	86.6	71.8	620.9	62.09
May	157.6	32	201	92	23.8	108.1	165.3	93.9	84	96.3	1054	105.4
June	372.9	147.2	187.3	203.6	181.9	305.1	183.2	298.9	168.5	337.2	2385.8	238.58
July	423.1	449.2	289	479.8	489.6	489.7	414.5	445	517.8	448.1	4445.8	444.58
August	339.9	278.4	346.3	357.2	483.6	233.7	314.1	446	295.1	468.7	3563.0	356.3
September	239.2	310.9	113.6	469.5	139.3	0	87.9	133.7	439.7	254	2187.8	218.78
October	73.2	0	107.9	75.7	18.4	57.8	47.4	0	9.4	0	389.8	38.98
November	81.7	0	0	0	0	0	10.6	0	0	0	92.3	9.23
December	0	0	0	24.9	0	0	0	0	41.6	0	66.5	6.65
TOTAL	1829.4	1376.9	1296	1748.2	1521.3	1229.1	1398.6	1556.4	1840.9	1784.5	15581.3	1558.13

From the table, the total average rainfall of 10 year frequency is resulted as 1558.13 mm. The rainfall with peak intensity fall on the month of June, July, August and September which is also shown in the chart below.

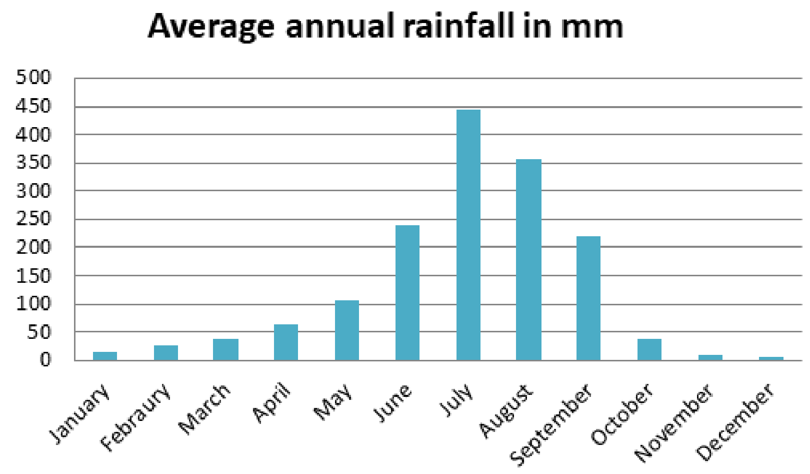


Fig.5-19: Average monthly rainfall of 10 year frequency

5.2. Potential rainwater for household use in selected case area

5.2.1. Water demand met by RWH

Table 5-3: Water demand met by RWH

S. N.	Plot Area	Roof top catchment * Run off Coefficient (sq.m.)	Rainfall in a year (m)	Total rainwater collection from roof top (litres/Year)	First Flush(5%) (litres/Year)	Effective Volume of RWH for consumption (litres per year)	Household Size	Standard Water Demand data (lpcd)	Water Demand of household (litres per day)	Yearly Water Demand (litres per year)	Demand Met by RWH in days	Demand Met by RWH in month	Demand Met by RWH in month (Round Off)	Demand Met by RWH System (%)
1	6A	0	1.558	0.000	0.000	0.000	0	150	0	0.0	0.000	0.000	0	0
2	5A-1P-2D	58.268	1.558	90781.544	4539.077	86242.467	4	150	600	219000.0	143.737	4.791	5	39
3	3A-1P	62.031	1.558	96644.298	4832.215	91812.083	4	150	600	219000.0	153.020	5.101	5	42
4	2A-1P	51.737	1.558	80606.246	4030.312	76575.934	5	150	750	273750.0	102.101	3.403	3	28
5	2A-1P-1D	40.348	1.558	62862.184	3143.109	59719.075	6	150	900	328500.0	66.355	2.212	2	18
6	5A-3P-1D	49.056	1.558	76429.248	3821.462	72607.786	5	150	750	273750.0	96.810	3.227	3	27
7	2A-3P-2D	63.09	1.558	98294.220	4914.711	93379.509	4	150	600	219000.0	155.633	5.188	5	43
8	1A-1P	26.91	1.558	41925.780	2096.289	39829.491	2	150	300	109500.0	132.765	4.425	4	36
9	1A-1P	24.241	1.558	37767.478	1888.374	35879.104	4	150	600	219000.0	59.799	1.993	2	16
10	3A-1P-1D	61.95	1.558	96518.100	4825.905	91692.195	7	150	1050	383250.0	87.326	2.911	3	24
11	4A	59.894	1.558	93314.852	4665.743	88649.109	4	150	600	219000.0	147.749	4.925	5	40
12	4A-2P	34.447	1.558	53668.426	2683.421	50985.005	8	150	1200	438000.0	42.488	1.416	1	12
13	9A-1P-3D	88.277	1.558	137535.566	6876.778	130658.788	10	150	1500	547500.0	87.106	2.904	3	24
14	6A-1P	61.201	1.558	95351.158	4767.558	90583.600	4	150	600	219000.0	150.973	5.032	5	41
15	8A-1P-1D	0	1.558	0.000	0.000	0.000	0	150	0	0.0	0.000	0.000	0	0
16	3A-3P	80.199	1.558	124950.042	6247.502	118702.540	7	150	1050	383250.0	113.050	3.768	4	31
17	5A-3P-1D	97.992	1.558	152671.536	7633.577	145037.959	8	150	1200	438000.0	120.865	4.029	4	33
18	6A-1P	79.749	1.558	124248.942	6212.447	118036.495	6	150	900	328500.0	131.152	4.372	4	36
19	3A-1P-1D	56.462	1.558	87967.796	4398.390	83569.406	3	150	450	164250.0	185.710	6.190	6	51
20	3A-1P-3D	45.703	1.558	71205.274	3560.264	67645.010	7	150	1050	383250.0	64.424	2.147	2	18
21	9A	54.047	1.558	84205.226	4210.261	79994.965	7	150	1050	383250.0	76.186	2.540	3	21
22	4A	38.682	1.558	60266.556	3013.328	57253.228	16	150	2400	876000.0	23.856	0.795	1	7
23	2A-2P	48.09	1.558	74924.220	3746.211	71178.009	13	150	1950	711750.0	36.502	1.217	1	10
24	2A-2P	37.618	1.558	58608.844	2930.442	55678.402	7	150	1050	383250.0	53.027	1.768	2	15
25	5A-3P	85.365	1.558	132998.670	6649.934	126348.737	8	150	1200	438000.0	105.291	3.510	4	29
26	2A-1P	37.961	1.558	59143.238	2957.162	56186.076	6	150	900	328500.0	62.429	2.081	2	17
27	2A-2P	39.354	1.558	61313.532	3065.677	58247.855	4	150	600	219000.0	97.080	3.236	3	27
TOTAL		1382.672		2154202.976	107710.149	2046492.827			23850.000	8705250.0	2495.430	83.181	82.000	

The above table shows the total volume of rainwater collection when only rainwater from the roof top considered deducting first flush of 5%, which is 107710.149 litres/year. There is no excess rainwater remaining to ground recharge. It is because the rainwater from the rooftop hardly fulfils the water demand of the residents for whole year. Here, the water demand for residential building is assumed as 150lpcd, which becomes 54.750 cubic meter in a year for a person.

Here only roof catchment is considered as there is supposed to be issues related to ground levelling and water quality and quantity if ground catchment is considered.

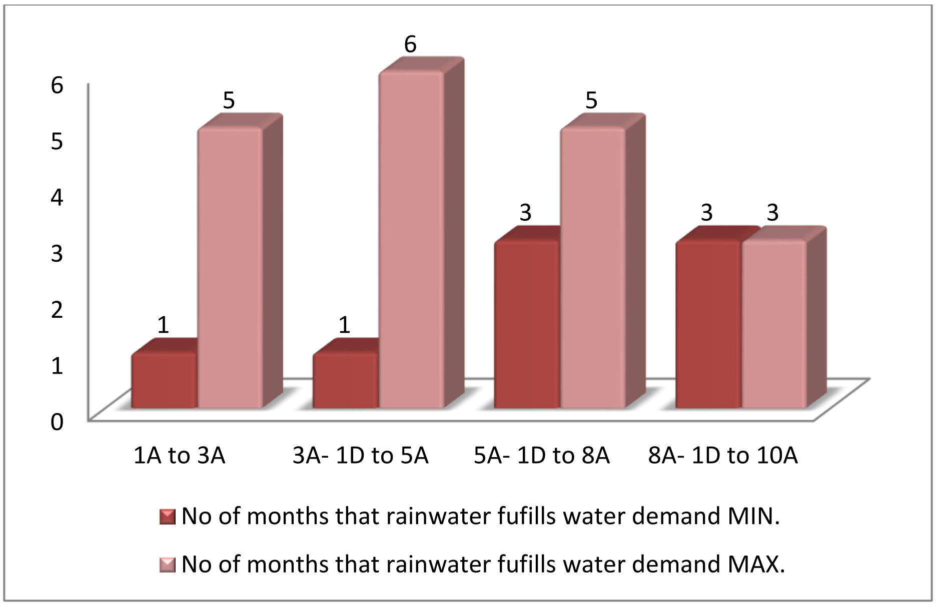


Fig.5-20: no. of months that rainwater fulfils water demand

If rainwater is used for household use taking 150 lpcd, then in average, water demand met by RWH would be only from one to six months depending upon the household size and the catchment area. The number of months that rainwater could fulfil the water demand is shown in above chart including minimum and maximum values for different plot sizes' categories.

