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INVESTIGATION OF RAIN WATER HARVESTING POTENTIAL FOR SUSTAINABLE WATER MANAGEMENT

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Abstract

Rapid urbanisation followed by the increase of paved surfaces conditions the infiltration of rain water into the soil. As the water demand started increasing with spiralling population, open wells and bore wells started drying up. The problem becomes very severe if no sincere attempt is made to replenish the ground water table with rainwater during the monsoon. In this paper, a study is carried out to estimate the runoff volume for B.S.Abdur Rahman Crescent University (BSACU) campus, Vandalur, Chennai, India by using Soil Conservation Service (SCS) curve number (CN) method. The water supply and demand for the university is studied in detail. The campus area is divided into sub watersheds and then the runoff is estimated using ArcGIS. The elevations at very closed intervals are measured using Global Positioning System (GPS) data collector and a Digital Elevation Model (DEM)of the campus area is generated. The sub watersheds contributing water in the study area are delineated with the help of Digital Elevation Model of the area. The subsequent runoff is calculated using the parameters such as rainfall, landuse, soil and slope. From the study it is found that about 74% of the rainfall is going away as runoff from the studyarea.

Suitable sites for recharge pits are suggested. Based on this study, it is suggested that suitable other harvesting methods are also to be adopted to save water and supplement the increasing water demand of the growing university for which the maps prepared in this study are useful.

Introduction

Rainfall- runoff process is a very complex one and depends on many factors like catchment and climatic characteristics. Hence it is very difficult to accurately represent the rainfall runoff process mathematically. Many empirical methods are available in literature for calculation of runoff, but it may not give concurrent values of runoff for same rainfall values. Curve number method was developed by USDA (US department of Agriculture) Natural Resources Conservation Service (NRCS) which is formerly called Soil Conservation Service (SCS) and is widely used for rainfall-runoff estimation for its simplicity and compatibility with RS & GIS techniques. Still it is popularly known as SCS curve number method. Many researchers (K.K.Gupta et al [1], Aseefa [2], D.Ramakrishnan et al [3], M.Ebrahimian [4] Arun.W.Dhawale [5], Jain M.K [6], Luiz [7], Romulus [8] have used this method for analysing watershed management practices in several watersheds. It is utmost necessary to effectively harvest and utilise the rain water to avoid a water crisis. The hydrological analysis of watersheds has become more methodical and accurate with the development of GIS as a spatial management and analysis tool. GPS data collector is very convenient and handy to measure the elevation of points. The capability of GIS is adopted in this study for the data analysis.

A. Study Area

The total land area of B.S. Abdur Rahman University campus is 62.07 acres. The land use consists of built up areas, roads, sports grounds and open plots. Apart from the university buildings, the campus houses, staff quarters, one residential school, ladies and men hostels. Figure 1 shows the study area.

Figure 1. Study Area Map

The total population of the campus was found to be around 6000 and the average water requirement was 3.46 lakh litres per day. The main source of water is ground water from open and tube wells. University purchases water to supplement the water from wells to fulfil the increasing water demands. There are proposals for future expansion of the campus which will again demand more water. The average annual rainfall is 120 cm and the average temperature is 26 °C.

B. NRCS Curve Number Method

The development of the method was intended to evaluate the hydrologic response of a changing condition (Ponce and Hawkins, [9] from storm rainfall depth, based on an empherical parameter called curve number. This method is used worldwide in hydrology for predicting direct runoff or infiltration from rainfall excess. The CN parameter depends on the following watershed properties:

1. Hydrologic soil group: A, B, C and D
2. Land use and treatment classes: agricultural, range, forest, and urban
3. Hydrologic surface condition of native pasture: poor, fair, and good
4. Antecedent moisture condition (AMC)

The CN method is applicable to areas less than 250 km^2 [9].

The hydrologic soil group of the study area can be obtained from standard tables based on the soil property, initial moisture condition existing in the soil prior to the rainfall under consideration. It represents the wetness or dryness of a watershed at the time of rainfall. NRCS developed three antecedent soil moisture conditions, which were labelled as I (dry), II (average) and III (wet) producing lowest to highest runoff potential respectively. The term "antecedent" varies from the previous 5 to 30 days of rainfall event. The NRCS uses antecedent 5-day rainfall as antecedent precipitation index for AMC. CN values are given for AMC II condition which can be adjusted for AMC I and III conditions using equations (5) and (6). After getting the CN value for each sub watershed, the runoff depth from each sub watershed can be calculated for different rainfall values. In this study the daily rainfall values for the years 2011 – 2012 are used.

