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Appreciation of Rainwater harvesting potentiality for sustainability in reduction of water stress–A case study of Guntur, Andhra Pradesh, India

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Abstract: Rainwater harvesting is the method of collection, store and use of rainwater where ever it falls. Tropical climatic conditions will receive extreme precipitation, i.e. in form of rain. Water stress and scarcity is happening around the world especially in urban areas as the demand is more because of density of population. As the infrastructure of basic needs at urban areas are almost up to the level, the paved areas will be present in most of the areas. The gap between supply and demand is varying much essentially in urban areas. Thus, the rainwater harvesting at plot level as well as at community level is becoming very much essential so as to minimize the gap between demand and supply. The harvested water lead to supplement the main supply of water and lessens the pressure on main source of water for the existing urban settlement. The present paper deals with the frame work for sustainable rainwater harvesting at a town level. The paper deals with correlating the selected eight study pockets in Guntur town, Andhra Pradesh, India by making the grouping of plots based on the area of the plots with regard to dwelling units related to occupants. The correlation analysis directed to establish strong relation between different study pockets with respect to LPCDs to workout settlement level Sustainable harvestable rainwater frame work with due consideration to density of population, slope, topography and meteorological parameters etc.

Keywords: Rainwater Harvesting, Plot level, Community level, Correlation, Frame work.

1. Introduction

The growing evidences related to scarcity of water and need for sustainable and equitable water locally and internationally were emphasized by UNO [2007] further the UN has made a resolution 64/292 during 2010 stating that clean drinking water and sanitation are essential to all human beings [UNO 2010]. Water scarcity is a global level concern which affects close to 3.0 billion people worldwide. Several towns in India are blessed with abundant water resources but in contradiction, the inhabitants of this region are facing a grave water crisis. The increase in population and urbanization put forth tremendous pressure on the municipal supply of towns. This paper explores the potential of domestic rainwater harvesting (rooftop rainwater harvesting) as the sustainable solution to reduce gap between the water demand and supply of the population. Developing countries are facing growing pressure on their finite water resources and are now recognizing the important role that traditional RWH technologies play in integrated water resources management (Gould and Nissen-Petersen, 1999). Gabriele Freni and Lorena Liuzzo 2019 investigated the reliability of RWH systems in terms of storm water retention. RS Krishna et al 2020 mentioned Rainwater harvesting

(RWH) has been proved to be a sustainable option in solving the on-ground water shortage to a great extent. India has been facing the wrath of a water crisis for over two decades.

Towns in india has high rainfall particularly the case study area of Guntur having 961mm/year so the sustainable strategy of harvesting the rainwater during the monsoon, storing it for usage in the during rainy season / post rainy season and using the excess to recharge aquifers/ underground water table will reduce the stress on municipal supply. It is stipulated that "everyone has the right to a healthy environment, the protection of the environment shall be the duty of every Cameroonian, and the state shall ensure the protection and improvement of the environment" (Tamasang, 2007).

2. Need for Rain water harvesting

In an effort to combat water scarcity and decrease poverty in this region, this paper analyses the possibility of domestic rainwater harvesting as a worthwhile alternative to augment the present conventional water supply system to stabilize the water demand. The study confirms that the Guntur water crisis is mainly as a result of poor water management and not due to physical scarcity. It reveals that about 86% of the population experience water shortages and has to increase its present capacity in order to meet up with demand. Over 80% of the population is willing to consider rainwater harvesting as a good alternative to augment their domestic water supply as far as possible. Conclusively, domestic rainwater harvesting if carried out extensively will rescue the population from a disastrous water deficiency leading to detrimental environmental problems. To realize these objectives, critical studies were carried out in 8 different locations of Guntur town. The aim of this study was to measure the harvestable rain water collected from the paved and non-paved areas from plots as well as from the community level, further to analyze the rainwater potential to reduce the gap between demand and supply of water.

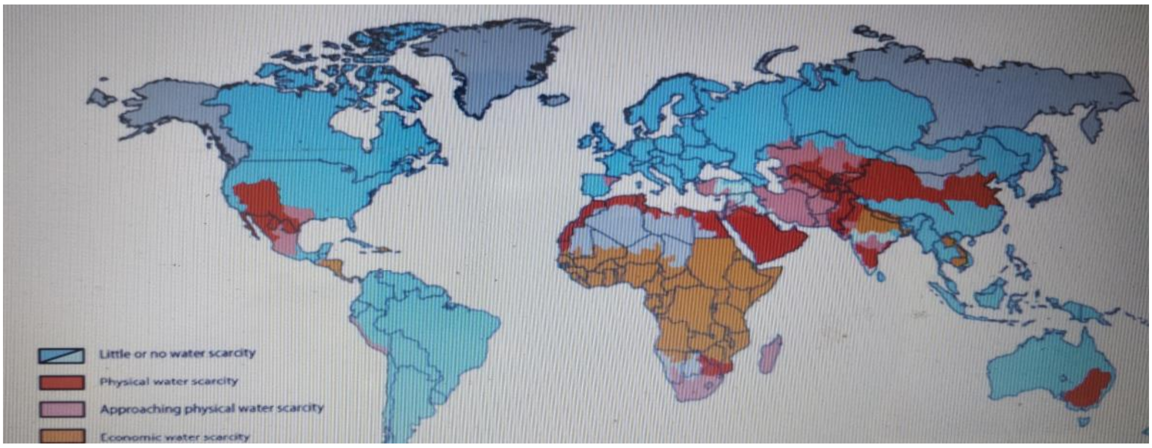


Figure 1: Physical and economical water scarcity (Source: IWMI report, 2006)

In recent years, global scenarios have been the popular trend with regards to the prognostication of climate change as a whole and its components in particular. Alcamo et al, 2007 analyzed the scenario portraying the change in average annual water availability by 2050. The figure below (Figure 2.) shows the percentage change in annual water availability as prognosticated by the scenario analyzed for 2050. This more or less represents a worst-case scenario. It is always important to consider such scenarios in an effort to attain better results in the fight against water scarcity by way of improving water policy and legislation. Rainwater harvesting (RWH) systems have many benefits being an effective alternative water supply solution, not only in arid and semi-arid regions. Also, these systems can be useful in the reduction of flood risk in urban areas. Nevertheless, most of the studies in literature focused on the potential of RWH in reducing water consumption, whereas few examples examined their efficiency in the retention of storm water in flood-susceptible residential areas. Daily water balance model was used to simulate the performance of a rainwater harvesting system using historical daily rainfall data for 20 years (Voilet KMA et al). The Diversion of flood water to the canals or water bodies so that flood related disasters can be mitigated w.r.t design of water channels from different pockets of the city (Uri nachson 2016). Rainwater harvesting as a method to induce, collect, store, and conserve local surface runoff for agriculture in arid and semi- arid regions (Boers and Ben-Asher 1982). Infiltration is a key process controlling runoff, but varies depending on antecedent conditions (Fletcher et al.2013; Redfern et al 2016). Rainwater harvesting is defined as the collection of runoffs and its use for the irrigation of crops, pastures and trees, and for livestock consumption (Prinz, 1996). Rain water harvesting is a process of concentrating, collecting, and storing rainwater for different uses at a later time in the same area where the rain falls or in another area during the same or later time (Mbilinyi et al., 2005).

