Chapter 36
Sustainable Rainwater Harvesting System and Storm Water Management: A Case Study in Raipur Airport

Digeshwar Prasad Sahu and Mani Kant Verma

Abstract The immense and growing scarcity of freshwater across the globe arises as a troubling issue for both developed and developing countries. Groundwater is the only source of water of the Swami Vivekananda Airport Raipur, and it faces a water crisis when the groundwater level decreases. In this scenario, Rainwater Harvesting (RWH) can contribute considerably to tackle these problems. Rainwater treatment systems can be installed at different potential locations in the study area based on their physical site conditions such as slope and elevation. The airport has a total area of 2.108 km^2 (Kms^2); through the properly designed drainage system, storm water is collected and separated into three potential zones. Zones I, II and III having areas 0.2393, 0.4307 and 1.4382 sq. Kms, respectively, which produce different runoff amounts based on maximum daily rainfall. The airport has a 38,955.62 m^2 rooftop area, and water collected from the rooftop will fulfil approximately 30% of the total daily demand of the airport. Storm water is treated by Slow Sand Filter (SSF) at the rate of 200 L per hour per square metre and stored under design capacity, and size and number of treatment units depend on the maximum discharge at their respective zones. Excess water of storage tank is used for groundwater recharge, and a recharge well is provided at different depths according to fracture available below the ground.

36.1 Introduction

Water is crucial and it has always been considered throughout history as a natural resource for the survival of humanity. Worldwide, the important issue is the shortage of water either by quantity or quality (Gogate and Rawal 2012). In highly populated areas like urban area, the availability of freshwater even for daily use is not within reach and need external processes to get the water to the inhabitants of the area.

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Assessing and managing the justified use of water resources can help for preservation, and sustainable use becomes a vital issue in people's life, mainly in an area where the groundwater level is very low and there is very low rainfall. In this sequence to complete the freshwater demand of inhabitants, the use of rainwater is becoming an extensively influential instrument. For harvested water to remove microbial contamination and other chemical substances, rainwater needs some treatment system prior to utilising that water. The type of treatment to be provided depends on the purpose of intended use and characteristics of collected water from the ground surfaces or roofs (Helmreich and Horn 2009). A low-cost traditional treatment method like slow sand filter and disinfection by chlorination can be used for the region like an airport where treatment should be done only for rainy days and SSF is a highly efficient filter that removes 98–99% of bacterial contamination from water.

India has approximately 17% of the world's population and has only 4% of water resources in the world. India gets freshwater from precipitation about 4000 trillion litres in the form of snowfall and rain, and the maximum of this water reaches to the ocean and seas through the so many rivers which are flowing across the country. The United Nations (UN) apprise that the shortage of freshwater is the most serious problem to produce enough amount of food for a growing population of the world. The declination in per capita availability of water from 1947 to 2017 is 5200 m^3 to 1500 m^3 per year, respectively (Report of Indian Institute of Remote Sensing, Dehradun). In different parts of India, water is being used at a much faster rate than can be only refilled by rainwater. Therefore, we can say that India is not far away from water crises so we need to adopt some other water resource.

The location such as the airport required water at a significant amount to manage their operational routine and infrastructural demand (Gurung and Sharma 2014). The main purpose of this study is to reduce flash floods and use rainwater for the non-potable demand of airports. A proper drainage system is also required for the collection of storm water at different potential zones where water gets treated. Problem related to this must be taken for granted in India because, in scarcity, this will become a most treasured resource (Helmreich and Horn 2009). After knowing all the significance of freshwater to our growing inhabitants and thriving industries, to compensate for these, highly increasing demands RWH techniques can be adopted.

36.2 Methodology

Study Area

In Raipur, the capital city of Chhattisgarh, Swami Vivekananda Airport is near to the city and its boundaries spread in the range between 21°10′15″ to 21°12′00″ North latitudes and 81°43′27″ to 81°46′20″ East longitudes (Fig. 36.1). Airport bounds are limited to toposheet no. 64G/12 and 64G/11 which is provided by the Survey of India (SOI). The total plot area of the airport is approximately 520.89 acre (2.108 Kms^2). Semi-arid tropical climatic conditions prevail in Raipur urban area (Fernandes et al.