Equation (2) is the basic equation for calculating run off depth. To get runoff depth, potential maximum retention S and initial abstraction I_a are required. For getting potential maximum retention S, curve number is needed. Curve number is obtained from land use, soil data and rainfall data in terms of antecedent soil moisture. Once curve number is obtained S and I_a can be found and runoff depth can be calculated.

The hypothesis of the NRCS method is that the ratio of the actual amount of direct surface runoff (P_e) to the total rainfall (or maximum potential surface runoff (p-Ia)) to the ratio of the amount of actual infiltration (Fa) to the amount of the potential maximum retention (S) are equal as given in equation (1).

$$\frac{F_a}{S} = \frac{P_e}{P - I_a} \quad (1)$$

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

where P_e - Depth of excess rainfall /direct rainfall (cm or inches)

P - Rainfall depth in cm or inches

F_a - Continuing abstraction

I_a - Initial abstraction

S - Potential maximum retention (cm or inches)

The value of I_a in Indian condition is given as:
Black cotton soil region: AMC II & III, $I_a = 0.1S$, for AMC I $I_a = 0.3S$ and for all other regions, $I_a = 0.3S$ and the equation (2) becomes,

$$P_e = \frac{(P - 0.3S)^2}{(P + 0.7S)}, \; p \geq 0.3S \quad (3)$$

The potential maximum retention(S) is computed using equation (4).

$$S = \frac{1000}{CN} - 10 \quad (4)$$

S is in inches. Thus after obtaining the CN value for the site, potential maximum retention and hence runoff depth can be computed.

The procedure of getting CN and S values are as follows:

From the rainfall data, calculate the five day antecedent soil moisture condition (AMC) and classify them into AMC-I, AMC-II, AMC-III based on the following criteria.

1. AMC- I condition represents dry soil with a dormant season rainfall(5 days) of less than 13mm and growing season rainfall (5 day) of less than 36mm
2. AMC – II condition represents average soil moisture condition with dormant season rainfall averaging from 13 to 28 mm and growing season rainfall from 36 to 53 mm.
3. AMC III condition represents saturated soil with dormant season rainfall of over 28 mm and growing season rainfall over 53mm.

The standard value of CN for the antecedent soil moisture condition II given in the National Engineering Handbook (NEH) is represented in Table 1and Table 2 shows seasonal rainfall limits for AMC [10].

Table 1. CN values for fully developed urban areas

Cover Description		**Curve numbers for hydrologic soil group**			
		A	B	C	D
Open space (lawns, parks, golf courses, cemeteries,etc.)	Poor condition (grass cover < 50%)	68	79	86	89
	Fair condition (grass cover 50 to 75%)	49	69	79	84
	Good condition (grass cover> 75%)	39	61	74	80
Impervious areas	Paved parking lots, roofs, driveways, etc. (excluding right of way)	98	98	98	98
Streets and	Paved; curbs and	98	98	98	98

roads	storm sewers (excluding right of-way)				
	Paved; open ditches (including right-of-way)	83	89	92	93
	Gravel (including right of way)	76	85	89	91
	Dirt (including right-of-way)	72	82	87	89
Western desert urban areas	Natural desert landscaping (pervious area only)	63	77	85	88
	Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)	96	96	96	96
Urban districts	Commercial and business (85% imp.)	89	92	94	95
	Industrial (72% imp.)	81	88	91	93
Residential districts by average lot size	⅛ acre or less (town houses) (65% imp.)	77	85	90	92
	1/4 acre (38% imp.)	61	75	83	87
	1/3 acre (30% imp.)	57	72	81	86
	1/2 acre (25% imp.)	54	70	80	85
	1 acre (20% imp.)	51	68	79	84
	2 acres (12% imp.)	46	65	77	82

$$CN(I) = \frac{4.2CN(II)}{10-0.058CN(II)} \quad (5)$$

$$CN(III) = \frac{23CN(II)}{10+0.13CN(II)} \quad (6)$$

Table 2. Seasonal rainfall limits for AMC (NEH-4, 1964)