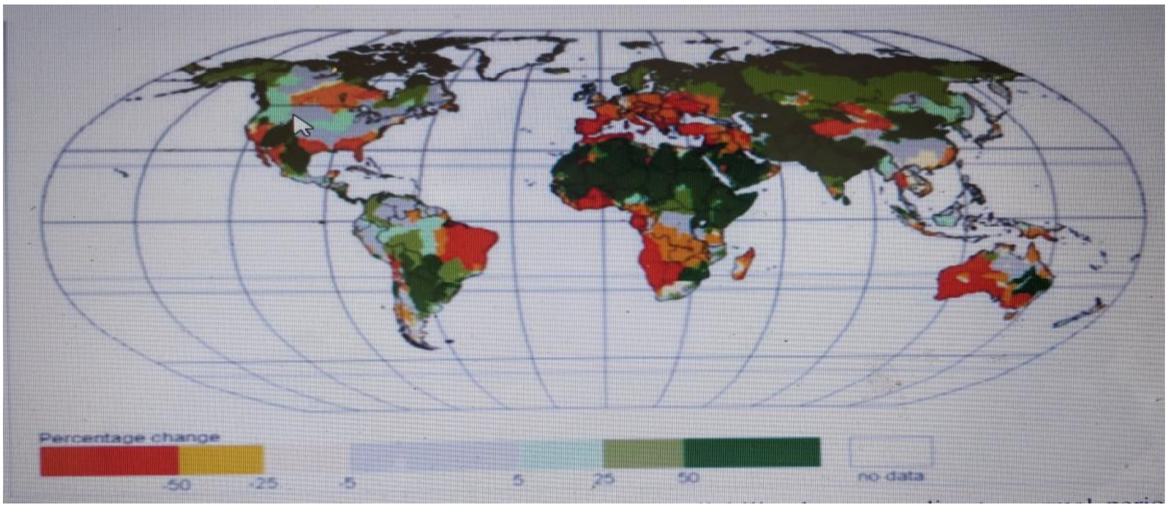


Figure 2: The percentage change in annual water availability between climate normal period (1961-1990) and the 2050's under A2 Scenario (Source: Alcamo et al, 2007).

Permeable surfaces offer infiltration potential, which can contribute to alleviate the runoff to combined sewer systems (Frida E.A Parnas et al, 2021). In an urban context, impermeable surfaces are the primary contributors to runoff, runoff from permeable areas is therefore becoming more important to consider (chahinian et al 2005). Compaction is common for urban soils and significantly decreases the infiltration capacity (Gregory et al, 2006; Pitt et all 2008). Runoff in a watershed affected by geomorphological factors, particularly, land use change effects the runoff volume and runoff significantly (S. Satheeshkumar et al, 2017). Runoff from urban pervious areas with the use of measured soil data, where the results showed a significant amount of runoff from some of the urban green surfaces (Becker, 2016). 30 years of historical rainfall events have been analyzed to investigate the runoff generation for compacted sandy and clayey soils, simulated runoff from the previous soils (Davidsen et al 2018). The common procedure is to assume that the infiltration rate is equal to the rainfall intensity (Rossman & Huber 2016)

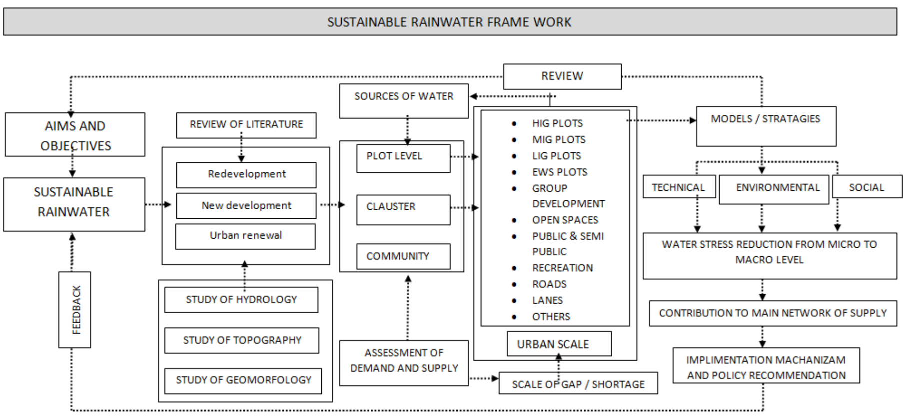
The literature review conveys that the studies were related to rain water harvesting and its storage for various activities at urban and rural setup. There is no direct study on to correlate the study among selected pockets so as to streamline the system so as to make the framework universal to make suitable for the areas with similar climatic, topographical and geographical conditions

3. Aims and objectives

Aim of the research is to develop a Sustainable rainwater harvesting mechanism for urban areas. It is to develop a framework to optimize the use of rainwater, reducing the gap between demand and supply of water by Guntur Municipal Corporation at neighborhood level. The objective of the paper is to conduct a critical assessment of rain water potential to reduce the stress on municipal supply of water to residences of a town. Appreciation of present condition and evaluation of the application of RWH in Guntur through secondary data and primary survey/Questionnaire is essential and crucial. Besides, this paper discusses the ways and means to address the supply gap through rainwater harvesting and its collection, storage and distribution so as to conserve the water. The study focuses to micro level units of plots to the community level, so that the frame work of sustainable rain water harvesting would facilitate to conserve the water, reduce the gap between demand and supply and provide clean development mechanize.