Or if rainwater is used for household use taking 150 lpcd, then in average, water demand met by RWH would be only from 7 % to 51% depending upon the household size and the catchment area. The percentage that rainwater could fulfil the water demand is shown in below chart including minimum and maximum values for different plot sizes' categories.

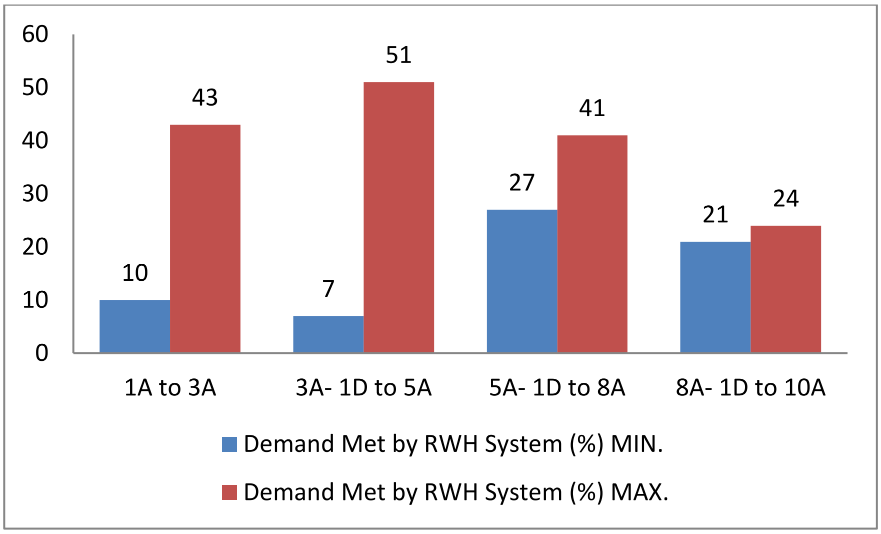


Fig.5-21: Water demand met by RWH system in percentage

5.3. Potential rainwater for ground water recharging in selected case area

For the calculation of volume of rainwater that could be sent to ground for recharging, the different roof material and surface material were studied by observations as their runoff coefficient are different. Also roof top catchment and ground surface catchment areas were estimated for the calculation of catchment area, which is also shown in chart below.

5.3.1. Potential rainwater for ground water recharging when all rainwater from the plot area is considered

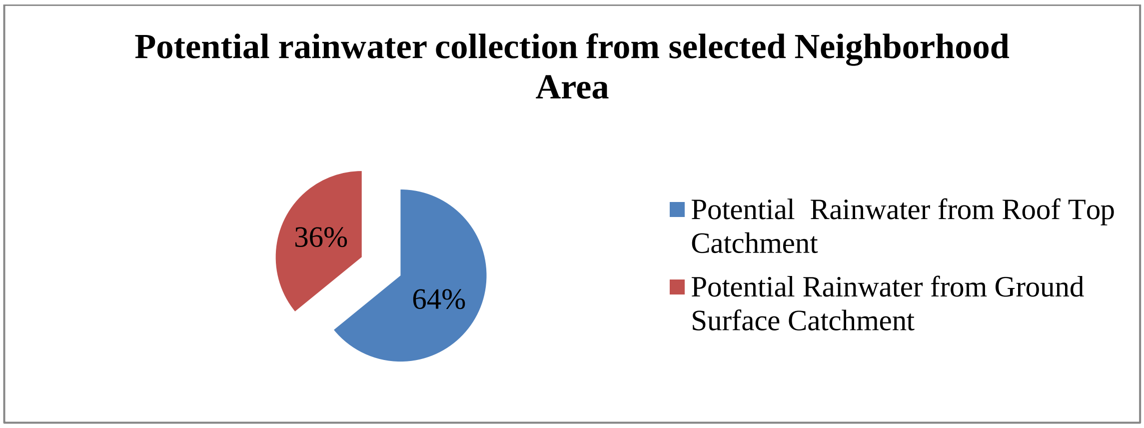


Fig.5-22: Percentage of rainwater collection from roof top and land surface of the case area

Table 5-4: Potential rainwater for groundwater recharging when all rainwater from the plot is considered

S. N.	Plot Area	Roof Material	Runoff Coefficient	Roof Catchment Area(m2)	Ground surface material	Runoff Coefficient	Ground surface area (m2)	Average Total Volume of Rainfall in a year (m)	Effective Rainwater from Roof Top Catchment (cu.m.)	Effective Rainwater from Ground Surface Catchment (cu.m.)	Potential RWH (cu.m.) in a year	Effective RWH for ground water recharge
1	6A	_	0	0	Bare land	0.2	193.83	1.558	0.000	0.000	0.000	0.000
2	5A-1P-2D	Concrete	0.7	83.24	Interlocking block	0.5	84.54	1.558	90.789	65.862	156.651	156.651
					Green surface	0.1	4.61	1.558	0.000	0.718	0.718	0.718
3	3A-1P	Concrete	0.7	56.55	Green surface	0.1	7.36	1.558	61.679	1.147	62.825	62.825
		CGI	0.9	24.94	Stone	0.6	16.18	1.558	34.974	15.126	50.100	50.100
4	2A-1P	Concrete	0.7	66.43	Concrete	0.7	10.72	1.558	72.455	11.692	84.147	0.000
5	2A-1P-1D	Concrete	0.7	57.64	Concrete	0.7	12.7	1.558	62.867	13.852	76.719	76.719
					Tile	0.9	5.06	1.558	0.000	7.096	7.096	7.096
6	5A-3P-1D	Concrete	0.7	70.08	Concrete	0.7	93.27	1.558	76.436	101.729	178.164	178.164
					G.S.	0.1	93.09	1.558	0.000	14.505	14.505	14.505
7	2A-3P-2D	Tile	0.9	70.1	Concrete	0.7	23.17	1.558	98.302	25.271	123.574	123.574
8	1A-1P	Tile	0.9	29.9	Concrete	0.7	11.82	1.558	41.929	12.892	54.821	0.000
9	1A-1P	Concrete	0.7	34.63	Concrete	0.7	7.09	1.558	37.771	7.733	45.504	0.000
10	3A-1P-1D	Concrete	0.7	57.9	Concrete	0.7	23.8	1.558	63.151	25.958	89.109	89.109
		CGI	0.9	23.8				1.558	33.375	0.000	33.375	33.375
11	4A	Concrete	0.7	21.65	Concrete	0.7	46.65	1.558	23.613	50.881	74.494	74.494
		CGI	0.9	49.71	G.S.	0.1	15.56	1.558	69.709	2.424	72.134	72.134
12	4A-2P	Concrete	0.7	49.21	Concrete	0.7	65.72	1.558	53.673	71.680	125.353	125.353
					G.S.	0.1	28.82	1.558	0.000	4.491	4.491	4.491
13	9A-1P-3D	Concrete	0.7	126.11	G.S.	0.1	110.91	1.558	137.547	17.281	154.828	154.828
					Stone	0.6	11.28	1.558	0.000	10.545	10.545	10.545
14	6A-1P	Concrete	0.7	87.43	Stone	0.6	39.21	1.558	95.359	36.657	132.016	132.016
					G.S.	0.1	39.21	1.558	0.000	6.109	6.109	6.109
15	8A-1P-1D	_	0	0	Bare land	0.2	265.02	1.558	0.000	0.000	0.000	0.000
16	3A-3P	Tile	0.9	89.11	Tile	0.9	31.85	1.558	124.960	44.664	169.624	169.624
17	5A-3P-1D	Tile	0.9	108.88	Tile	0.9	77.49	1.558	152.684	108.666	261.350	261.350
18	6A-1P	Tile	0.9	88.61	Concrete	0.7	108.55	1.558	124.259	118.395	242.654	242.654
19	3A-1P-1D	Concrete	0.7	80.66	Concrete	0.7	25.38	1.558	87.975	27.682	115.657	115.657
20	3A-1P-3D	Concrete	0.7	65.29	Concrete	0.7	41.14	1.558	71.211	44.871	116.082	116.082
					G.S.	0.1	4.2	1.558	0.000	0.654	0.654	0.654
21	9A	Concrete	0.7	77.21	Concrete	0.7	58.4	1.558	84.212	63.696	147.909	147.909
					G.S.	0.1	57.45	1.558	0.000	8.951	8.951	8.951
					Tile	0.9	35.81	1.558	0.000	50.217	50.217	50.217
22	4A	Concrete	0.7	55.26	Concrete	0.7	71.73	1.558	60.272	78.235	138.507	138.507
23	2A-2P	Concrete	0.7	68.7	Concrete	0.7	12.54	1.558	74.930	13.677	88.608	88.608
24	2A-2P	Concrete	0.7	53.74	Concrete	0.7	26.05	1.558	58.614	28.413	87.026	87.026
25	5A-3P	CGI	0.9	94.85	Bare land	0.2	89.79	1.558	133.010	27.981	160.991	160.991
26	2A-1P	Concrete	0.7	54.23	Concrete	0.7	18.25	1.558	59.148	19.905	79.053	79.053
27	2A-2P	Concrete	0.7	56.22	Concrete	0.7	56.22	1.558	61.319	61.319	122.637	122.637
TOTAL				1802.1			1924.47		2146.224	1200.975	3347.200	3162.728

The above table shows the total volume of rainwater collection when all rainwater from the plot area i.e. from the rooftop and the land surface considered, which is 3347.20 cu. m per year. Where total rainwater from rooftop is 2146.224 cu. m. per year and the total rainwater from the ground surface is 1200.975 cu. m. As the plot number 1 and 15 are vacant lands, the rainwater that could be from those plots is neglected, which is also highlighted as zero in the table above.

