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Design of Green Infrastructure: A Case Study of RGUKT Srikakulam

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ABSTRACT

Rainwater harvesting is a promising solution to ensure a year-round water supply, meet agricultural demands and maintain ecological flows in the water system. It is also a viable option to reclaim declining water bodies and offer a sustainable source of water. In correspondence, the study attempts to explore the feasibility of rainwater harvesting through green infrastructure for urban catchments, with an example of the RGUKT Srikakulam university campus in Etcherla. The study attempts to analyze the campus as a catchment for Rainwater harvesting and design green infrastructure solutions in accordance with the site conditions. The study uses the SCS-CN methodology to compute the runoff of the catchment by developing excel spreadsheets, using the rainfall of 10-year period. The solutions of green infrastructure explore options such as Bio-swales, rain gardens, infiltration strips, permeable pavements, retention basins, detention basins, etc. The purpose of the study is to analyze the feasibility of achieving zero runoff for the entirety of the RGUKT Srikakulam campus for a maximum over a 10-year rainfall. The study also attempts to explain the secondary benefits of green infrastructure development. This study aimed to develop simple models to replicate such work for complex and modified urban and semi-urban settings (catchments). When put into practice, these techniques were developed to ensure easy design, construction, and development of green infrastructure solutions with suitability to suit specific requirements of distinctive urban centers. When developed on a full scale, across the country, Green Infrastructure (GI) may act as a solution to renew the groundwater resources and ensure water supply throughout the year.

Keywords-- Green Infrastructure, MS Excel, Rainwater Harvesting, Infiltration Pits

I. INTRODUCTION

A report by NITI Aayog titled 'Composite Water Management Index" [1] predicts that by 2030, 40% of the Indian population will have no access to drinking water. India has become the world's largest extractor of groundwater, accounting to 25% of the total. A substantial number of India's 377 million urban residents face water shortages, while about 200,000 die each year from inadequate or unsafe water supplies. It is therefore of grave importance that remedial actions and preventive measures be taken up for the conservation of water resources.

An obvious remedy to this problem would be the use of sustainable sources like rainwater. Building new infrastructure to facilitate these sustainable, conservative practices like rainwater harvesting systems is bound to be a hassle, but modifying existing infrastructure or accommodating these measures during construction is plausible, quick and economic. This contemporary alternative of integrating nature into mainstream infrastructure is popularly known as Green Infrastructure. There has been a rapid growth in the field of GI in recent times. Governments have also taken up the trend of GI as is evident by the many laws (the city of Zürich has a law mandating all flat roofs be greened roof surfaces; Hammarby Sjöstad is a district in Stockholm where the City has imposed tough environmental requirements on building, technical installations and traffic environment to conform with an 'eco-cycle' solution developed by Fortum, Stockholm Water Company and the Stockholm Waste Management Administration to create a residential environment based on sustainable resource usage), and projects that have been passed to ensure large scale implementation of GI.

Despite all of this, there remains hesitancy in the general public to use GI as there is a lack of understanding of the concept and the misconception that it might be uneconomical or difficult to construct. This paper aims to simplify the concept of GI and provide general guidelines to provide a broad understanding of various types of GI that can be implemented on the level of a gated residential complex. The methods discussed in the paper can also easily be applied to larger and different spaces by making minor modifications as per requirement.

II. LITERATURE REVIEW

Over the coming century, climate change scenarios project that urban regions will be managing extremes of precipitation and temperature, increased storm frequency and intensity, and sea-level rise.[2] Excessive runoff leads to costly flooding events and the export of nitrogen and phosphorous to streams, which become

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concerns of environmental protection agencies and health agencies [3]. In his Inaugural Address in January 1999, Maryland Governor Paris Glendening said, "Practices such as green roofs, urban forestry, and water conservation are familiar to local governments as strategies to enhance sustainability and quality of life and they are increasingly being seen as best practices in climate adaptation."