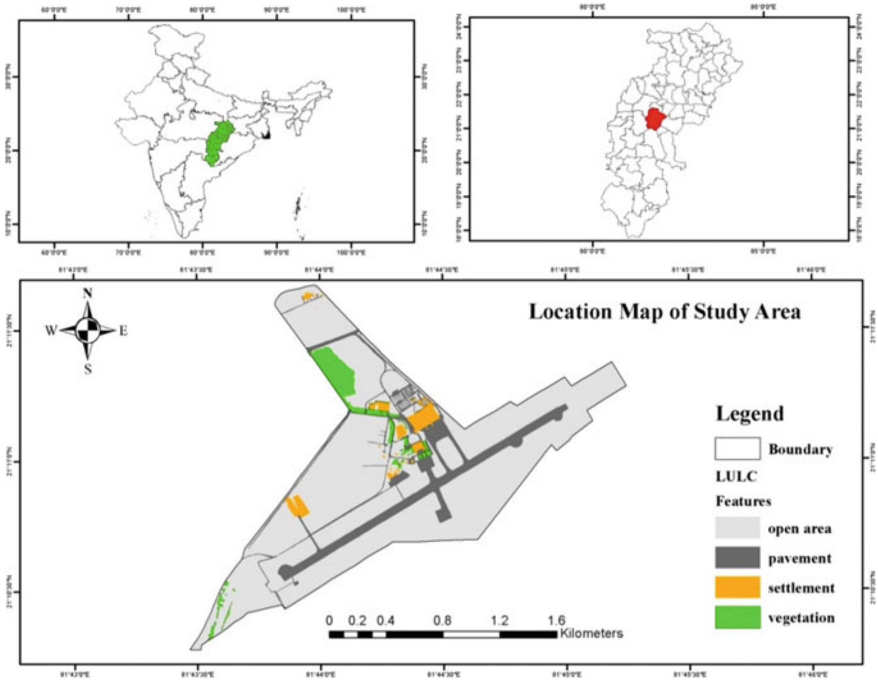


Fig. 36.1 Location map of the study area

2012). The area experiences a very warm summer of longer duration of March to the middle of June, and after this, the monsoon season will be started, which lasts for almost four months from the middle of June to September (Campisano et al. 2017). December to the end of February study area faces the winter season. Temperature varies from 10–46 °C, and humidity ranges from 30–85% and it receives 1185 mm average rainfall.

Physiographically study area is situated in the South-Central part of the Chhattisgarh basin having gentle undulating topography. Raipur is situated on the Proterozoic Chandi Formation of the Raipur group (Chhattisgarh Super Group), comprising of limestone, shale and sandstone. In the airport area, there is the occurrence of limestone and shale.

Rainfall-Runoff Modelling

The model was created using ArcGIS extension known as HEC-GeoHMS, which includes various steps in a series collectively term called as terrain preprocessing (Kumar and Jhariya 2017). The data needed for modelling such as DEM, LULC and soil maps are imported and merged with the proper projection system. Hydrologic Engineering Center's Hydrologic Modelling System (HEC-HMS) of version 4.1 is used for rainfall-runoff modelling. The HMS model allowed parameterisation of various infiltration losses could choose by the modeler (Fig. 36.2). For spatially

