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Calculation and mapping of rainwater harvesting potential through GIS to conserve water from the roads runoff of Lahore, Pakistan

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Abstract

More than half of the population is going to be urbanized, by 2025. Currently, Lahore is also going through the phase of rapid population growth and urbanization. Progressive urbanization has increased land impermeability, which is the main cause of reduction in recharging rate of Lahore aquifer. The difference between recharge and discharge from the groundwater is 427 million m^3per year. The water table of Lahore is depleting with an average rate of 55cmper annum. If undue extraction of water is continued at present rate without recharging aquifer, the water table depth in many parts of Lahore will be dropped below 70m by the year 2025. Rainwater could be an excellent source of water to feed this depleting aquifer of Lahore. Lahore is suitable for rainwater harvestingwith an average annual rainfall of 715mm.This paper introduces how to calculate rainwater harvesting potential (RWHP) on the selected roads of Lahore by using GIS techniques. ArcMap is used to generate RWHP maps. The total calculated RWHP is 9,280,525$m^3$from 649702m^2 areas of roads of Model TownLahore in the year 2017, when an average annual rainfall was 616.82mm. The generated map by GIS has become the strong lobby and advocacy tool to prove that Lahore city has great RWHP through roads runoff. This analysis would be advantageous for future advanced urban runoff simulation by locating RWHP sites on roads. It can also be used to mitigate water borne diseases, urban flooding and heat-islands along with to recharge the aquifer of Lahore.

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Introduction

Water is the focal point for life and roads are the life lines of urban socio-economic activities. When these roads are flooded by heavy monsoon rainfall and remain inundated for many hours without recharging urban aquifer then they become the source of stress to socio-economic life and threat for cities hydrological cycle. Water scarcity is an increasing problem in almost every urban areas of the world. Growing population and rapid urbanization are the main causes of growing water demand.

The rate at which water is being used at present is likely to cause a scarcity of fresh water in the near future. Environmental friendly development of urban areas needs water conservation (World Bank, 2006).

Lahore is the second largest urban hub of Pakistan and also going through the phase of rapid population growth and urbanization. Unfortunately, the positive role of urbanization is subjugated by infrastructural deficiencies. The groundwater of Lahore is depleting with the passage of time due to having more built up areas and concrete roads. According to urban unit statistics (2010) there has been 632% increase in built up area from 1973 to 2009 in Lahore.

It means that there is more impermeable land in Lahore than ever before. Impermeable surface does not allow water to percolate into aquifer through it and causes reduction in the recharging rate.

The difference between recharge (2,192 mcm/year) and discharge (2,619mcm/year) from the groundwater is 427 million cubic meters per year. Lahore city is facing alarming decrease of water table i.e. at the rate of 0.55m per annum (WWF, 2015).

Rainwater harvesting can be used to recharge depleting water table of Lahore aquifer. RWH technology is used for gathering and storage of rainwater for human consumption from any catchment surfaces (roads, rooftops and open spaces) by using simple scientific methods. Adopting RWH techniques on roads of Lahore city can be useful to reduce water shortage, because Lahore city needs sustainable solution for upcoming water crisis. RWH on roads of Lahore metropolitan is not new perspectives for rainwater conservation. Overall, Punjab urban water sector is willing to embrace learning-by-doing with the aim to recharge lowering water table. Infiltration of rainwater to underground aquifer is one of the solutions for monsoon seasonal urban floods and to control health issues like dengue and malaria.

Two experimental recharger pits were made by Water and Sanitation Agency (WASA), using to recharge aquifer of Lahore at Tajpura scheme and Gulberg. Lahore Development Authority (LDA) with the collaboration of Water and Sanitation Agency (WASA) has pointed out 39 RWHP sites on roads of Lahore including Qaddafi stadium and Lakshmi chowk (WASA, 2015).

This research can be helpful to estimate RWHP from these sites and to construct storage medium or to find out the size of recharger pit. Geographical information system (GIS) data base and tools of ArcMap have made it more reliable.