4. Methodology

At the beginning of the new Millennium, rainwater harvesting is looked upon as a sustainable and relevant system to cater for domestic and regional water deficiency issues all around the world more especially in South East Asia and Africa. The study area has abundant water for the needs of the population but still municipal supply is not meeting the requirement. So as to reduce the gap between demand & supply, to derive a pragmatic approach a methodology has been worked out to analyze systematically. In Line with aims and objectives to work out a water conservation strategy and to reduce the supply gap for redevelopments areas, new development areas and existing residential pockets, study of meteorological, hydrological and geomorphological conditions have been considered along with the review of literature. Further, different pockets in different locations have been delineated to give broader conditions to make solutions applicable to entire town. There after secondary and primary data collected through to analyze the runoff with respect to the available models to the plots of different sizes and to the other uses at community or neighborhood level to work out a model with due consideration to technical, environmental and social parameters as shown in the methodology diagram.



5. Delineation of micro-level Planning Unit

The study units have been delineated in different locations of the town with similar 3 to 5% slope of the terrain, density 220 to 290 population per hector of the pocket, and having predominantly plotted development where municipal water supply connection existing as shown in the Figure 3.

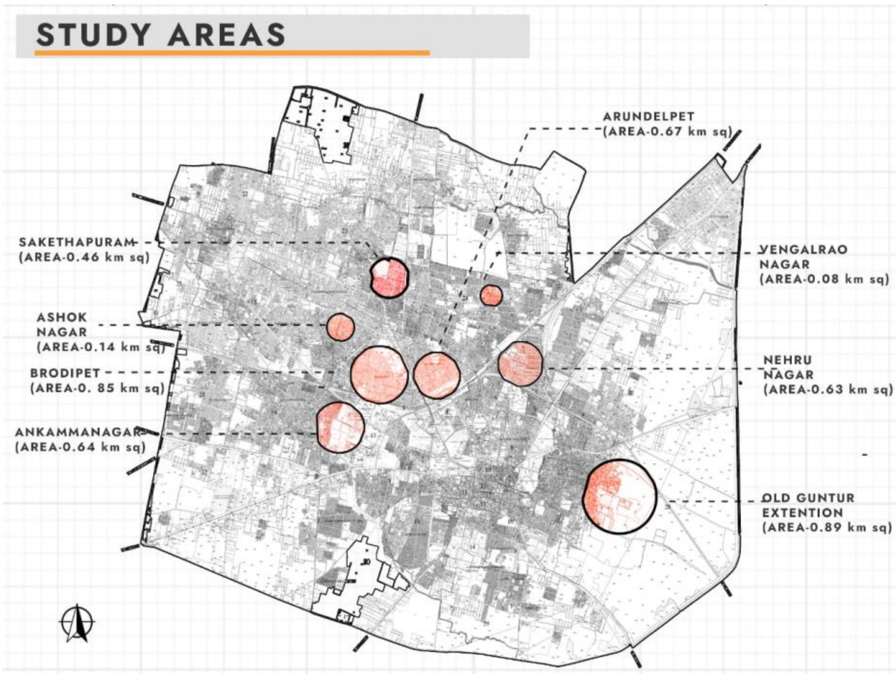


Figure 3: Study pockets with areas, Limits of municipal corporation, Guntur

Source: Master Plan 2041, Guntur

As per said methodology above, the plots have been grouped with regard to plot sizes such as 0-100sqm (EWS category), 100 to 200 sqm (LIG), 200-300sqm (MIG), 300 to 500sqm (HIG), 500 to 800 sqm (HIG) and above 800sqm (HIG). With reference to the building bye laws of the Guntur, the terrace areas and set back areas have been calculated to work out the rain water runoff with respect to rain water intensity, absorption as per paved and non-paved areas through rational method for every month with monthly average rainfall data for the period 1999 to 2020. There after community level surfaces such as roads, open spaces/ parks and other uses have been considered to work out the rainwater runoff to store at community level, further to distribute the filtered water for the plots having shortage comparing to present supply capacity of 96 LPCD. Further the bigger plots having excess to the standard 135LPCD that includes the harvestable rain water at plot level in addition to present supply level of 96LPCD. So, the excess water has reduced the supply water, the same is proposed to utilize for the plots category of (0 to 100) EWS and (100 to 200sqm) LIG. The harvestable rainwater from the bigger plots reduces the burden on municipal supply in turn the metered charges also reduce proportionally.

5.1 Description of Study Area

The unprecedented increase in population, urbanization, and agriculture activities in recent time have resulted in the massive depletion and deterioration of the existing water resources in fast growing towns in developing countries in general and in Guntur town in particular. Added to these problems is the threat of climate change that is expected to increase water scarcity. It will distort the hydrological cycle in the next 100 years increasing precipitation, evapotranspiration, occurrence and frequency of storm water events and will trigger significant changes in biogeochemical processes that influence the quality of water (Pandey et al, 2003).

5.2 Location and Description

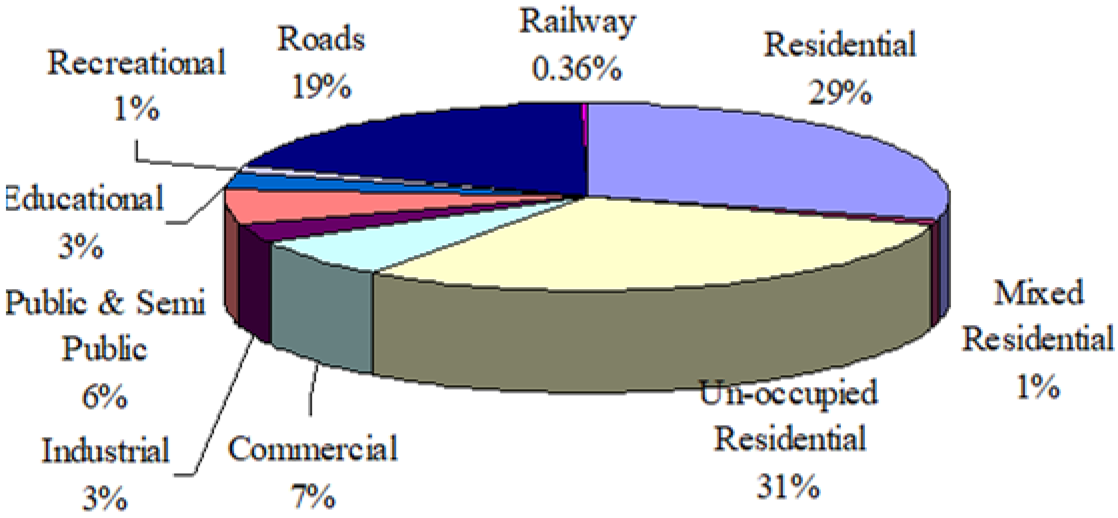


Figure 4: Percentage of Land use of Guntur, Andhra Pradesh 2017

Source: Guntur Municipal Corporation-2020

Guntur, one of the largest urban centers of Andhra Pradesh is located 33km away from