According to Charles Little, author of Greenways for America, the concept of green infrastructure began 150 years ago with Frederick Law Olmsted, Sr., the designer of New York's Central Park as well as Boston's Emerald Necklace. "No single park," Olmsted believed, "would provide people with all the beneficial influences of nature." Instead, parks should be linked to one another and to surrounding residential neighborhoods. In the UK, Howard's work promoted similar values to Olmsted's. Through his designs he suggested that placing green spaces in close proximity to residential zones would improve both the psychological and physical health of local population [4].

Recent research has highlighted the positive role urban green infrastructure can provide in terms of ecosystem services [5]; [6].and health agendas [7]. The need for green solutions is evident especially in the urban context where flooding, droughts and health hazards are becoming alarmingly frequent While the main focus of conventional drainage solution is peak discharge reduction, GI design aims at restoring the predevelopment flow regimes, such as reduction of runoff volume, enhancement of storm water quality, and maintenance of base flows [8]. To achieve the above performance benefits, GI design treats runoff close to where it is generated [9]. This can be achieved through various types of green infrastructure like bio-swales, permeable pavements, infiltration pits, etc.

While there is abundant literature on GI available in the form of textbooks, design manuals and countless case studies and papers, there remains a lack of simple and comprehensible tools and guidelines that can aid students or amateur individuals on the path of exploring GI. This paper therefore hopes to provide general guidelines on some commonly installed GI and present simple formulas defined in tools like MS Excel that will help with design of GI.

III. STUDY AREA

The RGUKT SKLM campus in Etcherla spans across an area of 659156 square meters and has vast open spaces that are perfect for the incorporation of green infrastructure. It is located in Srikakulam District of Andhra Pradesh. Lying within the geographic coordinates of 18º-20' and 19º-10' N and 83º-50' and 84º-50' E, the district is blessed with an average annual rainfall of 1154.6 mm.

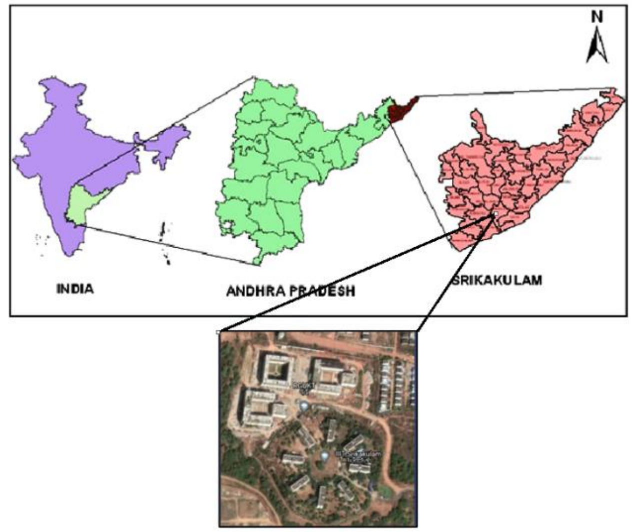

Figure 1: RGUKT Srikakulam

IV. METHODOLOGY

This section includes broad guidelines to design infiltration pits, an economical rainwater harvesting method to control storm-water runoff and improve ground water levels. The SCS-CN methodology was used to compute the runoff of the catchments by developing excel spreadsheets that will be available in the appendix.

The Curve Number is given by $CN=\frac{25400}{S+254}$.

Here 'S' represents the potential maximum retention or 'storage' factor of the surface; $S=\frac{25400}{CN}$.

The CN value is initially calculated for AMC II conditions and the corresponding AMC I and AMC III are given as follows:

$$CN_I=\frac{CNII}{2.281-(0.01281*CNII)} \; ; \; CN_{III}=\frac{CNII}{0.427-(0.00573*CNII)}$$

Once the CN value is determined, the S value is calculated. When the value of S and P (rainfall in depth) are known, the runoff, Q is calculated for Indian conditions as

$Q=\frac{(P-0,1S)^2}{P+0.9S}$ for P> 0.1S, valid for Black soils under AMC II and III conditions.