Also as there is no land for constructing recharge pits on the three plot areas, the rainwater that could be collected from those plots are excluded So, the effective rainwater for groundwater recharging is about 94%, where remaining 6% of the total rainwater will again goes to drain.

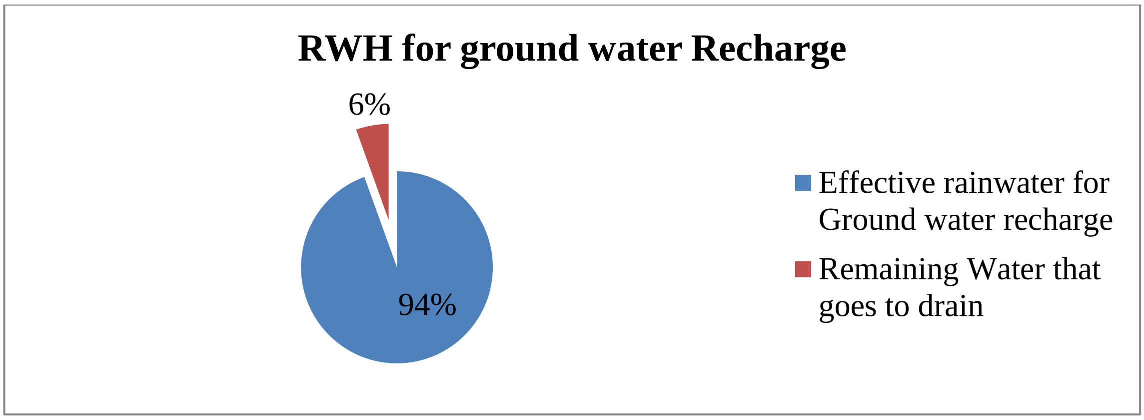


Fig.5-23: Effective rainwater for GWR

5.3.2. Potential rainwater for ground water recharging <u>when only rainwater from roof top is considered</u>

The total volume of rainwater collection from the rooftop is 2146.224 cubic meter as shown in the result from table 6-4, which is 64 % of the total potential rainwater collection.

5.3.3. Potential rainwater for ground water recharging <u>when only rainwater from ground surface is considered</u>

The total volume of rainwater collection from the ground surface considered is 1200.975 cubic meter as shown in the result from table 6-4, which is 36% of the total potential rainwater collection.

5.3.4. Mapping Feasible Location for recharge pits

For the calculation of number of recharge pits, a thumb rule was applied which is based on the data given by CIUD (Center for Integrated Urban Development) i.e. one recharge pit for 100sq.m. area. So, as per the total catchment area, number of recharge pits were estimated. The total number of recharge pits in the case area is 31. The recharge pits were design as per the technical details given by the source- CIUD. According to the source recharge pit comes with the filter chamber. The diameter of recharge pits are from 42” to

48” and about 20’ deep. Whereas, filter chamber is 42” diameter and 5’deep. It is also depicted in the figure below.

Components of Ground Water Recharging	Dia	Depth	Stuffing	Hollow Space
Filter Chamber	42" to 48"	15' to 20'	3' Boulders and pressure Pipe	approx. 2'
Recharge well	42"	5'	5' to 6' Boulder of 40mm to 80mm 5' to 6' Boulder of 20mm to 40mm 3' to 4' coarse sand Geotextile Filter material at Top	approx 5'
	Difference between two is 5 foot			

Fig.5-24: Technical aspect of Recharge pit as per CIUD

Table 5-5: Calculation of recharge pits for different plots

S. N.	Plot Area	Total Catchment Area	Calculation for nos of Recharge pit (1 Pit for 100sq.m.)	Availability of Space (1 for YES, o for NO)	No. of Recharge Pit
1	6A	193.83	1.94	0	0
2	**5A-1P-2D**	172.39	1.72	1	**2**
3	**3A-1P**	105.03	1.05	1	**1**
4	2A-1P	77.15	0.77	0	0
5	**2A-1P-1D**	75.4	0.75	1	**1**
6	**5A-3P-1D**	256.44	2.56	1	**3**
7	**2A-3P-2D**	93.27	0.93	1	**1**
8	1A-1P	41.72	0.42	1	0
9	1A-1P	41.72	0.42	1	0
10	**3A-1P-1D**	105.5	1.06	1	**1**
11	**4A**	133.57	1.34	1	**1**
12	**4A-2P**	143.75	1.44	1	**1**
13	**9A-1P-3D**	248.3	2.48	1	**2**
14	**6A-1P**	165.85	1.66	1	**2**
15	8A-1P-1D	265.02	2.65	0	0
16	**3A-3P**	120.96	1.21	1	**1**
17	**5A-3P-1D**	186.37	1.86	1	**2**
18	**6A-1P**	197.16	1.97	1	**2**
19	**3A-1P-1D**	106.04	1.06	1	**1**
20	**3A-1P-3D**	110.63	1.11	1	**1**
21	**9A**	193.06	1.93	1	**2**
22	**4A**	126.99	1.27	1	**1**
23	**2A-2P**	81.24	0.81	1	**1**
24	**2A-2P**	79.79	0.80	1	**1**
25	**5A-3P**	184.64	1.85	1	**2**
26	**2A-1P**	72.48	0.72	1	**1**
27	**2A-2P**	112.44	1.12	1	**1**
		Total		**24**	**31**

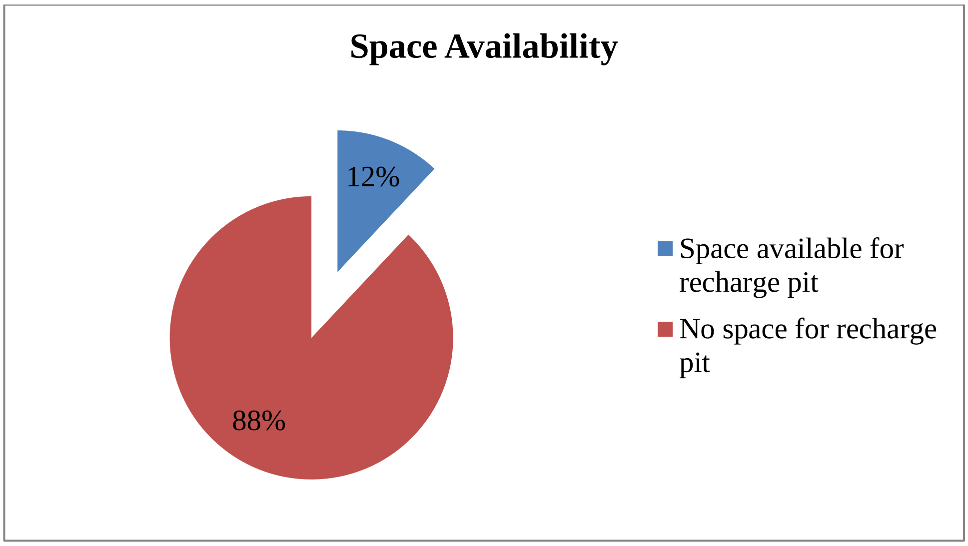


Fig.5-25: Space availability for recharge pits

The chart above shows the space availability for constructing recharge pits in the case area, which is 88%. 88% means the total percentage of the residents that has space for constructing pits for ground water recharging.