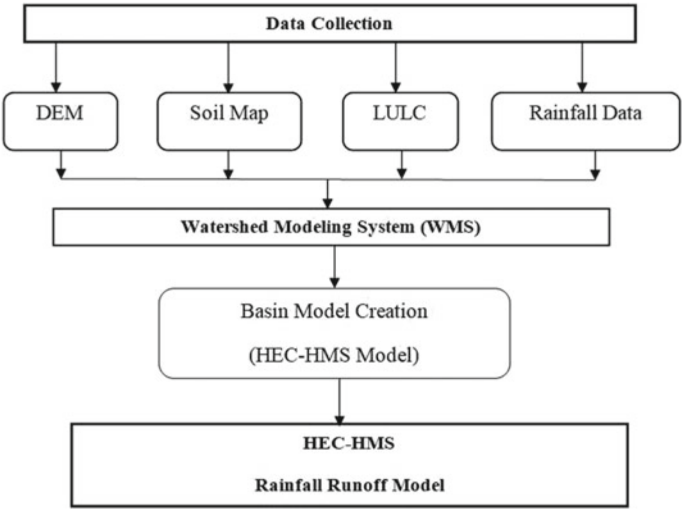


Fig. 36.2 Flow chart of rainfall-runoff model

dispensed calculation of infiltration enables by the Soil Conservation Service (SCS) curve number (CN) method (Kadam et al. 2012). The SCS-CN method is used for quantifying storm runoff of a particular area on the basis of their soil, land use land cover type and hydrological soil group (Domènech and Saurí 2011). The ability of infiltration of any soil helps to decide that soil fall under which hydrological soil group (Kumar et al. 2006). To differentiate the infiltration and runoff from the rainfall, some important equations are used which are empirical and derived by the infiltration loss method.

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)}$$

where P is effective rainfall depth, Q is event discharge or Surface runoff (mm), S is the potential maximum soil retention and Ia is Initial abstraction.

$$I_a = \lambda S$$

$$S = \frac{25400}{CN} - 254$$

where the value of λ varies according to soil type and Antecedent Moisture Content (AMC) and CN also varies in the range of 0 (no runoff produce) to 100 (produce all rain as runoff) which depend on LULC and soil condition (Kumar and Jhariya 2017).

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \text{ if } P > I_a\text{; Produce runoff}$$

$$Q = 0 \text{ if } P < I_a\text{; No runoff}$$

Drainage Design

The Storm Water Management Model (SWMM) is developed by EPA, which is extensively used for urban runoff simulation (Xing et al. 2016). The SWMM is widely operating for analysis, design and planning related to the urban drainage system. SWMM of version 5.1 is used for designing the drainage network, input data editing and simulation run and showing the results in the suitable form of tables, thematic maps, graphs and reports in a statistical format. IDF curve has been generated to determine the intensity of the rainfall event at various time durations for different return periods. These curves have been generated for the return periods of 2, 5, 10, 20, 25, 30, 50 and 100 years. The design of the drainage system was done for the 20 year return period. The cross-section of the barrel is taken as a rectangle and the size (depth & width) of the barrel is depending on the water accumulated at a particular point (Bitterman et al. 2016). The study area has 14 sub-catchments and 27 junctions which collect and divert storm water towards the outfall. The outfall is located at the lowest elevated point of respective zones, and water is forwarded to the treatment unit where it gets treated and stored.

Rainwater Treatment and Storage

Storm water contains sediment particle, and to remove the sediment, a settling tank can be constructed so that the filter will not be chocked during filtration (Bitterman et al. 2016). The size of the settling tank and SSF is based on the maximum discharge at the outlet point (Burman 1978). The Rate of Filtration (ROF) must be high so that the filter system can complete the demands and to meet this filtration, the rate thickness of the layers in the filter will be specified (Fig. 36.3).

After filtration, clear water is forwarded to the rainwater tank, water can be stored in the tank under its design capacity and excess water is used for groundwater recharge when it reaches to recharge structure (Moreira et al. 2012). In the recharge pit, two perforated borewells are installed to recharge groundwater because of the geological formation in the form of limestone and shale available in the study area (Burman 1978). Therefore, some fractures are present in the ground, which can be utilised for water recharge, and the depth of the borewells depends on the availability of fracture below the recharge structure.

36.3 Result and Discussion

Estimating the maximum daily water demand of the airport is essential to know the consumption profile of the premises and terminal building because to find the

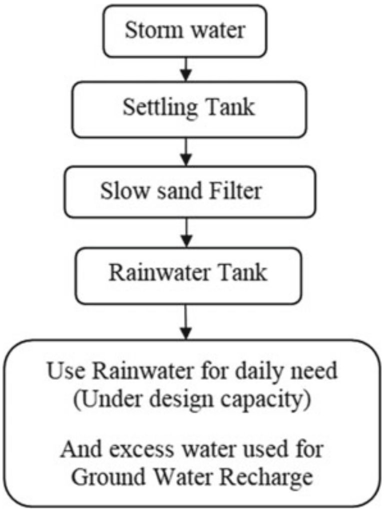


Fig. 36.3 Flow chart of rainwater treatment

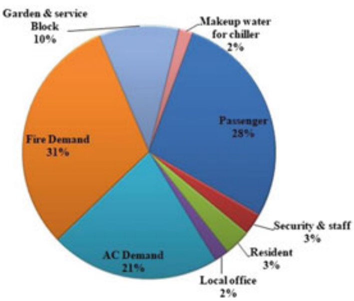
duration of service provided with the utilisation of harvested water. The data were collected from the airport authority of Raipur, which shows the consumption profile of the area. The rooftop water has enough to serve approximately 30 % of the total daily demand of the airport (Fig. 36.4).