the Amaravati, the state capital. Geographically, Guntur lies on 80^0, 28' latitude and 16^0, 28' longitude. It is well connected by road and rail to all major cities of southern India. The town is reputed to be a renowned education center. In addition, Guntur boasts one of the largest centers of chilly and tobacco trade in this region. With a population of about 7.43 lakh/ 0.743 million (Census 2011, India), it is one of the fastest growing towns of Andhra Pradesh. Since its up-gradation as Corporation in 1994, Guntur Municipal Corporation (GMC) is focused on making Guntur as a modern city. Residential and mixed residential areas form about 32% of the total developed area while commercial area has a share of 7%. Public and semi public, Educational and recreational land uses occupy about 10% of the developed area while industries cover only around 3% of the area. Residential plots lying vacant constitute nearly 31% including open spaces in the unconstructed layout areas, and area under Recreational account for only about 1% of the developed area. In the entire city both railways and roadways occupied around 19% of the GMC developed area.

5.3 Water Supply

Protected water supply came into force in 1905 with the establishment of an infiltration gallery in Vengalayapalem villege for Guntur town. The head works were located in the reserve forest of Nallapadu about five miles from Guntur. A comprehensive water supply scheme was sanctioned in 1994, 42 km from Kammamur canal at Sangam Jagarlamudi with head-works at the canal in the same village. In 1982 another scheme was sanctioned to tap water from Guntur canal at Thakkellapadu village. In spite of availability of rain water quantity the town facing acute shortage of the water.

Salient features of water supply scheme are:

- Present Water Supply -11.90 MGD (or) 53.55 MLD
- Per Capita Supply -96 LPCD
- Pro Rata Supply as per Standards -120 LPCD
- Existing Installed Capacity -16.50 MGD (or) 74.25 MLD
- Total No. of Elevated Level Service Reservoirs - 21
- Total Capacity of all Reservoirs -57.00 lakh gallons
- Total No of Bore Wells -1146
- Total No of open wells -110
- Total No of House Connections -39,788
- Total no of Public stand posts -3045

S.No	Description	Remarks
A	Total no. of households	128907
	Total no. of houses	108217
	Household size	4.73
	Population / house	4.0
B	Percentage of house covered through service connections	28.4
C	**Surface water source (MLD)**	**74.25**
	Excluding Transmission and pumping loss	**53.55**
	Distribution loss @7.7 %	4.12
	Net Supply (MLD)	**49.43**
	Ground water (MLD)	**2.0**
	Excluding Pumping loss @ 5 %	1.9

	Total Supply (MLD)	51.33
D	**House Service connections (nos.)**	36603
	Public connections	
	Public Fountains	3073
	Bore Wells	1146
E	**Percentage of population covered (%)**	
	HSC	28.39
	Public Tap @ 20 Household	47.68
	Bore wells @ 15 household	13.34
	Total population coverage	89.41
F	**Average Per capita supply (LPCD)**	100

Table 1: Details of Water supply connections and population coverage

Source: Guntur Municipal Corporation-2020

Guntur city with 7.43 lakh populations as per 2011. At total rated capacity of approximately 74 MLD, the current per capita water availability in Guntur is about 96 lcpd with coverage of 89.41% of population, which itself is low as per the norms. As per standards, in an urban area where the population is >200000, water should be supplied at 130 to 140lpcd. So, the requirement has been considered to have 135LPCD for all applications. Out of 89.41% of supply water has 13.34% of water was through bore pumps for ground water and 47.68% for public taps, the public taps serving 20 persons per tap. The overall municipal water covered the 76.07% of the population. It is proposed to avoid the taping of ground water and utilizing the Rainwater for domestic usage.

6. Assessment of Harvestable rainwater at Neighborhood

The Harvestable rain water has been compiled with respect to the selected study pockets which have been mentioned in the table 2 below.

ZONES	**AREAS (Hts)**	**POPULATION (master plan)**	**DENSITY (persons per Hectare)**	**Total RUNOFF at COMMUNITY Level, RAINFALL averaged to 4 MONTHS (Cum)**	**Total RUNOFF at PLOT level, RAINFALL averaged to 4 MONTHS (Cum)**
Ashok nagar	14	3092	220.86	1053.75	1174.15
Vengalarao nagar	8	1255	156.87	734.33	825.75
Brodipet	85	18708	220.09	5318.07	7776.08
Nehru Nagar	63	14846	235.65	3419.18	6051.92
Sakethapuram	46	10160	220.87	2209.34	4609.77
Arundalpet	67	15074	224.9	3792.27	6310.22

Old Guntur extension	89	8944	100.49	2905.57	9691.01
Ankamma nagar	64	18240	285	2810.34	6038.08

Table 2: Details of potential of harvestable rainwater from the selected study pockets, Guntur

7. Assessment of Harvestable rainwater at dwelling units level

The Harvestable rainwater computed through Rationale method considering the varying plot sizes and occupancy of dwelling units per plot as per primary survey as shown in the table 3. The areas of Paved and non-paved surfaces of each classified plot sizes assessed to derive harvestable rain water for monsoon and post monsoon months of the year i.e., July, August, September and October.