Materials and methods

Study Area

Lahore is selected for rainfall runoff simulation. It is located between 31° 15′- 31°42′N latitude and 74° 01′- 74° 39′ E longitude with total area of 1,772 km². It is bounded on East by India (International border), on the North and West by Sheikhupura district and on the South by Kasur District. Lahore is located on the left bank of Ravi River.

The research work is conducted in the selected housing society (Model Town)of Lahore district. The case study area Model Town is circumscribed on West by Fasial Town, on North by Garden Town, on East by Ferozepur road and on South by Township. The Cooperative Model Town Limited was established in 1921 as a co-cooperative housing society (Fig. 1).

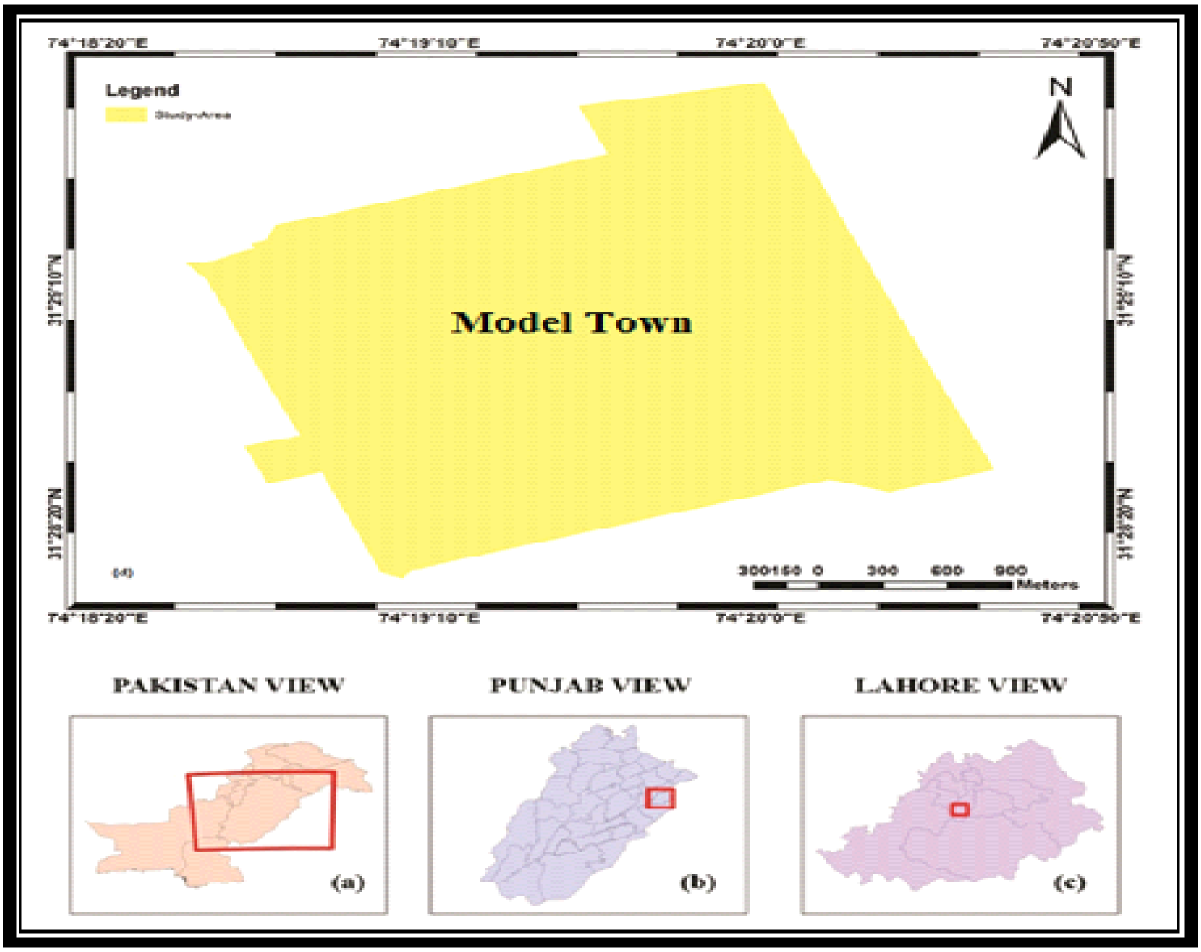

Fig. 1. Map showing spatial location of study area. (a) Showing location of Punjab province in Pakistan (b) Showing location of Lahore district in Punjab (c) District map of Lahore showing location of study area i.e. Model Town (d) Showing map of Model Town, Lahore.