Models Calibration

Rainfall-runoff relation monthlywise is calibrated through the HEC-HMS modelling. This relation is essential for managing the drainage design, and dimensions of barrel and junctions are provided for 20 year return period (Fig. 36.5).

In the HMS, the monthly variation of rainfall-runoff is calculated for 34 years (1980 to 2013) which shows the scenario of runoff (Table 36.1).

The drainage system is designed using SWMM, and a detailed network system is shown in (Fig. 36.6); through the barrels, storm water passes and goes to the treatment



Category	Final (Kl/d)
Passenger	135
Security & staff	13.5
Resident	16.875
Local office	9
AC Demand	105
Fire Demand	150
Garden & service Block	50
Makeup water for chiller	8.571

Fig. 36.4 Water consumption profile of study area

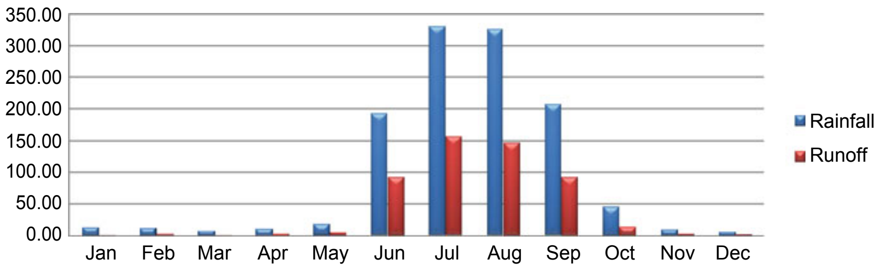


Fig. 36.5 Monthly rainfall—runoff relation

Table 36.1 Runoff volume of the study area

Region	Basin No	Area (km^2)	Runoff volume (1000 Cubic metre)	Total volume of runoff water (1000 cubic metre/year)
A	1	0.062	73.90	283.31
	2	0.113	133.64	
	4	0.064	75.76	
B	3	0.303	358.64	510.13
	5	0.128	151.49	
C	6	0.149	176.72	1703.47
	7	0.512	605.88	
	8	0.060	70.83	
	9	0.170	200.87	
	10	0.068	80.43	
	11	0.257	304.29	
	12	0.084	99.14	
	13	0.078	92.37	
	14	0.062	72.93	

unit. Some essential flow checks can be provided inside the storm water drains to retain the debris.

Sedimentation Tank

The design of the sedimentation tank is based on the maximum daily runoff in the study area (Gurung and Sharma 2014). Some important flow checks should be installed within the drains which contain storm water so that settling of the silt is restricted. A mesh can be provided near the inlet of the tank to remove the debris entering inside the settling tank. The size of the sedimentation tank is varied according to the water availability at outlet points (Fig. 36.7).