$Q=\frac{(P-0,3S)^2}{P+0.7S}$ for P> 0.3S, valid for Black soils under AMC I and all other soils of AMC I, II and III conditions.

Use of MS Excel for runoff calculation

This section aims to depict the procedure followed to obtain the runoff for a specific location once the CN value, area and rainfall are entered as input parameters in a simple tool like MS Excel.

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4.1 Finding CN Value for Catchment Area

We used the weighted average method for finding the CN value of the catchment. For this, we opened up an Excel sheet and named the columns as shown in Table. 1. After the columns were labeled, the values were entered manually. The measurement of the areas for each land cover was done in AutoCAD from the Master plan of the RGUKT Srikakulam Campus. The CN value was assigned as per the SCS-CN method.

NOTE: The first row was allotted for column headings. Only 5 Land cover types were considered, so the formulas depict summations between rows 2 and 6. If there are more land cover classifications, the formulas will have to change correspondingly.

4.2 Finding 48-Hours Runoff for given Rainfall Data

Table.2 represents the headings assigned to each column in the MS Excel sheet and the formula used to derive specific values. It can be observed that only the runoff for the non-rainy/dry season is calculated. This is because the quantity if runoff is larger in the drier season than the wet season when growing plants use up the rainwater, and the design is done for accommodating the largest quantity possible. While the runoff formulas for the rainy season are not mentioned here, the same formulas shown in the table can be used for deriving runoff in the rainy/growing season with the input of rainfall in the rainy season.

NOTE: For the formula for maximum 48-hour runoff in non-rainy season, the first row was allotted for column heading. Rainfall for 365 days was input. Therefore, the summation involves the rows 2 to 366.

4.3 Formula to Achieve Zero Discharge

Now that the maximum rainfall in 48 hours was obtained, we opened a new sheet and data was assigned to the following columns as depicted in Table.3.

NOTE: All the formulas shown correspond to the 3rd row.

4.4 Formula to Maximize Infiltration for Available Area

Once the columns are labeled, the area available for infiltration, depth of pit in meters and infiltration rate of the soil is entered as input into the sheet. The formulas for calculation of the remaining rows are described in Table.4.

NOTE: All the formulas shown correspond to the 11th row.

Thus, we derived formulas for achieving zero discharge and maximizing infiltration for fixed available area.

V. RESULTS AND DISCUSSIONS

This section will discuss the results by depicting the tables or part of the tables when there is too much data.

5.1 Finding CN Value for Catchment Area

The assignment of CN value for specific land covers was done manually. The area of each land cover was measured using the Master plan of the IIIT Srikakulam campus in AutoCAD using the Area measurement tool. We arrived at an average weighted value of **CN=81** for the entire campus area.

Table 1: Finding CN Value for catchment area

Row	Heading	Formula
A	Land cover	Input manually
B	Area	Area of each land cover is input manually Total area B7=sum(B2:B6)
C	CN value for HYSG C	Input manually
D	Area * CN value	Area * CN value =B2*C2 Sum of area* CN value D7 =sum(D2:D6) Weighted CN value = D7/B

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Table 2: Finding 48-Hours Runoff for given Rainfall Data

Column	Heading	Formula
C	CN I	C10=D10/(2.281-(0.01281*D10))
D	CN II	Manually input
E	CN III	E10=D10/(0.427+(0.00573*D10))
F	5 Day Rainfall	F10=SUM(B6:B10)
G	Non rainy season	CN Value assigned for Non-Rainy season based on 5 Day Rainfall: G10=IF(F10<13,C10,IF(F10>28,E10,D10))
I	Storage in Non rainy season	Value of 'S' Storage in Non-rainy season: I10=(25400/G10)-254
K	Q in Non-rainy	Flow 'Q' calculated in mm for non-rainy season: K10=IF(B10>0.3*I10,(((B10-0.3*I10)^2)/(B10+0.7*I10)),IF(B10>0.1*I10,(((B10-0.1*I10)^2)/(B10+0.9*I10)),0))
M	Area in Sq m	Manually Input
N	Runoff in Non-Rainy	Runoff for total catchment in non-rainy season: N10=M10*K10*0.001
R	Considering only Non rainy season runoff	N10=M10*K10*0.001
S	48 hours runoff	48-hour Runoff in non-rainy season: S10=N10+N9
U	Maximum of 48-hour runoff	Maximum of 48-hour Runoff in non-rainy season: U10=MAX(S2:S366)