It was a dream society of Dewan Kem Chand and designed by Sir Ganga Ram Agrawal (civil engineer and architect); original map of Model Town Housing society made by Sir Ganga Ram is given in Fig. 2. Model town covers an area of 5.9 km^2 (1,463 acres). This area is subdivided into ten blocks, which are A, B, C, D, E, F, G, H, J and K blocks. While L, M, N, P, Q, R, and S are in the peripheries of Model town and called as Model town extension.

Methodology

Case study approach is used in present paper. Roads of Model Town Cooperative Housing Society, Lahore is selected as case study purposefully because it is a well-developed residential area. Present need and consumption of fresh water can be calculated and the need of RWH can be advocated on sound footed.

Implementation of RWH is depending upon harvestable quantity of rainwater. Harvestable quantity of rainwater is called rainwater harvesting potential (RWHP). Estimated RWHP is calculated from the Surface Catchment Method (Equation 1). This is the most common, easiest and economical method for the calculation and estimation of RWHP in any particular catchment surface.

$S = A \times R \times Cr$ (Equation 1)

According to above equation, for the computation of RWH potential following three main factors are needed:

A = Catchment area

R = Mean annual rainfall in mm

Cr = Coefficient of runoff

Runoff catchment area (A)

An area of any type of surface from where rainwater can be collected is called catchment area. RWHP is calculated on the roads of Model Town, Lahore by digitizing on ArcMap 10.5. Quick bird satellite image is obtained as a primary data source for area calculation and to generate base maps of area as well as RWHP. Then in GIS data base the corresponding area of polygons are calculated in square meter (m^2) by using area calculation tool in ArcMap 10.5.