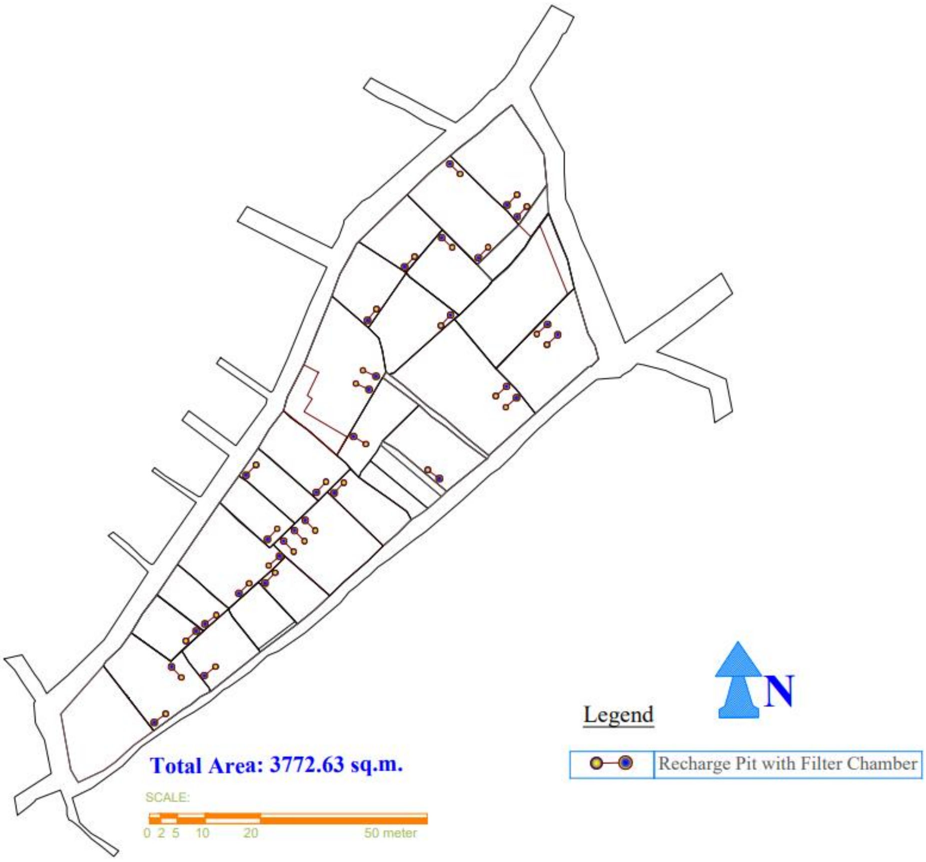


Fig.5-26: Feasible spots for recharge pits in map

The figure above shows the feasible spots for recharge pits along with filter chambers in the area. So, the Case area with recharge pits along with existing scenario is shown in figure below. The recharge pits were designed considering the existing scenario.

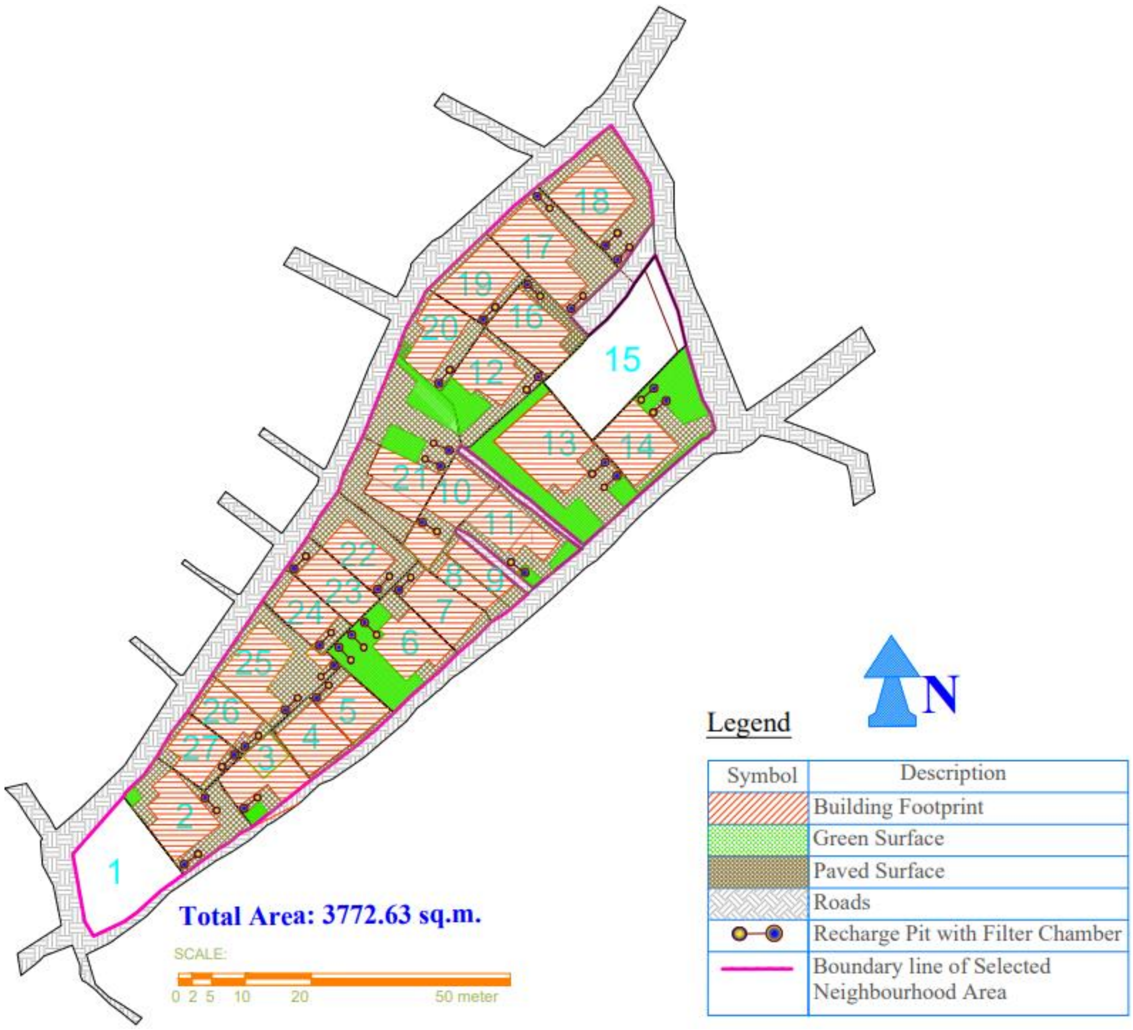


Fig.5-27: Case Area with recharge pits in existing scenario

5.3.5. Increase in infiltration by artificial ground water recharging

The infiltration rates were referenced from the literature as shown in table below. As shown earlier, there is about 76% of impervious surfaces (hard surfaces) in the case area, the literature says that the infiltration in such area is only 15% i.e. 850.718 cubic meters of rainwater for such cases. The total infiltration along with evapo-transpiration, runoff are also shown in chart below for different cases having different percentages of impervious surfaces.

Table 5-6: Evapo-transpiration, runoff and infiltration of different surfaces (Saraswat, Kumar, & Kumar Mis, 2016)

Nature of Area	Evapo-Transpiration	Runoff	Infiltration
Natural Ground Cover	40%	10%	50%
35 -50% Impervious Surface	35%	30%	35%
70 - 100% Impervious Surface	30%	55%	15%

Based on the above data, a comparison table is generated among the literature and the findings.

Table 5-7: Infiltration in percentage for different case by ground water recharging

Nature of Area	Total rainwater in selected neighborhood with runoff coefficient 1 (cu.m)	If all rainwater is recharged i.e. from roof top and ground surface, INFILTRATION (cu.m)	If all rainwater is recharged i.e. from roof top and ground surface, INFILTRATION in %	If only ground surface rainwater is recharged, INFILTRATION (cu.m)	If only ground surface rainwater is recharged, INFILTRATION %,	If only roof top rainwater is recharged, INFILTRATION (cu.m)	If only roof top rainwater is recharged, INFILTRATION in %,
Before Ground Water Recharging	5878.248	881.737	15	881.737	15	881.737	15
Potential Ground Water Recharging	5878.248	3347.200	56.94	1168.658	19.88	1994.070	33.92

Comparing the contribution in infiltration of urban areas when ground water recharging is done in different cases is shown is table above. Where, the percentage of infiltration when all rainwater is recharged i.e. from the rooftop and the ground surface is about 57%. The percentage of infiltration when only the rainwater from ground surfaces is recharged is about 20%. The percentage of infiltration when only the rainwater from the rooftop surfaces is recharged is about 34%.

Based on these data, the increase in infiltration is calculated in percentage for different cases are shown in table below.

Table 5-8: Increase in infiltration in percentage for different case by ground water recharging

Infiltration % having 70 to 100% impervious Surface	INCREASE IN INFILTRATION (%)		
	If all rainwater is recharged i.e. from Roof top and Ground surface in %	If only ground surface rainwater is recharged in %	If only roof top rainwater is recharged in %
15%	41.942	4.881	18.923

So, the percentage of increase in infiltration when all rainwater is recharged i.e. from the rooftop and the ground surface is about 42%. The percentage of increase in infiltration when only the rainwater from ground surfaces is recharged is about 5%. The percentage of increase in infiltration when only the rainwater from the rooftop surfaces is recharged is about 19%.