AMC group	Total 5-day antecedent rainfall (mm)	
	Dormant season	Growing season
I	Less than 13	Less than 36
II	13 to 28	36 to 53
III	More than 28	More than 53

Since slope also influences the values of curve number the curve number is modified and the modified curve numbers are calculated using the equations (7), (8) and (9)

$$MCN_2 = (1/3)(CN3-CN2)(1-2xe^{-13.86SP}) + (CN2) \quad (7)$$

$$MCN_1 = \frac{4.2\,MCN2}{10-0.058MCN2} \quad (8)$$

$$MCN_3 = \frac{23MCN2}{10+0.13MCN2} \quad (9)$$

where CN is the curve number, SP is the slope percentage and MCN is the modified curve number. Then the weighted MCN value for each sub watershed is computed using the formula (10).

$$MCN_w = \frac{\sum_{i=1}^{n}(MCN_i * A_i)}{\sum_{i=1}^{n} Ai} \quad (10)$$

where MCN_w - Area weighted curve number of land use soil group polygon

Ai - Area of each land use soil group polygon

N - Number of land use soil group polygon in the sub watershed

Methodology

The whole campus is surveyed and the elevations of the area are measured at closer intervals and 3000 elevation points were collected. The base map of the area is collected from Google earth using Elshayal package. It is then digitized for doing analysis. All the measured existing built up area is compared with digitized map and found to be agreeing.

Using the elevation data, contour map and DEM are prepared. The DEM is used to delineate the sub watersheds in the study area. Then the runoff volume is calculated for each sub watershed using the modified curve number method by considering the weighted CN for each sub watershed. The site for recharge pit is selected in such a way that it is surrounded by areas with higher elevations with suitable soil stratum below and is demarcated as W,X,Y and Z in Figure 5.

A detailed study is conducted to find out the daily water demand of the campus considering water demand for day scholars, residents, and hostellers separately and found that the average demand of water is 3.46 lakh litres per day. Apart from open and tube wells, water is purchased from tanker lorry at an average of 1.5 lakh litres per day. Figure 2 shows the amount of water purchased and treated for the year 2012.

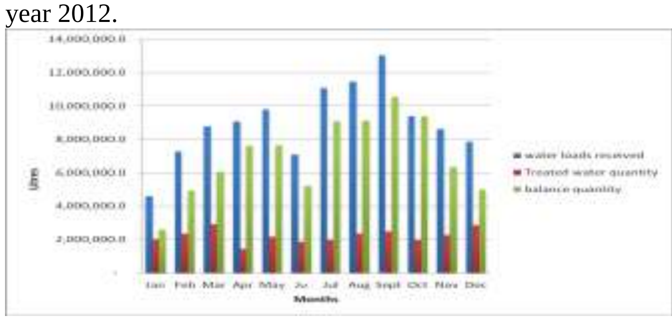

Figure 2. Quantity of water purchased, treated and balanced for the year 2012

The methodology is depicted as a flow chart in Figure 3.

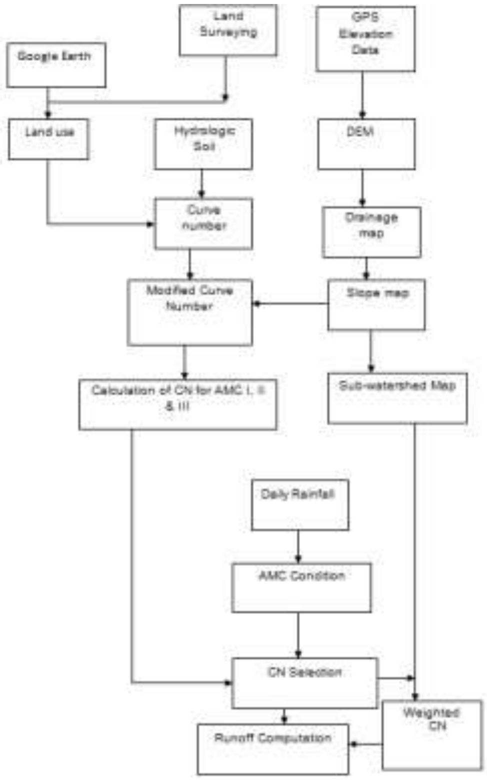

Figure 3. Methodology Flowchart

Figures 4, 5, 6 and 7 represents the Land use, TIN, Flow accumulation, and subwatershed maps of the study area respectively.