	UNIT LEVEL												Harvestable Rainwater, PLOT level, rainfall Averaged to 4 MONTHS (Cum)
	1 -100 sqmtrs		100-200 sqmtrs		200-300 sqmtrs		300-500 sqmtrs		500-800 sqmtrs		Above 800 sqmtrs		
ZONES	Paved Area	Non Paved Area	Paved Area	Non Paved Area	Paved Area	Non Paved Area	Paved Area	Non Paved Area	Paved Area	Non Paved Area	Paved Area	Non Paved Area	
Ashok nagar	4860.00	0.00	27495.00	0.00	23037.50	712.50	13240.50	409.50	11591.50	358.50	8245.00	255.00	1174.15
Vengalarao nagar	7500.00	0.00	12500.00	0.00	22310.00	690.00	11252.00	348.00	2720.00	760.00	1620.00	180.00	771.34
Brodipet	20600.00	0.00	135800.25	0.00	219627.65	6792.61	88990.69	2752.29	93360.97	2887.45	27070.92	837.24	7776.08
Nehru Nagar	65100.00	0.00	129600.00	0.00	113199.00	3501.00	145015.00	4485.00	3240.00	360.00	0.00	0.00	6051.92
Sakethapuram	49590.00	0.00	98670.00	0.00	177995.00	5505.00	1570.00	299.25	5379.00	1260.00	0.00	0.00	4424.02
Arundalpet	18000.00	0.00	105750.00	0.00	144064.40	4455.60	126973.00	3927.00	66591.00	7399.00	12015.00	1535.00	6310.22
Old Guntur extension	33000.00	0.00	44900.00	0.00	160000.00	6636.00	189557.40	5862.60	53825.30	1664.70	16150.50	16150.50	6672.08
Ankamma nagar	64700.00	0.00	162400.00	0.00	146373.00	4527.00	70034.00	2166.00	11931.00	369.00	0.00	0.00	6038.08

Table 3: Assessment of harvestable rainwater from the paved and non-paved areas of eight delineated study pockets, Guntur.

The community level harvestable water has been further analyzed with respect to the paved and non paved areas and with its related coefficients covering public and semipublic uses, roads, open spaces and recreation areas as shown in the table 2. All the calculations related to different uses under category of community level added together and total quantity of harvestable rain water distributed to the entire pocket level population. The total community level contribution of harvested rain water per capita and plot level collection of harvested rainwater, both from paved and non paved sections yielded to reduce the gap between demand and supply, the same is shown in table 4 to 9 in the units of LPCD for every study pocket.

8. Correlation of study pockets

The study of rainwater harvesting in different pocket conducted to drive the town level considerations as taking the pockets of study and related projections to work out a macro level frame work to reduce the water stress. The Guntur town level projection of harvested rainwater is dependent on the correlation components of the case study areas of 8 pockets. The projections of sustainable considerations of harvested rainwater of different plot sizes and related occupancy analyzed and brought to the scale of support in Liters per capita per day (LPCD). It is essential and crucial to bring similarity of the results so as to work out a sustainable rainwater harvesting method to reduce the gap between municipal supply and demand by sustainable harvested rainwater. The variable of harvested rain water of (1-100) sqm plots related occupancy based on LPCDs were analyzed in comparison to other plot sizes of (100-200) sqm, (300-500) sqm and (500-800) sqm of occupancy's harvested rainwater support in LPCDs as shown in Table 4. The Pearson Correlation of linear correlation coefficient defines the degree of relation between two variables and is denoted by "R". It is also called as Cross correlation coefficient as it predicts the relation between two quantities. The R^2 value < 0.3 this value is considered a None or Very weak effect size, if R^2 value 0.3 < r < 0.5 this value is considered a weak or low effect size, if R^2 value r > 0.7, this value is considered strong effect on each other.

If x & y are the two variables of discussion i.e. LPCDs of different plot sizes,, then the correlation coefficient can be calculated using the formula

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}$$

Here,

n = Number of values or elements

Sum$\sum$ x = Sum of 1st values list of LPCDs

Sum$\sum$ y = Sum of 2nd values list of LPCDs

Sum$\sum$ xy = Sum of the product of 1st and 2nd values

Sum$\sum x^2$ = Sum of squares of 1^{st} values

Sum$\sum y^2$ = Sum of squares of 2^{nd} values

This value is generally considered strong effect size.

The statistical way of calculating the correlation coefficient carried as elaborated above and found that LPCD of (1-100) has correlation to other LPCD's of (100-200) sqm, (300-500) sqm and (500-800) sqm Plots where the 'R^2' value is 0.88, 0.65 and 0.90 respectively as show in Fig.5: The Harvestable rain water further analyzed to workout with other plots related LPCDs to the rest of the plot sizes as discussed below.

S.NO	**Name of the study pocket**	**Total harvestable water from paved and non- paved areas (LPCD)**			
		Plot areas in sqm			
		1-100	**100-200**	**300-500**	**500-800**
1	Ashok nagar	17.40	23.96	20.00	25.00
2	Vengalarao nagar	20.00	27.43	30.05	32.56
3	Brodipet	18.00	26.46	27.00	29.00
4	Nehru Nagar	12.06	19.58	21.00	22.00

5	Sakethapuram	15.00	18.90	20.00	26.73
6	Arundalpet	11.95	14.72	20.32	22.16
7	Old Guntur extension	18.78	25.90	25.00	31.00
8	Ankamma nagar	9.00	4.83	18.00	19.46

Table 4: Varying plot sizes for harvestable rainwater in case study pockets

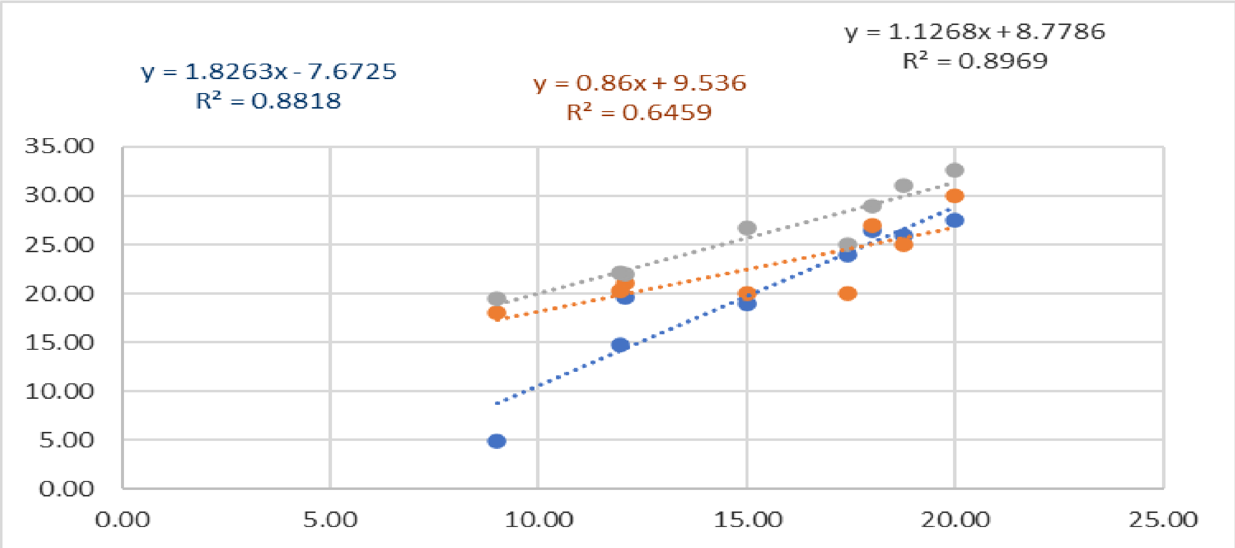


Figure 5: Correlation of plots having an area of 1 to 100 sqm through varying other plot sizes (100-200, 300-500 & 500-800sqm)

It is found that LPCD of (100-200) has correlation to other LPCD's of (200-300) sqm, (300-500)sqm and (800 above)sqm Plots where the 'R^2' value is 0.75, 0.60 and 0.84 respectively as show in Fig.6.