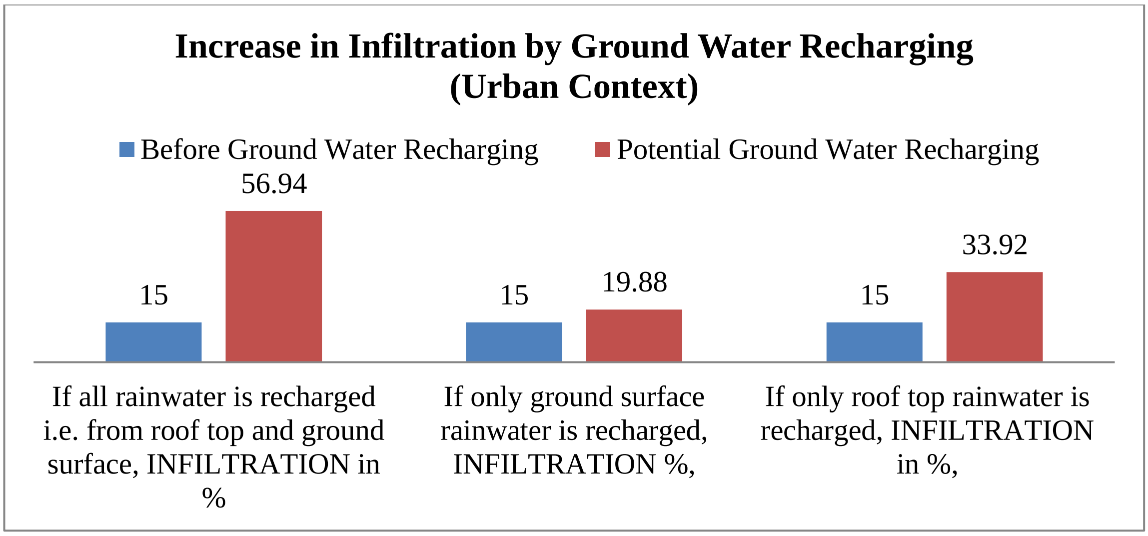


Fig.5-28: Chart showing infiltration before and after ground water recharging in percentage

Above chart clearly shows that the change in infiltration percentage before and after groundwater recharging is done. The result shows that the infiltration increases obviously if ground water recharging is done. But the more of infiltration is in case if all rainwater from rooftop and the ground surface is considered followed by if rainwater from rooftop surfaces are considered and if rainwater from only ground surfaces are considered.

5.4. Potential volume of waste water reduction from ground water recharging (if all rainwater is considered)

Table 5-9: percentage of rainwater comparing to domestic sewage of KMC ward 26

S. N.	KMC Ward 26 Area (sq.m.)	Total waste water (Domestic Sewage) of KMC Ward 26 in litres (data of 2020)	Selected Neighborhood Area (sq.m.)	Annual Average Rainwater to drain from selected neighborhood (ltr.)	Amount of waste water (Domestic Sewage) per sq.m. (litres)	Annual Amount of rainwater in drain per sq. m. (litres)	% of Rainwater i.e. even more than the domestic sewage
1	1971300	1,582,275,000	3640.21	3368552	802.656	925.373	13.26

Table 5-10: Percentage of rainwater comparing to Peak DWF wastewater of KMC ward 26

S. N.	KMC Ward 26 Area (sq.m.)	Total waste water (Peak DWF) of KMC Ward 26 in litres (data of 2020)	Selected Neighborhood Area (sq.m.)	Annual Average Rainwater to drain from selected neighborhood (ltr.)	Annual Amount of waste water (Peak DWF) per sq.m. (litres)	Annual Amount of rainwater in drain per sq. m. (litres)	% of Rainwater taking total of Peak DWF
1	1971300	4,272,325,000	3640.21	3368552	2167.263	925.373	42.70

From the data given by DIP (Project Implementation Directorate), annual amount of domestic sewage in drain per square is calculated as 802.656 litres and annual amount of peak DWF of wastewater in drain per square is calculated as 2167.263 litres. Where, annual amount of rainwater in case area is 336855 2litres. So, there is huge percentage of rainwater comparing to waste water i.e. is 13.26%rainwater is more than domestic sewage and about 42.70% of peak DWF is equal to potential rainwater in drain. If the rainwater harvesting were done then this would eventually reduce the sewer and wastewater treatment plant overloads and help in urban sustainability. This will also help in water clogged streets in rainy days.

5.5. Social perspective towards rainwater harvesting

5.5.1. Stakeholder Mapping

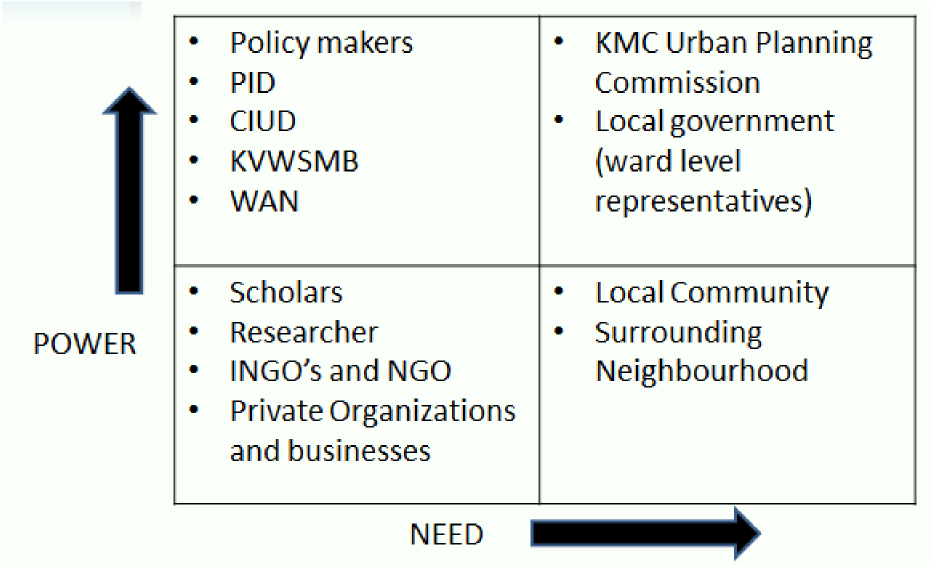


Fig.5-29: Stakeholder Mapping

The figure above shows the stakeholder mapping for the selected subject area, with power at the vertical side and need at the horizontal side. According to the stakeholder mapping, KMC Urban Planning Commission, Local government (ward level representatives) are on the high power and high need for integrating rainwater harvesting system in residential buildings for improving the sustainability of such urban area. Whereas, the organizations like PID, CIUD, KVWSMB, WAN and the policy makers are on the high power. Similarly, the local community and the surrounding neighbourhood are on the high need for such project development. Moreover, the scholars, researchers, INGOs and NGOS, private organizations and businesses falls on low power and need of such subject area but are also the important stakeholders.

5.5.2. Concept of Rainwater harvesting from residents of case area

People's perception on rainwater harvesting, people in the urban areas have the idea of rainwater harvesting but have very less positive responses towards rainwater for drinking and ground water recharging. The concept of RWH is not new to the residents but they are not certain about the short term and long-term benefits.