Table 3: Formula to achieve Zero Discharge

Column	Heading	Formula
A	Flow/Runoff in cubic meters	Input Manually
B	Depth in meters	Input Manually
C	Infiltration rate in mm/hour	Input Manually
D	Infiltration rate in m/day	=C4*(24/1000)
E	Area of pit	=A4/B4
F	Check for detention time	=IF((A4/(E4*D4))<2,G3,H3)
G	-	Detention time requirement of 48 hours is met, design is satisfactory
H	-	Decrease in depth is recommended to meet Detention requirement

Table 4: Formula to Maximize Infiltration for Available Area

Columns	Heading	Formula
A	Area available for infiltration in square meters	Manually Input
B	Depth in meters	Manually Input
C	Infiltration rate in mm/hour	Manually Input
D	Infiltration rate in m/day	=C11*(24/1000)
E	Runoff that can be accommodated for detention period of 48 hours	=A11*D11*2

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Table 5: Finding CN Value for Catchment Area

Land cover	Area	CN Value (for HYSG C)	Area*CN value
Buildings	159950	91	14555450
Roads	92192	89	8205088
Landscape	4195	74	310430
Parking	20140.95	98	1973813
Miscellaneous	382678.1	74	28318176
Total Area=	659156	**Weighted CN =**	**81.0**

Table 6

Date	Rainfall in mm	CN I	CN II	CN III	5-Day Rainfall	Non rainy season
1/1/1900	0	65.08032	81.0	90.872427	0	65.08031954
1/2/2015	0	65.08032	81.0	90.872427	0	65.08031954
1/3/2015	17.2	65.08032	81.0	90.872427	0	65.08031954
1/4/2015	2.4	65.08032	81.0	90.872427	17.2	80.95649103
1/5/2015	0	65.08032	81.0	90.872427	19.6	80.95649103
1/6/2015	0	65.08032	81.0	90.872427	19.6	80.95649103
1/7/2015	0	65.08032	81.0	90.872427	19.6	80.95649103
1/8/2015	0	65.08032	81.0	90.872427	19.6	80.95649103
1/9/2015	0	65.08032	81.0	90.872427	2.4	65.08031954

Table 7 In continuation (horizontally) to Table.6…………..

Rainy season	Storage in Non rainy season	Storage in Rainy season	Q in Non rainy	Q in Rainy	Area in Sq m
65.0803195	136.2869589	136.2869589	0	0	659156
65.0803195	136.2869589	136.2869589	0	0	659157
65.0803195	136.2869589	136.2869589	0.091193847	0.09119384	659158
65.0803195	59.74877638	136.2869589	0	0	659159
65.0803195	59.74877638	136.2869589	0	0	659160
65.0803195	59.74877638	136.2869589	0	0	659161
65.0803195	59.74877638	136.2869589	0	0	659162
65.0803195	59.74877638	136.2869589	0	0	659163
65.0803195	136.2869589	136.2869589	0	0	659164

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Table 8 In continuation (horizontally) to Table.7…………..