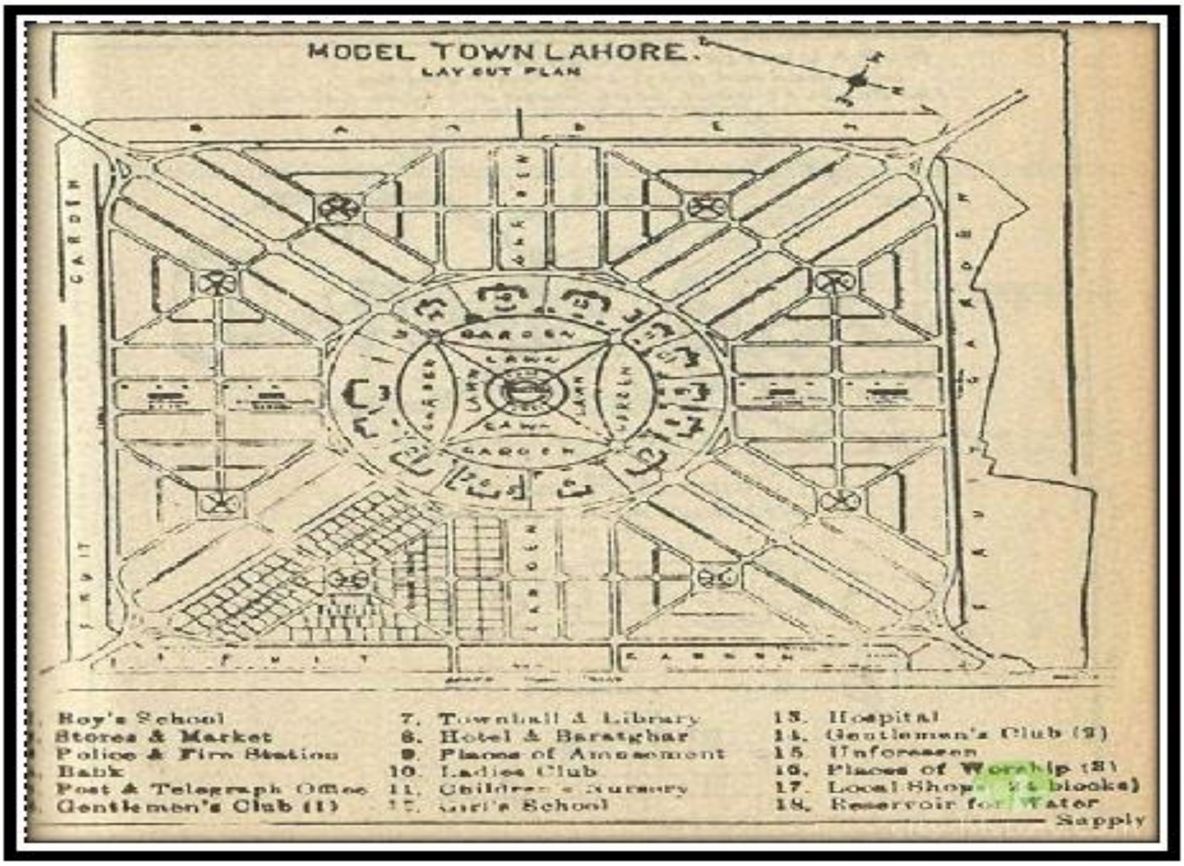

Fig. 2. Original map designs by Sir Ganga Ram Agrawal (civil engineer and architect). Source: Office of the Cooperative Society Model Town Limited.

Coefficient of runoff (Cr)

Storm water runoff is rainfall that flows over the ground surface. It is created when rainfalls on roads, parking lots, rooftops and other paved surfaces that do not allow water to soak into the ground. Storm water runoff is main cause of flooded streets rainy season.Runoff coefficient is a ratio between rainfall and runoff rate. It is a factor which is determined by considering the fact that all the rainfall runoff from a catchment surface cannot be captured. There is always a handsome amount of runoff lost from the catchment surface due to evaporation or retaining on the surface itself. It is a combined effect of catchment losses (Fig. 3). It can be calculated using Equation 2.

$Cr = Vr/Rt$ (Equation 2)

Where Vr is volume of run off and Rt is total volume of rain falls on the surface.

According to Table 1 the value of runoff coefficient for roads is taken as 0.8. This value indicates 20 % loss of runoff from catchment area of roads made of concrete.

Mean annual rainfall (R)

Amount of rainwater is a crucial component to adopt rainwater harvesting (RWH) system. First of all, rainfall data of last 30 years (1987-2016)has been obtained from Pakistan Metrological Department (PMD) Lahore, to check the trend of rainfall in Lahore. On the other hand, rainfall data of 6 stations of Lahore is obtained to calculate an average annual rainfall, for year of 2017 from WASA and PMD.

The collected data was analyzed and converted into mean annual rainfall in millimeter (mm). After which, the mean annual rainfall data of 2017 is analyzed and used to calculate rainwater harvesting potential.

Results and discussion

Computation of rainwater harvesting potential (RWHP) from roads

Infrastructure is the back bone of the city life. Socio-economic activities of city dependsupon roads. Therefore, systematic management of city roads system must be carried out on priority bases.

It is largely relying on an efficient drainage system. There should be a comprehensive plan for city drainage system which can be implementable and can also provide relief to the sewerage system during monsoon season. Lahore is famous for its artistic and beautiful roads networks. But unfortunately, many of the roads become flooded during rainy season due toincreased built-up areas and inefficient drainage capacity of the city, and thus, disturbed the socio-economic activities of the city life.

To make roads functional in rainy season too, RWH can be adopted as a solution.

Therefore, in addition to other sources like rooftops, roads offer a huge opportunity for rainwater harvesting as a practical solution of urban flooding.

Table 1. Factor of runoff coefficient for various types of catchments.

Type of Catchmen	Coefficients
Tiles and bricks	0.8 – 0.9
Corrugated metal sheets	0.7 - 0.9
Concrete	0.6 - 0.8
Brick pavement	0.5 - 0.6
Untreated ground catchments	0.0 – 0.3
Soil on slops less than 10%	0.2 – 0.5
Rocky natural catchments	

Pacey & Cullis (1989).