S.N.O	**Name of the study pocket**	**Total harvestable water from paved and non- paved areas**			
		Plot areas			
		100-200	**200-300**	**300-500**	**Above 800**
1	Ashok nagar	23.96	19.00	20.00	30.00
2	Vengalarao nagar	27.43	27.00	30.05	34.00
3	Brodipet	26.46	24.00	27.00	30.00
4	Nehru Nagar	19.58	15.00	21.00	24.00
5	Sakethapuram	18.90	17.00	20.00	27.00
6	Arundalpet	14.72	19.11	20.32	24.00
7	Old Guntur extension	25.90	21.00	25.00	32.00
8	Ankamma nagar	4.83	10.00	18.00	21.00

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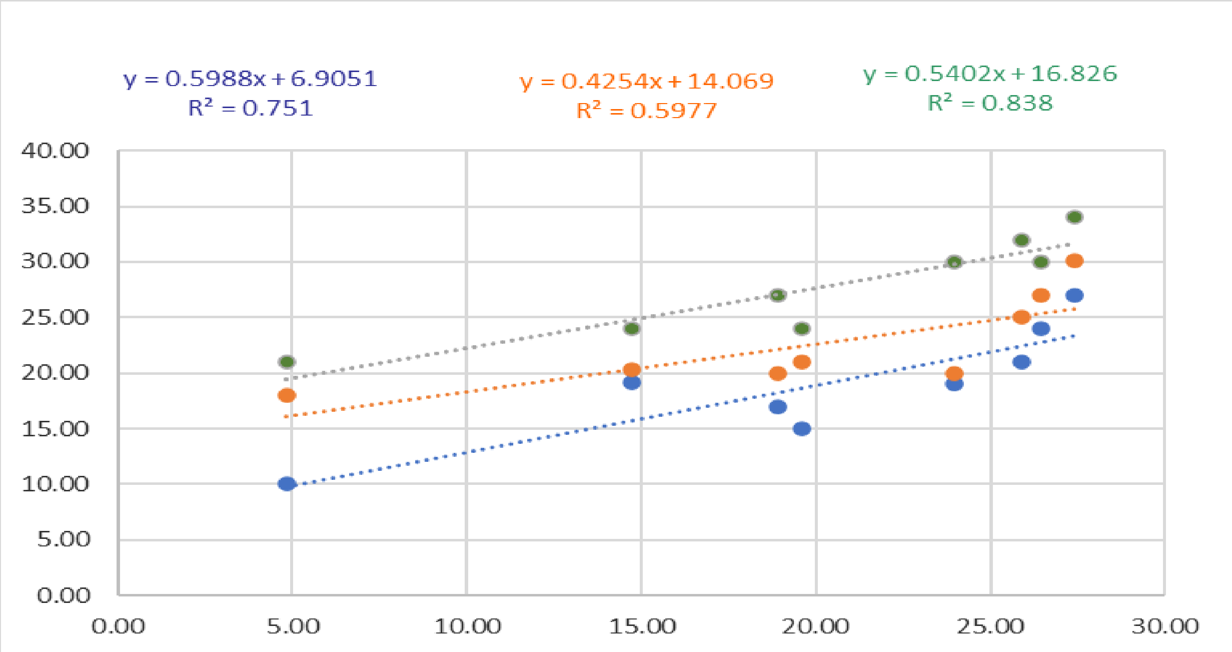

Figure 6: Correlation of plots having an area of 100 to 200 sqm through varying other plot sizes (200-300, 300-500 & above 800sqm)

It is found that LPCD of (200-300) has correlation to other LPCD's of (1-100) sqm, (300-500) sqm and (500-800) sqm Plots where the 'R^2' value is 0.78, 0.81 and 0.77 respectively as show in Fig.7

S.NO	Name of the study pocket	Total harvestable water from paved and non- paved areas			
		Plot areas			
		200-300	1-100	300-500	500-800
1	Ashok nagar	19.00	17.40	20.00	25.00
2	Vengalarao nagar	27.00	20.00	30.05	32.56
3	Brodipet	24.00	18.00	27.00	29.00
4	Nehru Nagar	15.00	12.06	21.00	22.00
5	Sakethapuram	17.00	15.00	20.00	26.73
6	Arundalpet	19.11	11.95	20.32	22.16
7	Old Guntur extension	21.00	18.78	25.00	31.00
8	Ankamma nagar	10.00	9.00	18.00	19.46

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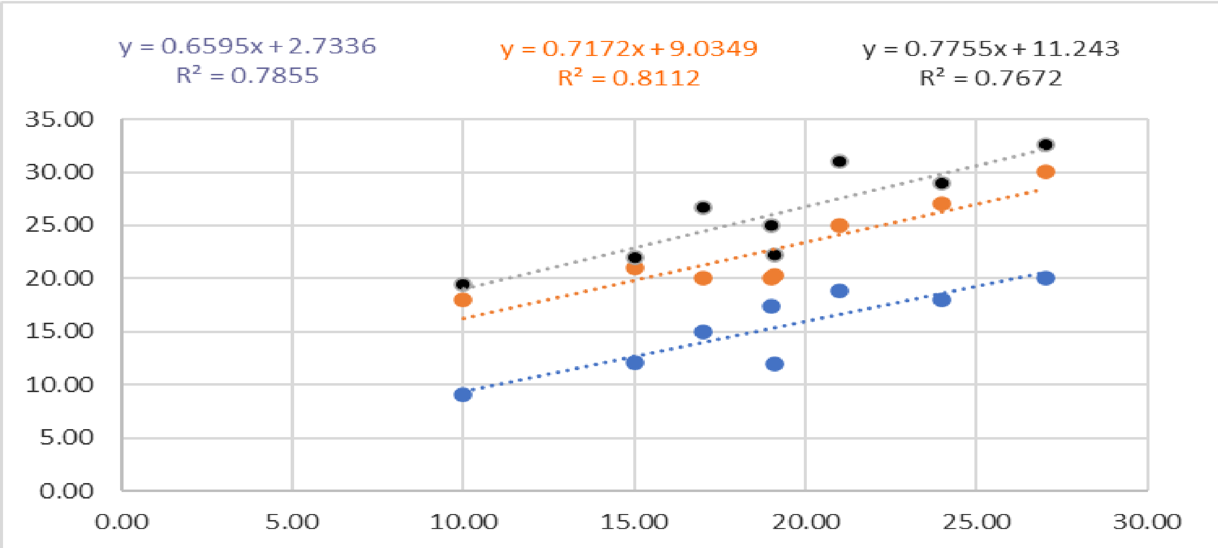