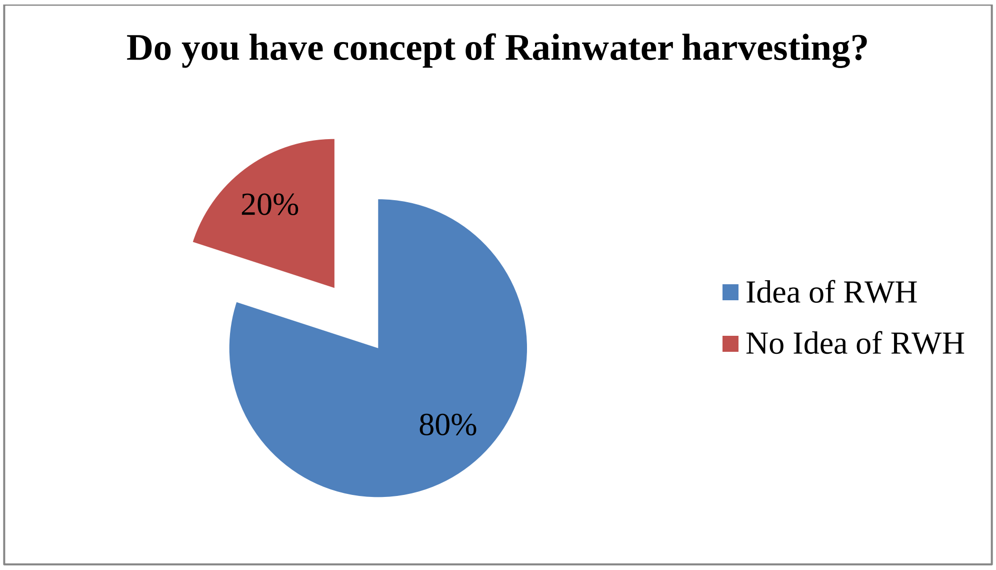


Fig.5-30: Concept of Rainwater Harvesting of residents of case area

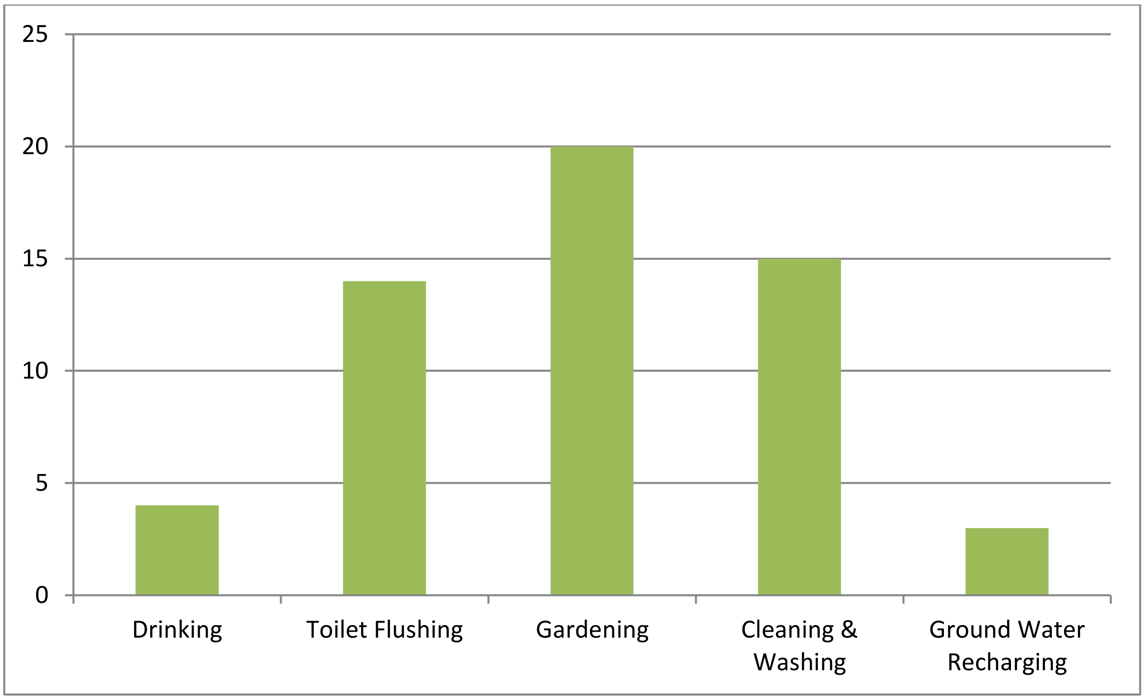


Fig.5-31: Respond to the question: What purposes rainwater could be used?

Talking about the response of the residents to the question, if RWH system is installed in your house, then for what purposes you would like to use the rainwater, the most of the respondents responded as rainwater could be used for gardening followed by cleaning and washing, toilet flushing, drinking and groundwater recharging. This shows that the residents prefer less to use rainwater for groundwater recharging in comparison to other domestic uses.

5.5.3. Concept of Rainwater harvesting from private and government institutions

Government and nongovernment institutions are involved in rainwater harvesting projects for immediate/household use of rainwater where there is no availability of fresh water. The projects that done for groundwater recharging are only on community level than on individual level as per CIUD. There are no policies for ground water recharging to implement in individual level according to governmental offices like ward office and Department of water supply and sewerage management. It is also said that the individual project of RWHS is only circulating among the people who could easily afford according to source- Smartpaani.

5.5.4. Community perception on the cause of drying water wells in near past

Even if drying water wells are the serious and on-going water issues on an urban residential area, people are unknown about their causes and the idea about water and water cycle management.

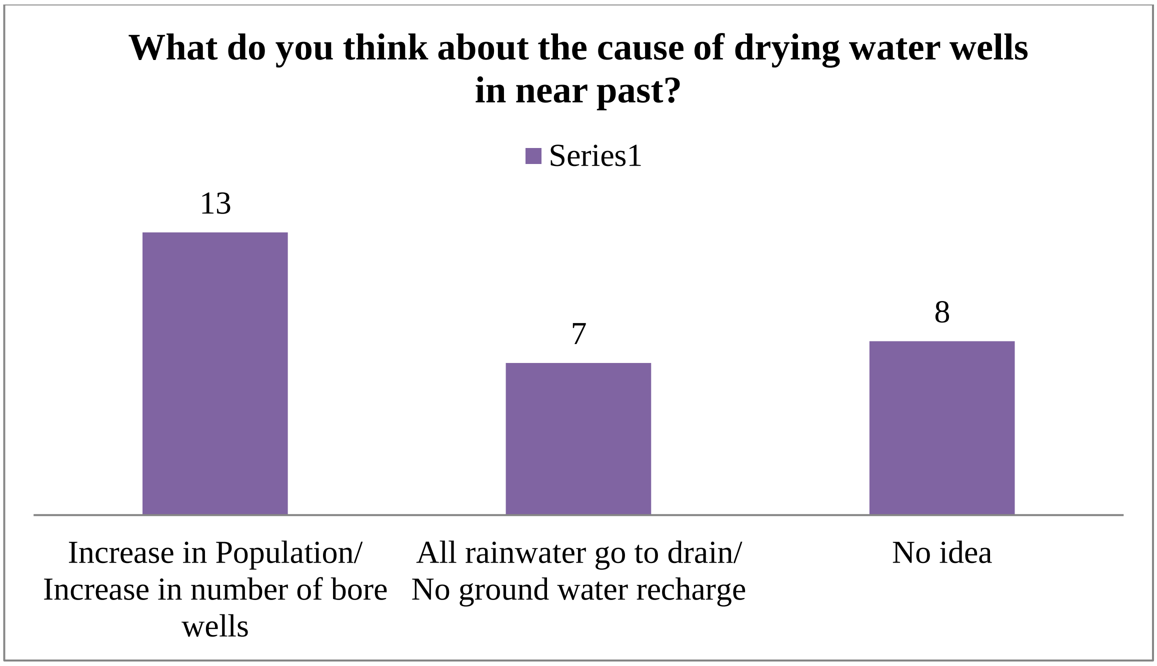


Fig.5-32: Community perception on the cause of drying well in near past

The chart above shows the number of views on different reasons for the problem like drying wells in near past and present. Where most of the people think that it is due to the increase in population or the increase in number of bore wells in the neighbourhood area.

Very less number of the respondents think that the cause is due to no ground water recharging.

5.5.5. Community perception on the cause of water logged streets during rainy days

Even if water logged streets during monsoon season is the serious and on-going water issues on an urban residential area, people are unknown about their causes and the idea about water and water cycle management.

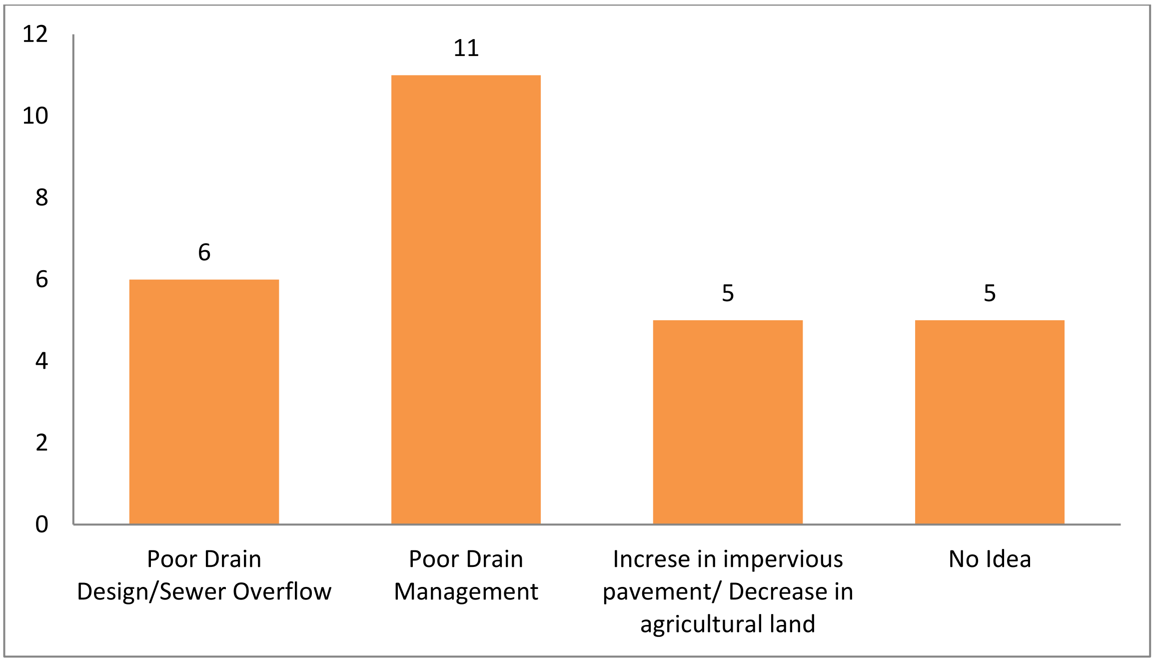


Fig.5-33: Community perception on the cause of water logged streets during rainy days

The chart below shows the number of views on different reasons for the problem like water logged streets during rainy days. Where most of the people think that it is due to poor drain management. Very less number of the respondents think that the cause is due to increase in impervious surface or no area for seeping water to the ground.