Fig. 4 illustrates the extensive area of Model Town roads in square meters. All the roads have been digitized and converted into polygons in order to calculate area. The conversion to polygons enabled area computation of roads which is a major input in calculation of rainwater harvesting potential volume. The total area of roads calculated by GIS ArcMap 10.5 is 649,702 square meters (649.702 kilometers). Total 425 polygons were digitized related to the roads of Model Town. Maximum area of road available for RWH is 67,095 square meters (m^2) and average calculated area is 3074 m^2. A huge road surface area is available within study boundaries carrying RWH potential (Fig. 4). Potential of RWH is shown in Fig 5. Total volume of harvestable rainwater is 280,525 m^3.

On an average, potential of RWH is 1,323 m^3while maximum potential is 28,970 m^3. RWH potential from roads is calculated by multiplying total catchment area of roads with runoff coefficient and average annual rainfall.

The estimated volume of RWH potential from a 1000 m (1 km) long and 5 m wide road, heaving a rain shower of 50mm can be estimated as follows:

Road area = length * width

= 1,000 m *5 m

= 5000 m^2

Run-off co-efficient = 0.8 (roads made of concrete)

Rainfall = 0.5 m

RWH potential = 5000 m^2 x 0.8 x 0.5 m = 2000 cubic meters

It means that one km (1000 m) road with 5m width has 2000 cubic meters (20,00,000 liters) rainwater harvesting (RWH) potential. 2,000,000 liters from only 1 km road is a huge potential volume for rainwater harvesting. It is keeping in mind that the average annual rainfall in a season is about 0.6 m (600 mm) in Lahore city.

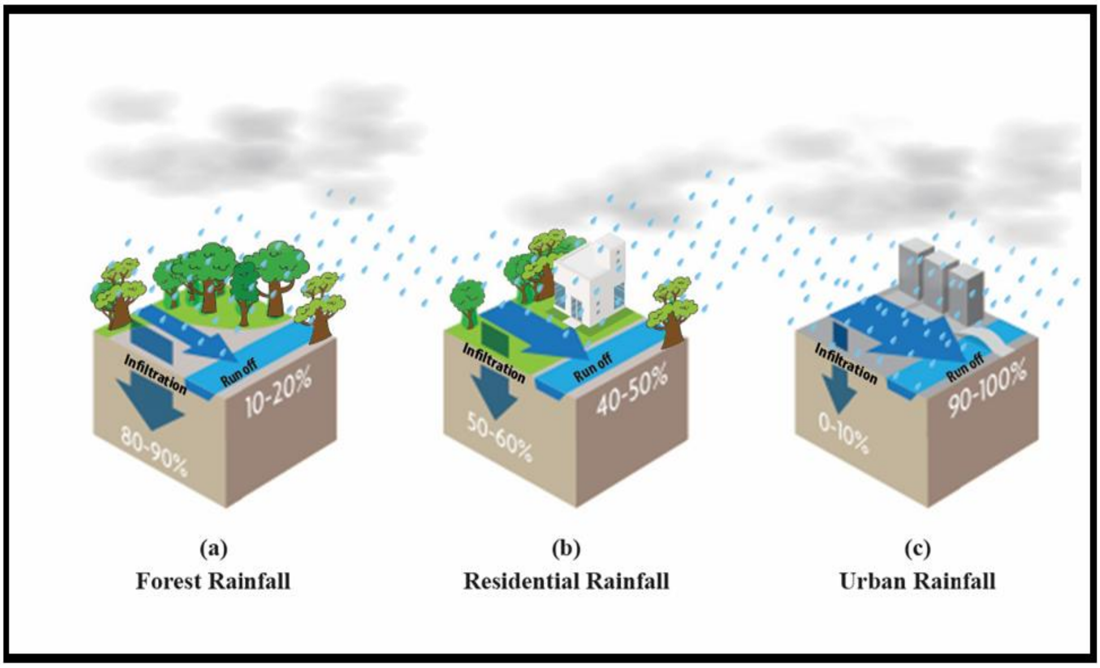

Fig. 3. Impact of urbanization on infiltration (a) Presenting rainfall in forest. (b) Presenting rainfall in residential area (c) Presenting rainfall in urban area.