Figure 7: Correlation of plots having an area of 200 to 300 sqm through varying other plot sizes (100-200, 300-500 & 500- 800sqm)

It is found that LPCD of (300-500) has correlation to other LPCD's of (500-800) sqm and (300-500) sqm plots where the 'R^2' value is 0.77, and 0.67 respectively as show in Fig.8.

S.NO	**Name of the study pocket**	**Total harvestable water from paved and non- paved areas**		
		Plot areas		
		300-500	**500-800**	**Above 800**
1	Ashok nagar	20.00	25.00	30.00
2	Vengalarao nagar	30.05	32.56	34.00
3	Brodipet	27.00	29.00	30.00
4	Nehru Nagar	21.00	22.00	24.00
5	Sakethapuram	20.00	26.73	27.00
6	Arundalpet	20.32	22.16	24.00
7	Old Guntur extension	25.00	31.00	32.00
8	Ankamma nagar	18.00	19.46	21.00

Table 7: Varying plot sizes for harvestable rainwater in case study pockets

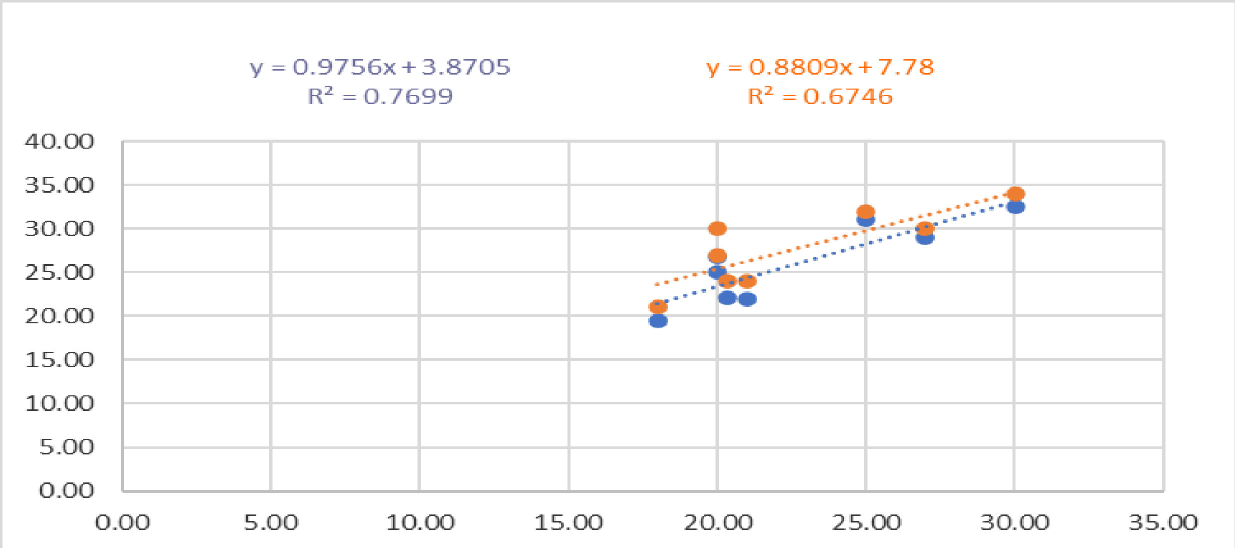

Figure 8: Correlation of plots having an area of 300 to 500 sqm through varying other plot sizes (500-800, & above 800sqm).

It is found that LPCD of (500-800) has correlation to other LPCD's of (100-200) sqm and (above 800) sqm plots where the 'R^2' value is 0.74, and 0.90 respectively as show in Fig.9.

S.NO	**Name of the study pocket**	**Total harvestable water from paved and non- paved areas**		
		Plot areas		
		500-800	**100-200**	**Above 800**
1	Ashok nagar	25.00	23.96	30.00
2	Vengalarao nagar	32.56	27.43	34.00
3	Brodipet	29.00	26.46	30.00
4	Nehru Nagar	22.00	19.58	24.00
5	Sakethapuram	26.73	18.90	27.00
6	Arundalpet	22.16	14.72	24.00
7	Old Guntur extension	31.00	25.90	32.00
8	Ankamma nagar	19.46	4.83	21.00