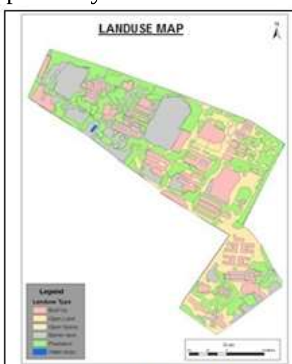

Figure 4. Landuse map

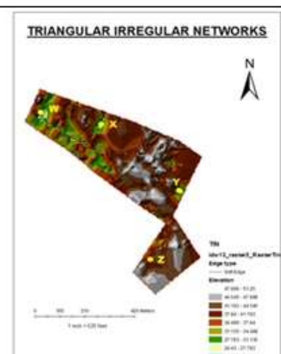

Figure 5. Triagular Irregular Network map

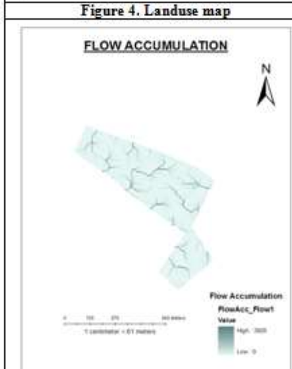

Figure 6. Flow Accumulation map

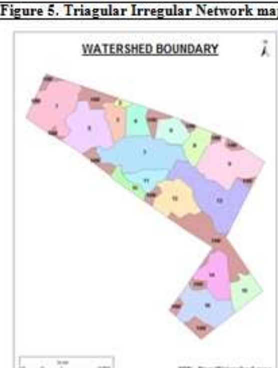

Figure 7. Sub watershed map

Results and Discussion

From the rainfall values it is found that the average daily rainfall value is 15.4789 mm in 2011 and 14.3182 mm in 2012. There are 76 rainy days in 2011 and 56 rainy days in 2012. The total runoff from the study area is found to be 179453 m^3in 2011 & 118785 m^3 in 2012. Taking the total number of rainy days into account the total rainfall volume is 238721.374 m^3 in 2011 & 162675.478 m^3 in 2012.The average percentage of runoff in the study area compared to the total rainfall volume is found to be 74. As the university is purchasing water for its daily use, other than the recharge pits suggested in this study, providing small check dams, recharge wells, recharge shafts etc at suitable sites, will definitely augment the ground water quantity and help to reduce the amount of water to be purchased. A detailed site suitability study should be done to accurately locate the above mentioned recharge structures.

According to the elevation data, the whole study area is divided into two viz ABDHIA (Area-1) where the drainage is from east to north-west and HIJKL (Area-2) where the drainage is from north-east to south-west. Area-1 measures 49.45 ac.res and Area-2 measures 12.62 acres.

Out of the runoff volume contributed by the study area, area-1 contributes152632.5746 cu.m and area-2 contributes 26821.02 cu.m in the year 2011. The respective values for the year 2012 are 101125.9 cu.m and 17660.61 cu.m. In the subwatershed map of study area (Figure 7), it is found that the areas marked as' NW' are not contributing water to the study area but may contribute to the next adjoining area. So for site suitability analysis, the watershed in which the study area lies is to be considered and analyzed for better results.
The locations identified for recharge pits are demarcated in the Figure 5 as W, X, Y and Z.

Conclusion

From the study, it is found that there is enormous potential for recharging the ground water of the campus with suitable recharge structures. A detailed rainfall-runoff estimation of the study area is carried out. Sites for recharge pits are identified. A comprehensive site suitability analysis is to be conducted with the guide lines prescribed by the Central Ground Water Board[11] to accurately fix the other types of recharge structures to be adopted .If it is executed properly, the water problem in the campus can be managed sustainably. Thus the amount of water to be purchased can be reduced and subsequently made nil. The maps prepared in this study can be utilized for this purpose.

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