Chapter 6: Conclusion and Recommendations

6.1. Conslusion

The objective of my research is to investigate the role of decentralized rainwater harvesting for improving scenario of urban residential area in terms of sustainability applying the different methods discussed above. From this research, I can conclude that rainwater harvesting could be helpful in reducing potable water consumption to some extent and contribute to water sustainability. However, being more focused on ground water recharging, an urban area could contribute much as water sensitive urban development, which is also in, reverse to groundwater depletion.

The case area takes a perfect example of an urban residential area, which has almost 76% of impervious surface, and thus the result can be generalized as a reflection of compact urban residential area. There is water shortage in urban areas where people are approaching the alternative sources. They are paying the government for municipal water as well as paying to private water vendors to fulfil their water demand. They have also dig the bore wells to extract underground water for their water security with 96% of residences having bore wells in their plots. Whereas, people are letting rainwater drain to sewer lines. Therefore, the analysis shows that if rainwater is harvested only from roof catchment in decentralized way it could save almost 30% of potable water consumption in average annually depending upon the roof catchment area and the household size which directly helps in water sustainability by conserving water.

The findings also show that the population are more dependent on groundwater as 96% of the total population of the selected area has installed boring water but they do not return the water by seeping into the ground, reducing natural recharge thus causing the groundwater level to drop further. If every household take upon themselves to make arrangements to allow rainwater seep back into the ground, the urban area with also can act as an area with natural ground cover by increasing the infiltration by around 42%. Even if only roof top rainwater is allowed to ground water recharge then it will increase the infiltration by around 19%, which will reflect the given case area's nature as there is only 35% to 50% impervious surface from 70% to 100% impervious surface. On the other hand, even if only ground surface rainwater is allow to ground water recharge then it will increase the infiltration by around 5%. Therefore, recharging rainwater into the ground will help to regenerate water sensitive urban development by replenishing groundwater. Thus, decentralized ground water recharging plays a major role to improve the water infiltration in such urban residential area as also discussed on case studies with their success stories.

Although residences have separate pipe system to drain rainwater from rooftop, it directly enters to sewerage, if there is the use of rainwater harvesting system in every household then it will help to minimize urban flooding and wastewater treatment overloading. The analysis shows that the rainwater is more than the domestic sewage i.e. almost 13% more than the domestic sewage which when harvested will help in minimizing the sewer overload and urban flooding. While comparing with the peak dry weather flow of the waste water then the rainwater from the selected neighbourhood area would be equal to around 42% of the peak DWF. In this way, using the huge amount of rainwater for either household use or for groundwater recharging directly helps to minimize wastewater of an urban residential area along with limiting the issues like urban flooding or water logged streets during rainy days.

Regarding people's perception on rainwater harvesting, people are not much aware about its short term and long-term benefits. If RWH is installed, people from community are willing to use rainwater mainly for the purposes like gardening, washing and cleaning, toilet flushing followed by drinking and ground water recharging. Where 20% of the respondents do not have any idea on rainwater harvesting system. However, most of the respondents showed their interest to use RWH systems for water management and ground water recharging.

Even if the condition of water table/level in the urban areas is in decreasing state and people are digging second bore well with more of depth than before i.e. Up to 100' from around 30', people are not much aware about the cause of the issues like dry wells. Although the urban residential population are facing problems like urban flooding during rainy days, they do not realize its causes and their roles. So, the awareness level is much less among the residents about rainwater harvesting system and issues related to water and water cycle management in such urban residential areas.

We know that rainwater harvesting is an old technology but not much popularized in terms of water sustainability and water sensitive urban development. From the analysis and observations, it can be said that the rainwater harvesting systems are more focused on immediate use and only excess water goes to ground water recharging in case of residential projects which are only circulated among the people who are known about the direct benefits of RWH and easily can afford this technology. And in case of projects in community level, rainwater harvesting is done for ground water recharging that is mainly targeted for reviving stone sprouts, wells.

So, in conclusion, I can say that in decentralized projects also, if ground water recharging is treated as another major component of rainwater harvesting then it would be instrumental in promoting and regenerating overall sustainability of an urban residential area.

6.2. Recommendations

The case area reflecting urban residential scenario has many water related problems and its negative impact can easily observed on the environment. To overcome these challenges the considerable effort has to be made from individual household by using rainwater harvesting systems that will eventually leads to societal change in terms of sustainability. Governments, businesses and individuals should take responsibility at all levels for recharging and harvesting rainwater before it is too late by supporting depleting ground water system.

There should be awareness program to make people realize about the benefits or potentials of rainwater harvesting systems. The long term benefits to individual and society should be informed and make aware to every individual along with the current water related issues and their causes.

So, rainwater harvesting should be the part of policy and could be practiced in individual scale in the form of bye laws to the residents of rechargeable zones as like in different parts of India. For eg. Rainwater harvesting could be made mandatory in new buildings with an area of 1000sq m/1500sq m or more. Rainwater harvesting could be made mandatory in new buildings with a roof area of 100 sq m or more. Provision of around 6 or certain percentage of discount on property tax could be offered as an incentive for implementing rainwater harvesting systems. All new water and sewer connections could be only provided after the installation of rainwater harvesting. Where various offices related to Urban Development authority, ground water authority, Municipal Council, Ward office can be participated in formulating and implementing new law.

Rainwater harvesting systems should be incorporated into property development at the design stage. So, not only locals but also the experts like architects and environmental engineers should be involved in the planning process regarding water sustainability.

It is strongly recommended to encourage rainwater harvesting and ground water recharging to retard the runoff to the sewers and prolonging the life of the networks. There should also be clear demarcation about the agency i.e. responsible for development and maintenance of the storm water system

Before implementing, detail survey of the topography, surface overflow study, study of sub surface flow, infiltration, recharge capability, hydrological analysis are required and detail planning of the area is required to apply this approach.

Therefore, if there is increase in joint effort from individual, businesses and government level to popularize the rainwater harvesting technology along with its favourable impacts and implement right from the household level, it eventually promotes sustainability of an urban environment in one or other ways.

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Appendices

Appendix 1: Questionnaires for Survey

QUESTIONNAIRES DEVELOPMENT

NAME:

HOUSEHOLD SIZE (Family members of owner +On Rent):

PROPERTY DETAILS (ON FOOT)

Total Plot Area (l X b): _R- _A- _P - _D

(Building Footprint) Ground Floor Area approx. (l X b):

CATCHMENT AREA DETAILS

ROOF-TOP	RCC	Stones/ Slates	Clay Tiles	Terrace tiles	Galvanized Sheet	Marble/ Granite	Others
Slope Area (lXfXh):							
Flat Area (l X b):							

GROUND SURFACE	Stones	Parking Tiles	Bricks	Interlocking Pavers	Concrete	Marble/ Granite	Others
Pavement Area (l X b):							

WATER SOURCES USED:

Water Supply	**Frequency per week**	**Using from year**	Cooking	Drinking	Bathing	Dishwashing	Toilet Flushing	For Gardening	Cleaning/ Washing Vehicles, Clothes
Municipal Pipe System									
Tube well (Depth)									
Deep Boring (Depth)									
Tankers									
Jars									
Stone Sprouts									
Others									

1. **What are the water treatment practices for drinking or for other purposes:**

2. **Do you have separate piping system to drain roof water? and where does it go?**

RECHARGE PIT

Do you have recharge pit in your house for ground water recharge?

Recharge pit	NO	YES	Water enters from	Amount of water in litres	SIZE (lXbXh)	COMPONENTS
Pit 1						
Pit 2						

MEASURING PERCEPTION

1. Do you know about Rainwater harvesting?

CONCEPT	Rainwater harvesting
YES	
NO	

2. Do you like the idea of having rainwater harvesting system for drinking, toilet flushing, gardening, washing vehicle or ground water recharging?

Purposes	Drinking	Toilet flushing	Gardening	Cleaning /washing Vehicles	Ground water recharging	Others
Rainwater Harvesting						

3. What do you think about the cause or water logged streets during rainy days?

Causes	**Poor Drain Design/Sewer Overflow**	**Poor Drain Management**	**Increase in impervious pavement/ Decrease in agricultural land**	**No Idea**	**Others**
May be due to					

4. What do you think about the cause dry wells in near past?

Causes	**Increase in Population/ Increase in number of bore wells**	**All rainwater go to drain/ No ground water recharge**	**No idea**	**Others**
May be due to				

IF THERE IS RAINWATER HARVESTING SYSTEM IN THE HOUSE

1. What is the quantity of rainwater used per year in cubic meter?

2. What is the percentage of annual potable water consumption substituted with recycled rainwater or the volume of rainwater for ground water recharging?