After calculating the area of Model Town roads, which is the major input in the procedure, the amount of rainwater harvesting potential (RWHP) were estimated through ArcMap by adding another field with query. GIS data base findings are represented in shape of thematic maps of area showing rainwater harvesting potential on roads, comprehensively (Fig. 5). Symbology is used to show RWHP from five classes with natural breaks.

RWHP is directly proportional to the area of roads. The total calculated RWHP is 9,280,525cubic meters for the year 2017 when an average annual rainfall is 616.82 mm. It is the huge amount of harvesting rainwater and the generated map by GIS has become the strong lobby and advocacy tool to prove that Lahore city has great rainwater harvesting potential and a right solution for its future water crisis.Model Town roads have a great RWHP. It should be encouraged in the Town to do rainwater harvesting from potential sites of roads to mitigate flooded streets in monsoon season. RWH on roads can be adopted by doing suitable modifications in infrastructure. A RWH system can be done along the roads in a way that rainwater cannot erode the roads structure and water is always available for watering the road side plants and to recharge the depleting aquifer.

Advantages of Rainwater Harvesting through Roads Runoff

Rainwater harvesting (RWH) or storm water harvesting (SWH) through roads run off improves water security in big cities.

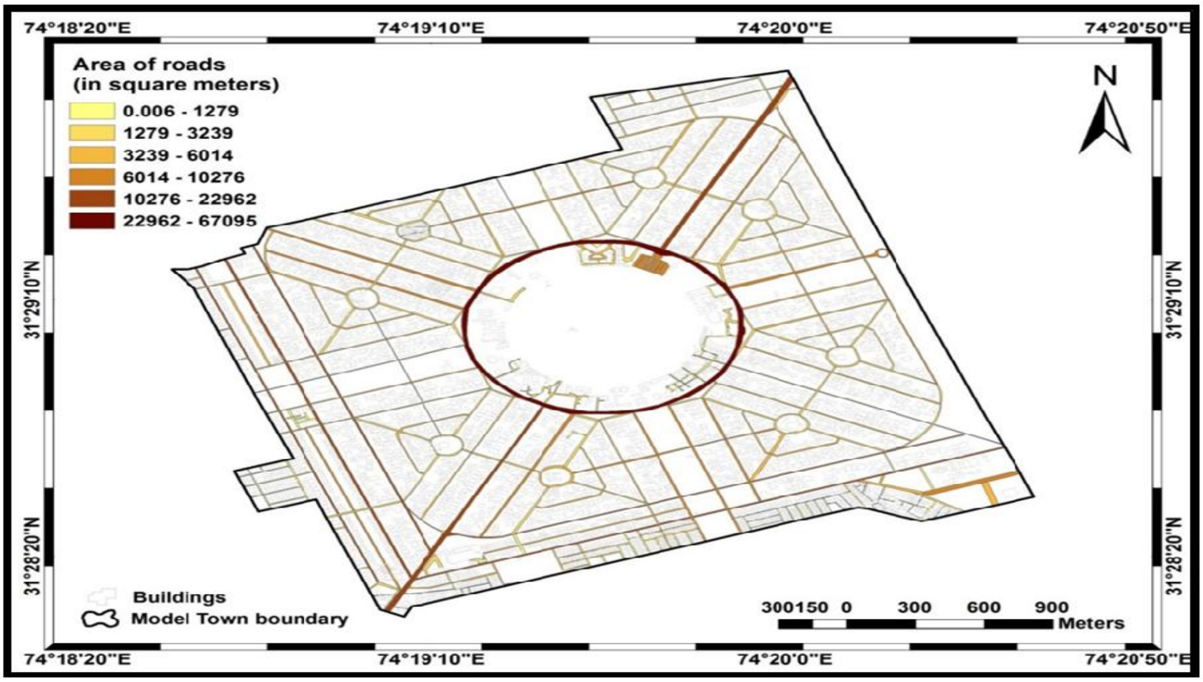

Fig. 4. Map showing area of roads in Model Town, Lahore.