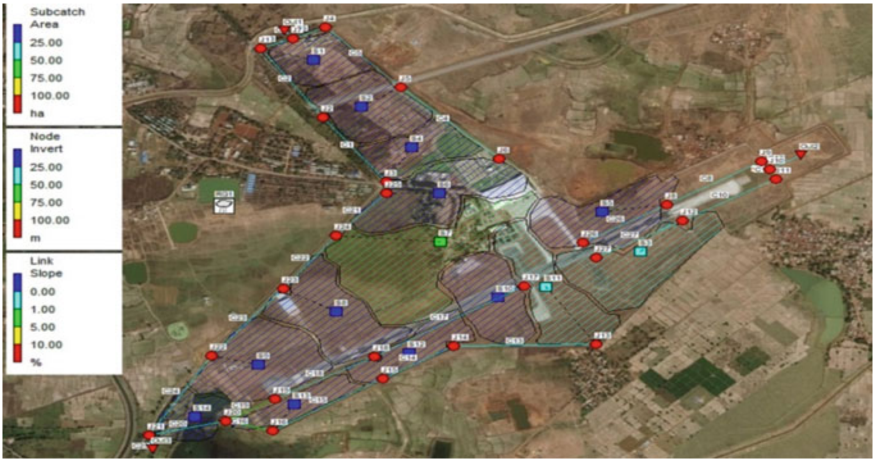


Fig. 36.6 Drainage map of the study area

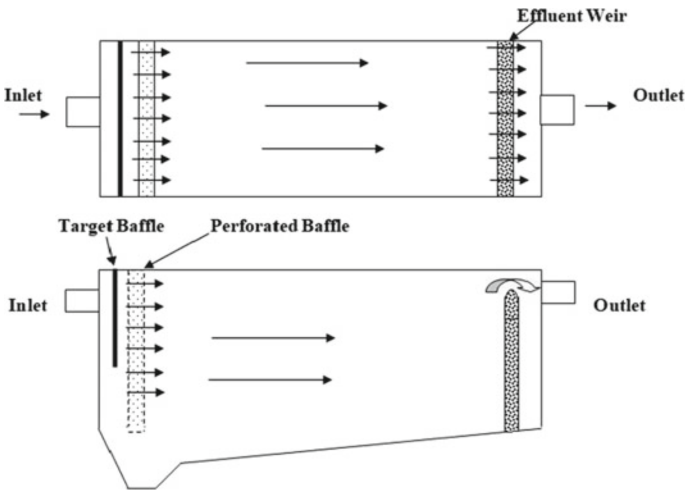


Fig. 36.7 Sedimentation tank

Slow Sand Filter

Clean river sand is of effective size 0.2–0.35 mm and thickness of the sand bed is 0.9 m. Gravel effective size is 3–60 mm and thickness of gravel bed is 0.4 m (Fig. 36.8). The rate of filtration is 200 L per hour per square metre and the width of the wall is taken as 0.23 m of the filter (Burman 1978). SSF should be installed parallel near the settling tank and a minimum of 2 filters must be provided as per guidelines (Table 36.2).

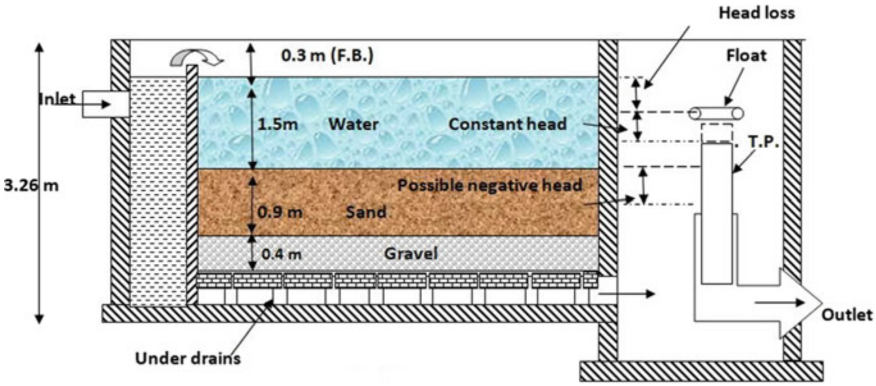


Fig. 36.8 Section view of SSF

Table 36.2 Depth of layers in SSF

Freeboard	0.3 m
Supernatant water	1.5 m
Filter medium (sand)	0.9 m
Gravel bed	0.4 m
Brick filter bottom	0.16 m
Total depth	3.26 m

Rainwater Tank

A rainwater tank is designed for 80% capacity of total runoff accumulated in 48 hours because of the limited area and 10% extra volume is provided for airspace in the tank (Fig. 36.9). Excess water goes to the recharge trench to raise the groundwater level