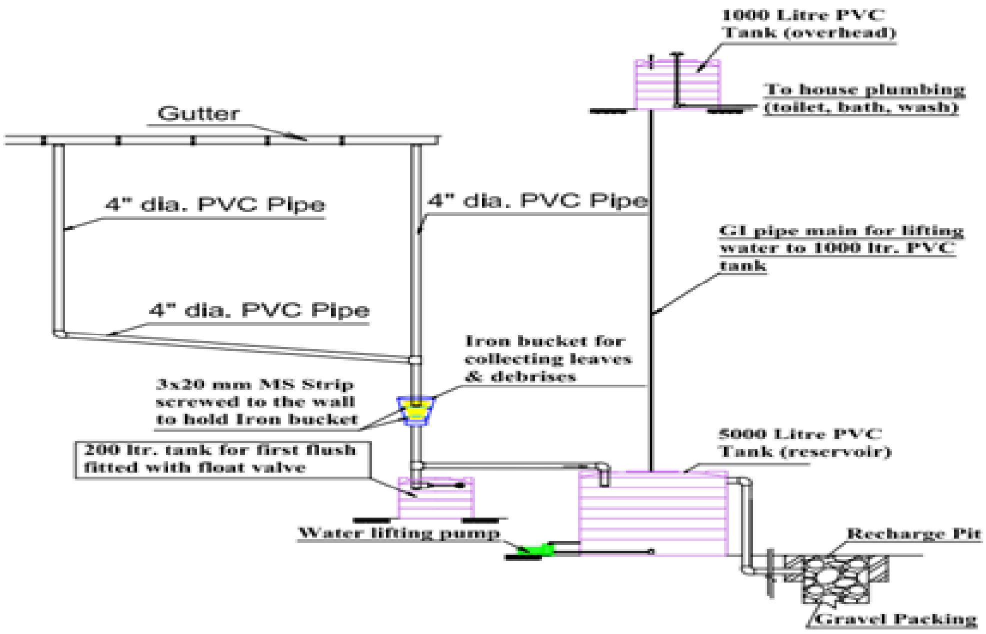
3. What are the rainwater treatment methods used?

4. What is the tank size to collect the treated rainwater and/or the recharge pit size?

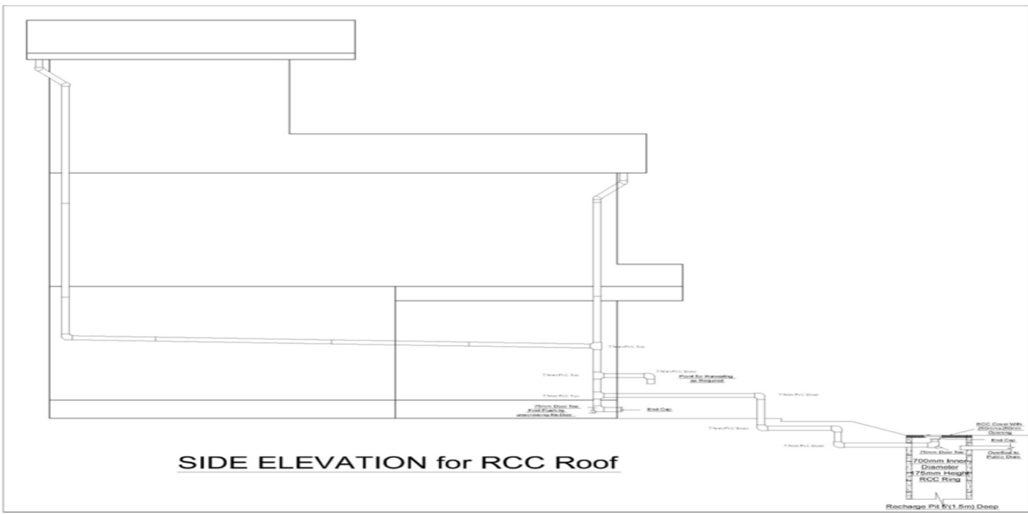
5. How often are you involved in maintenance and what are the procedures?

6. For what purposes treated rainwater is used for?

Appendix 2: Technical details for RWH systems



Typical Examples of RWH-GWR Schemes in Houses



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Typical Examples of RWH-GWR Schemes in Houses

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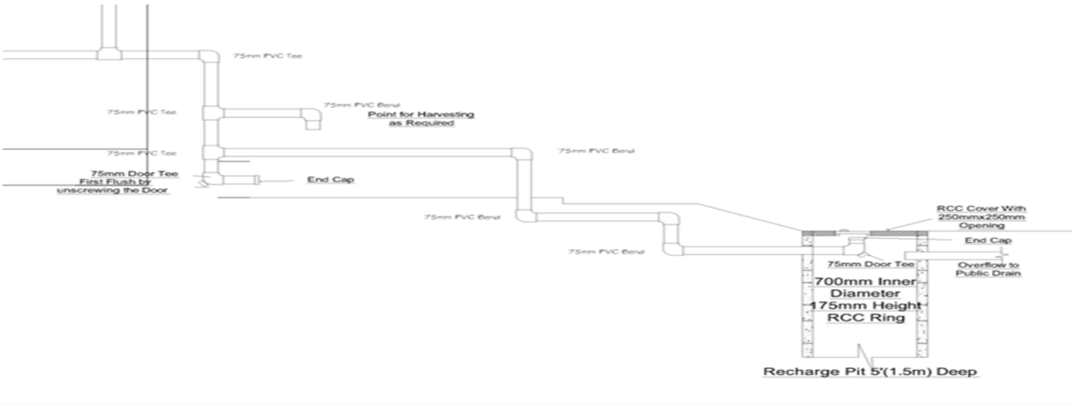
Proposed Typical RWH-GWR Scheme for Individual Household



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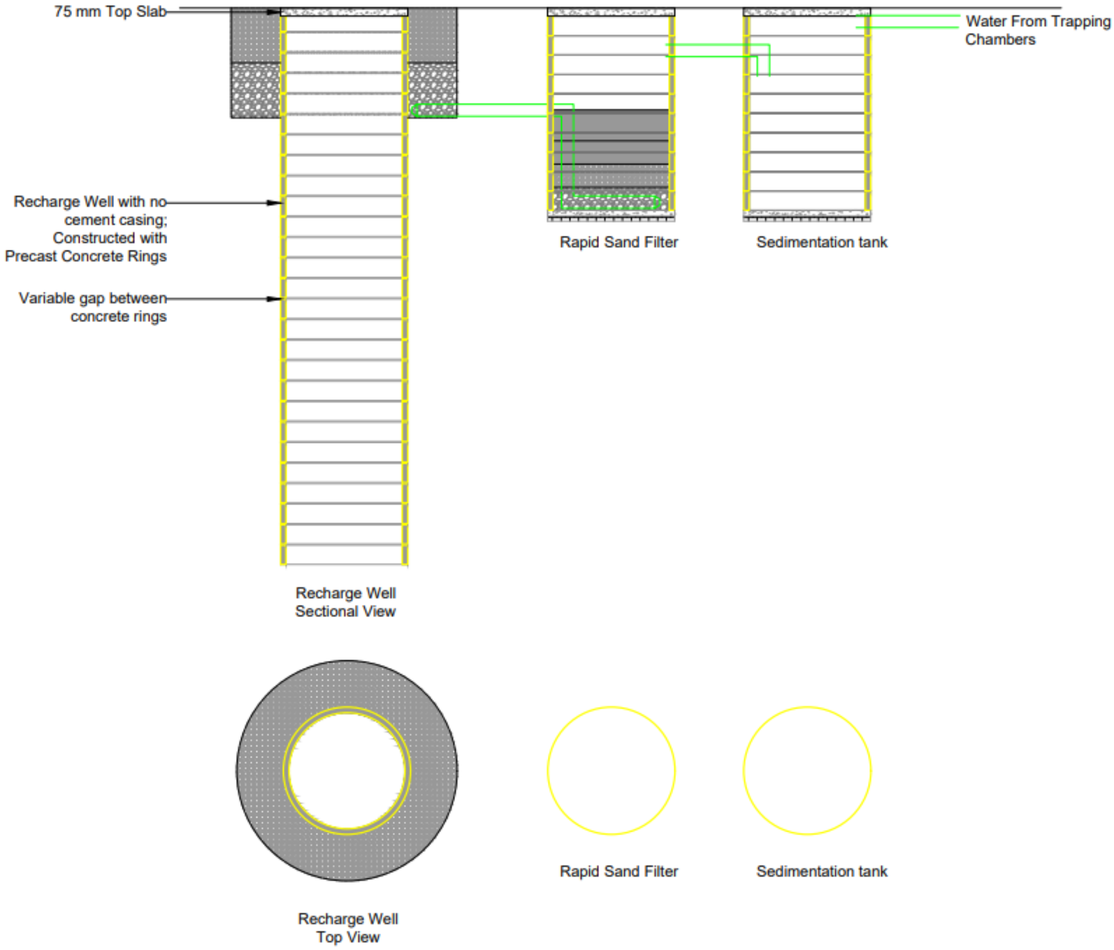
(Source: GyaneshBajracharya, team leader of International Centre For EnvironmentalManagement (ICEM)



Drawings of Recharge well

(Source: Smartpaani)

Appendix 3: Site Survey Photos