Runoff in non-Rainy	Runoff in non-rainy	Day	Considering only Non rainy season runoff	48-hour runoff	Max Rain in 48 hours
0	0	1	0	0	18775.43
0	0	2	0	0	
60.11	60.11115	3	60.11115375	60.11115	
0	0	4	0	60.11115	
0	0	5	0	0	
0	0	6	0	0	
0	0	7	0	0	
0	0	8	0	0	
0	0	9	0	0	

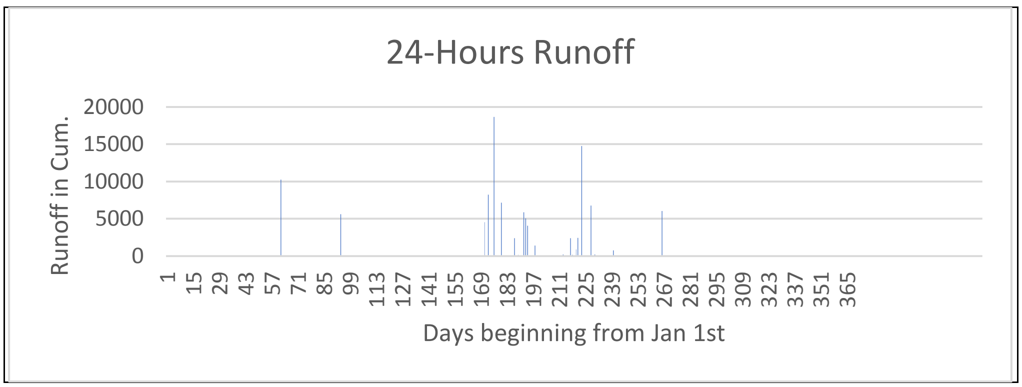

Figure 2 Graph for 24-Hours Runoff

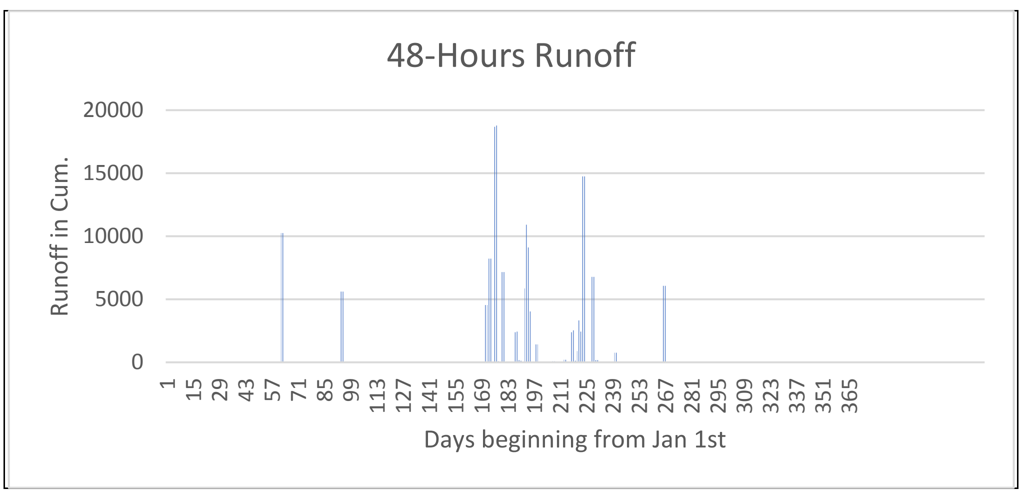

Figure 3 Graph for 48-Hours Runoff

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Table 9: Calculation for Achieving Zero Discharge

Flow (Runoff) in Cubic meters	Depth in meters	Infiltration rate in mm/h	I.R in m/day	Area of Pit	Check for detention Time
18775.42922	0.4	10	0.24	46938.57305	Detention time requirement of 48 hours is met, design is satisfactory.

Table 10: Calculation for Optimizing Available Area

Area in Square meters	Depth in meters	Infiltration rate in mm/h	I.R in m/day	Runoff that can be accommodated for detention period of 48 hours
31043	1	10	0.24	14900.64

5.2 48-hours Runoff Calculated for Input Rainfall Data

Table.6, Table.7 and Table.8 above only depict the data of the first 9 days of the year. The actual table in the Excel sheet was fed the rainfall data of all 365 days. The Maximum rainfall in 48 hours in the non-rainy season throughout the year was found to be **18775.43 cubic meters** of water.