In order to promote RWH or SWH through roads it is necessary to estimate RWHP at potential site to design harvested rainwater storage system or the size of the recharging pit to recharge ground water. Harvested runoff water can be used to fulfill the demand of watering plants after storing this water in underground water tanks along the potential roads. There will be a long run advantageous effect on urban runoff control and secured urban water cycle and so on by introducing RWH on roads of urban hubs. Thus, it will mitigate urban flooding. Harvested water can be held in soil as soil moisture by watering the plants and in the form of evapotranspiration. Handsome amount of this invisible water is vital for urban areas.

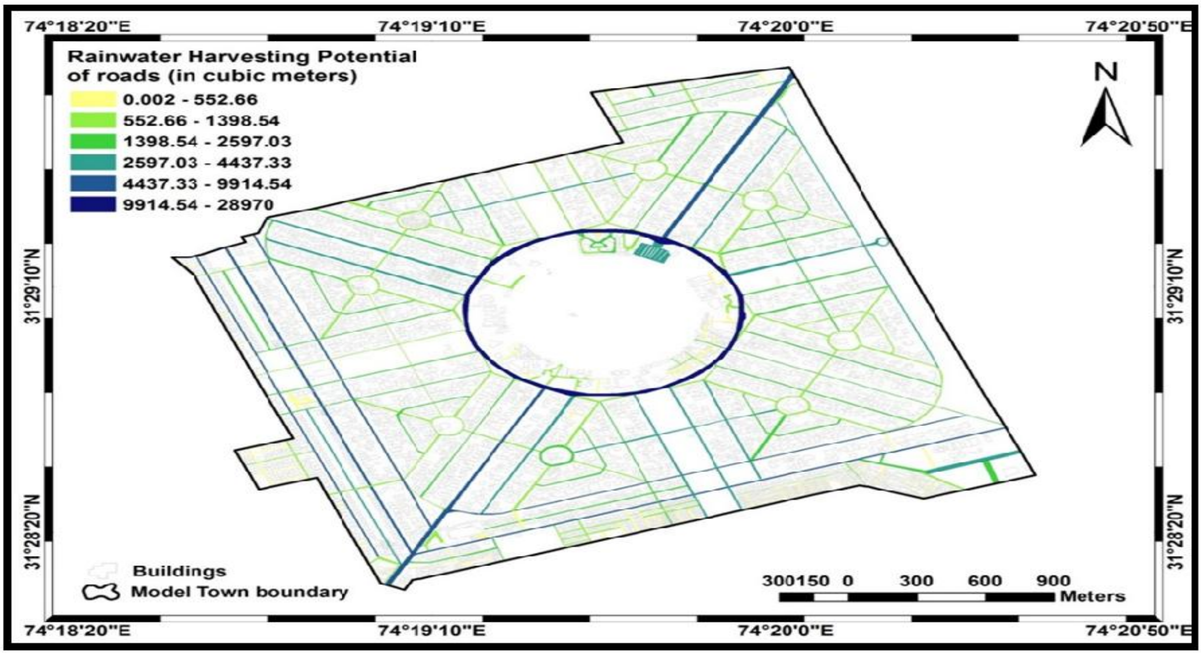

Fig. 5. Map showing RWH potential volume on roads in Model Town, Lahore.

Evapotranspiration reduces the urban heat island effects by invisible water. This is achieved by green infrastructure of cities. Greenery intercepts rainfall and slows down its travel, reducing the magnitude of flooding risks. Greenery also consumes heat energy by evaporation, therefore decreasing the temperature. It is declared that 1m³ of water consumes 700kwh of heat energy by evaporation that is the equal to the energy spent in a day by 100 air conditioning window units.

Rainwater harvesting is also used to mitigate water borne diseases like dengue and malaria in rainy season by capturing rainwater in storing harvested underground tanks. Harvested rainwater can be channelized through individual water system to the river Ravi other than sewerage system.

It means that urban areas need two underground water systems (Fig. 6). By implementing such ideas water can be conserve.