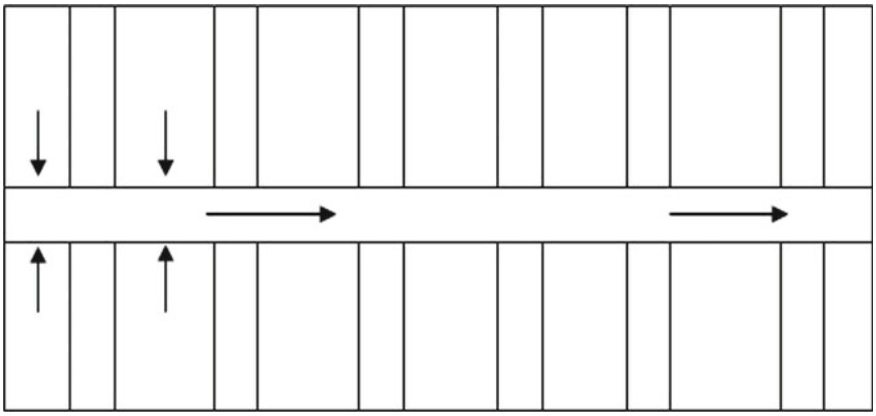


Fig. 36.9 Plan view of SSF

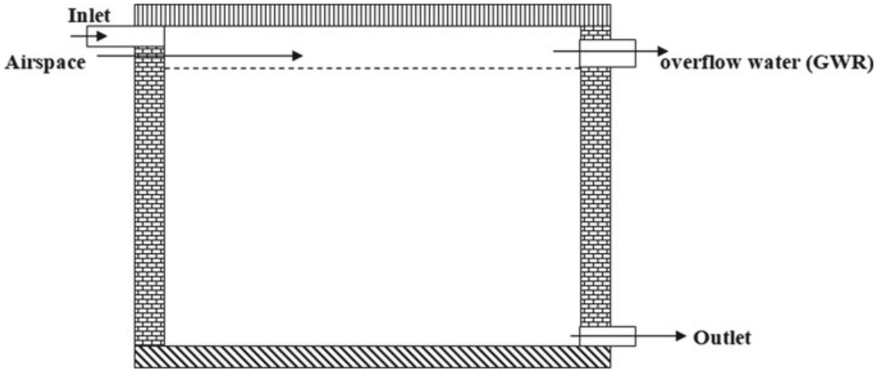


Fig. 36.10 Section view of Rainwater tank

(Gurung and Sharma 2014). A separate rainwater tank is also constructed for rooftop water which is collected near the existing treatment unit of the airport (Moreira et al. 2012). The rainwater tank should be clean before the rainy season so that the tank is free from any contamination (Fig. 36.10).

Recharge Structure

The artificial recharge systems are engineering techniques, where available surface water is injected in or on the ground for the process like infiltration and some other subsequent movements to aquifers to increase groundwater level (Yadav and Setia 2016). Some other purposes of artificial recharge are to improve the quality of the water through soil-aquifer treatment or geo-purification, to make groundwater out of the surface water where groundwater is traditionally preferred over surface water for drinking purpose, to store surface water and to use the aquifers as a water conveyance system. The geological formation of the airport is situated on the Proterozoic Chandi Formation, which is having a low infiltration capacity. Therefore, a recharge well can be constructed at significant depth based on the geological survey by instruments such as resistivity metre which can show the availability of fracture below the ground.

36.4 Conclusion

In Swami Vivekananda Airport, the application of rainwater harvesting is needed to meet the increasing water consumption demands such as cooling system and domestic use. The water supply at the airport depends on groundwater which is taken from five borewells located within the study area. The wastewater from the terminal building is treated at the sewage treatment plant and the treated wastewater is used for irrigation of gardens. The model performance criteria with different parameters showed that the model's results were excellent in runoff estimation, drainage design, rainwater treatment and recharge of groundwater in the study area.

The airport has a large open area that collects a huge amount of storm water at different zones of the study area that will help to save about 126.34 × 10^3 m^3 of water per year and excess water is used for groundwater recharge. Filter systems such as slow sand filter can provide economical and sustainable water reuse facilities for large areas like the airport, and it is used where the rate of filtration demand is less.

Construction of the recharge wells can be done at pre-determined locations. The depth of the recharge wells may vary as per specific site conditions and depth is to be restricted up to the depth where the well starts giving discharge. This will ensure the intake of runoff water so that water gets recharged at a rapid rate.

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