5.3 Graphs for Runoff

Shown in Figure.2 and Figure.3 are the graphs for runoff in the RGUKT Srikakulam campus distributed throughout the year. Graph.1 shows the 24 hours runoff as it occurs for the input rainfall data. Graph.2 shows the cumulative 48 hours runoff as it occurs for the input rainfall data.

5.4 Calculations for Achieving 0 Discharge

In this Table.9, the runoff, depth and infiltration of the soil in mm/hour is entered. The area required is then shown as output and the 'check' column displays if the detention period of 48 hours is met.

Area of Infiltration pit = Runoff/Depth

Check for detention time = Runoff/(I.R * Area)≥ 48h

If it is not met, the output suggests the user to decrease the depth of the pit, which would lead to an increase in area, leading to decreased infiltration time.

5.5 Calculations for Optimizing Available Area

In the above table, the area, depth of the pit and infiltration rate of the soil is input. According to these parameters the amount of runoff that can be accommodated for a detention time of 48 hours is displayed.

Runoff that can be accommodated in 48h = Area * I.R * 48 Hours

In the table, a trial area of 10,000 square meters, a depth of 1 meter and infiltration rate of 10 mm/hour is input. The output shows that a runoff of 4800 cubic meters can be accommodated.

5.6 Design of Green Infrastructure for RGUKT Srikakulam Campus

The areas assigned for landscape are recommended to be used for infiltration. Use of other areas would be uneconomic and unfeasible in terms of drainage. The total area allotted in the campus for landscaping is 31043 square meters.

As discussed in the preceding section, the required area for 48-hour runoff generated for the conditions in campus is 46938.6 square meters. This is greater than the landscape area available. Let us therefore use the formula in 4.5 to make use of the available landscape area.

Upon entering the area of 31043 square meters as input, we get the output as 14900.64 cubic meters of runoff. Therefore, a maximum of **14901 cubic meters of runoff** in 48 hours can only be accommodated for the landscape area exclusively. The details of the different landscape locations and calculations are shown below:

a) Infiltration Rate – 10 mm/hour
b) Depth of each Basin – 0.4 m
c) Depth of Freeboard – 0.2 m
d) Basin Side slopes – 6:1
e) Proposed basin depth – 0.8 m
f) Design Surface area – 31043 Square meters (Split into 19 Landscape areas)
g) Runoff that can be accommodated for detention period of 48 hours = 14900.64

VI. CONCLUSION

This paper discusses the necessity, challenges and opportunities of adopting Green Infrastructure (GI) as viewed by various stakeholders. It contemplates the issues of arising due to unplanned urbanization and the necessity of ground water recharge as a solution to various issues such as water security and reducing the contamination of ground water bodies.

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The paper attempts to address GI design challenges as perceived by community members, builders and designers and explores the development of simple technical worksheets and tools to aid in the process of designing Green Infrastructure.

The two requisites presented are the approaches to either achieve zero discharge or design in accordance with the availability of space. The tool sets developed are recommended for efficient design of GI in urban modified catchments, and to improve the water security through recharge of groundwater and reducing the pollution of ground water. This method also encourages bottom-up approach by allowing the communities to participate in the building sustainable future.

Within the RGUKT Srikakulam campus, it is estimated that the proposed GI can be either designed to achieve zero storm water discharge or be designed and executed within the available area with maximum effectiveness. The area required to accommodate all of the rainfall in infiltration basins and achieve zero discharge amounts to almost 4.7 thousand square meters. Given the spatial constraint in the campus in this regard, the better route would be to optimize the available area. The land assigned for landscaping would prove to be an excellent choice for the infiltration pits. Its maintenance would be easy and economical while its very presence would impart immense social, ecological and economic benefits to the campus.

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