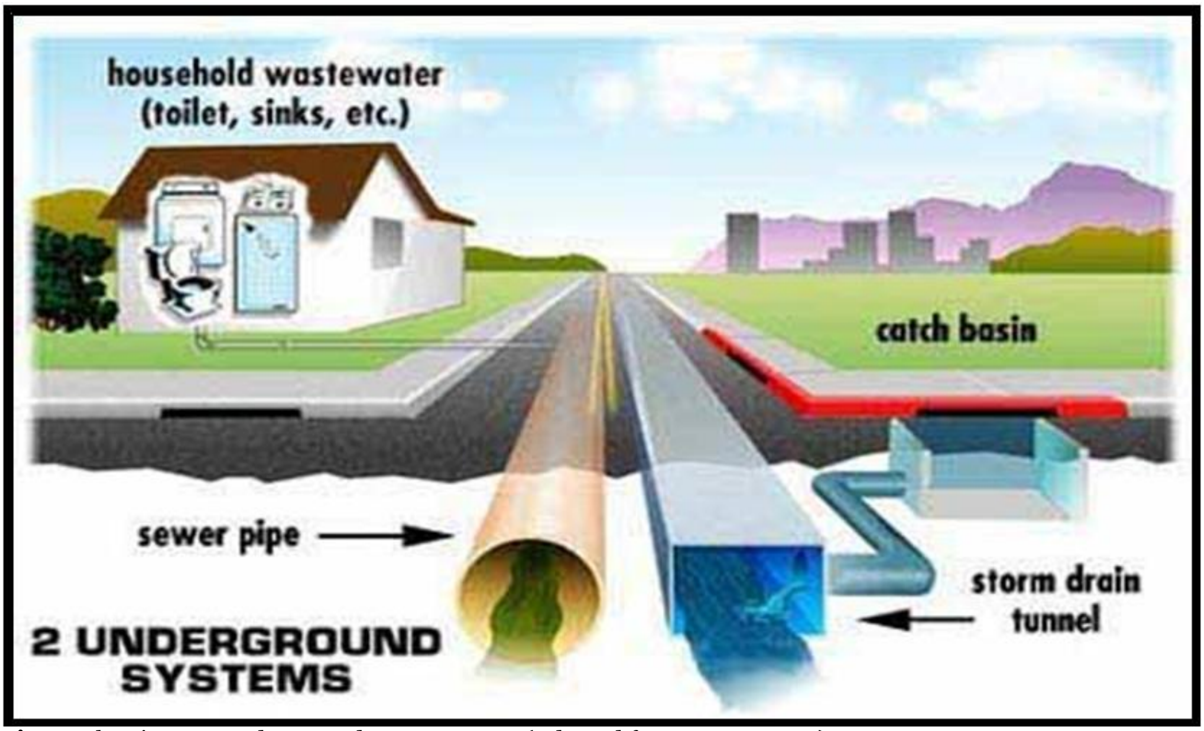

Fig. 6. Showing two underground water systems (Adapted from Mayor, 2017).

The use of modern technology will also be beneficial to achieve a higher rate of water recharge in urban area for instance porous paved landscaping can be used.

It allows percolation of rainwater into the ground. Now there is the need to avoid short sighted water management policies which rely only on groundwater.

The highlighted advantages of rainwater harvesting through urban runoff are simple enough to be adapted by the stakeholders and urban water system managing bodies to have sustainable urban water management in Lahore.

Conclusion

The total estimated amount of RWHP is 9,280,525cubic meters from the 649,702 square meters (649.702 kilometers) area of roads of Model Town, Lahore in the year 2017 when an average annual rainfall was 616.82 mm. The result strongly advocates and concludes that there is a need of a sensible; an effective and integrated water management system to meet the present and future water challenges of Lahore. Lahore is facing water challenges like increasing demands of water, lowering of water table, deceasing recharging resources of aquifer, chaos of inundated streets and roads in monsoon spell. Pakistan is located in the monsoonal climatic zone and Lahore shows composite monsoon type of climate with five seasons that are pleasant spring, foggy winter, hot summer, dry autumn and rainy monsoon. The rainwater harvesting (RWH) experts recommended that 70 mm (minimum) rainfall is required for doing rainwater harvesting. So that, Lahore is suitable for RWH with 715mm average monsoon rainfall (PMD Lahore, 2017). Using RWH techniques for urban runoff is a paradigm shift. It is obligatory to adopt the new paradigm of rainwater use along roads of urban areas which focuses on water conservation. It is one of best method to deal with depleting water table of big cities like Lahore.

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