Table 8: Varying plot sizes for harvestable rainwater in case study pockets

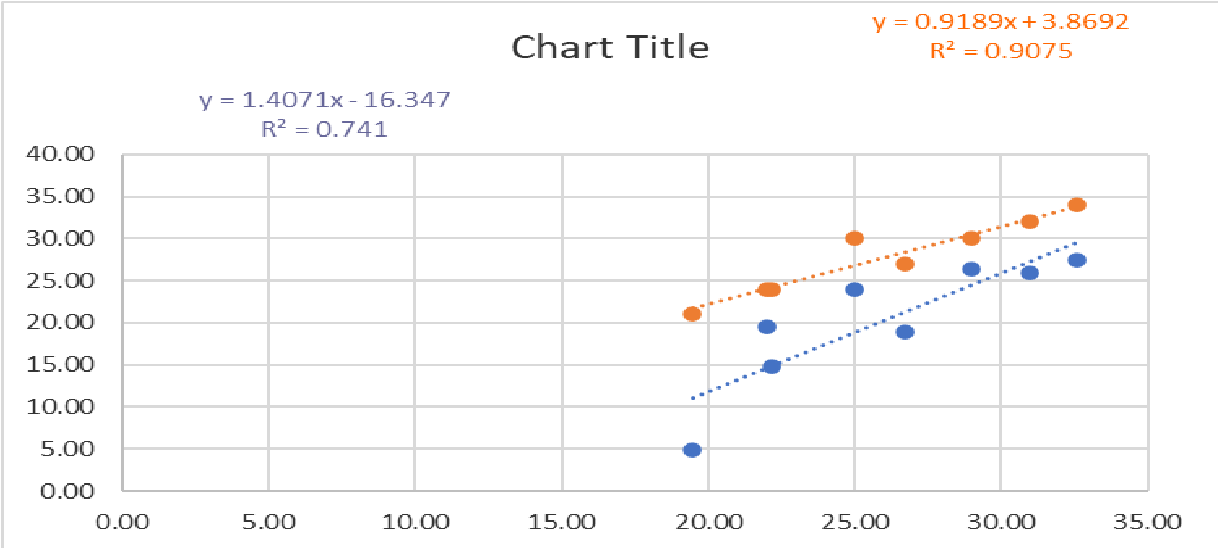

Figure 9: Correlation of plots having an area of 500 to 800 sqm through varying other plot sizes (100-200, & above 800sqm)

It is found that LPCD of (above 800sqm plots) has correlation to other LPCD's of (1-100) sqm and (200-300) sqm plots where the 'R^2' value is 0.98, and 0.78 respectively as show in Fig.10.

S.NO	**Name of the study pocket**	**Total harvestable water from paved and non- paved areas**		
		Plot areas		
		Above 800	**1-100**	**200-300**
1	Ashok nagar	30.00	17.40	19.00
2	Vengalarao nagar	34.00	20.00	27.00
3	Brodipet	30.00	18.00	24.00
4	Nehru Nagar	24.00	12.06	15.00
5	Sakethapuram	27.00	15.00	17.00
6	Arundalpet	24.00	11.95	19.11
7	Old Guntur extension	32.00	18.78	21.00
8	Ankamma nagar	21.00	9.00	10.00

Table 9: Varying plot sizes for harvestable rainwater in case study pockets

The correlation among the various harvested rain water quantities among the residents of each pocket strongly related to each other with respect to the LPCDs. It will emphasis that the macro level solutions of sustainable harvested rainwater framework at Guntur town will yield the desirable results.

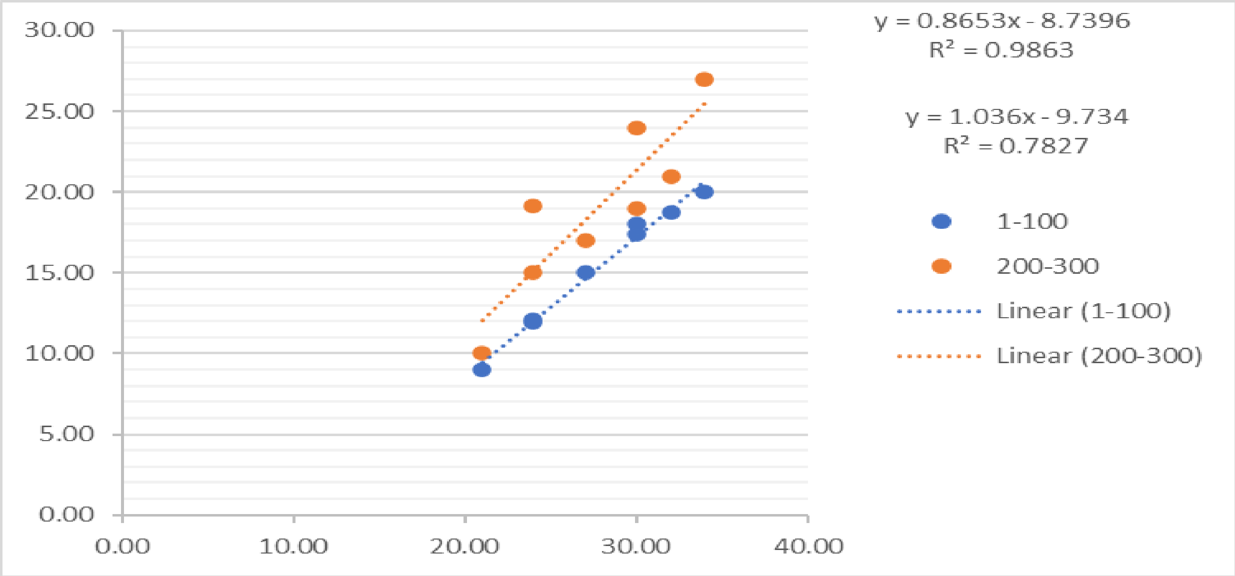

Figure 10: Correlation of plots having an area of above 800sqm through varying other plot sizes (1-100 & above 200 to 300sqm)

9. Drivers for RWH Systems

In third world countries, due to the increased scarcity of water to the municipal, industrial and the agricultural sectors, which resulted in increased food insecurity, health problems, poverty and the lack of some basic socio-economic facilities. In line with augmenting the water resources, the Rainwater harvesting is a sustainable method to be followed in a longer period as it is directly connected with the hydro cycle and conservation and management of available rainwater. So the study areas of 8 pockets shown the similarity and correlation among each pocket in terms of its sustainable harvestable rain water supporting LPCD's so the clean development mechanism of storing harvested rain water at plot level and further the supply of harvested rain water from community level storage at neighbor levels of city residential zone can reduce the stress on municipal supply and taping of the ground water can be avoided , the main drivers of this mechanism is to derive a sustainable frame work to implement the obtained results related to quantity of water savings and it can augment the stress on municipal supply.

10. Results and Discussion

The Public Health and Municipal Engineering Department (PHED) in Andhra Pradesh (AP) is the main nodal agency for planning, design and implementation of water supply and sanitation facilities in the urban local bodies (ULBs). There are different norms were adopted for water supply depending on the size of the town and the level of sewage/drainage facilities. It is relevant to indicate that the norms are 40 lpcd (litres per capita per day) in case of public stand posts, 70 lpcd in case of towns without underground drainage and 135 lpcd in case of towns with underground sewerage system and 150 lpcd in case of metropolitan cities having population more than one million. Where in Guntur has 96 lpcd including the ground water. Towns in AP facing similar crises as observed in Guntur.

The present scenario of water supply system in majority of urban local bodies in AP is far below the prescribed norms. Adequacy and equitable distribution are the major problems. The present installed capacity of all the ULBs put together is 1060 MLD (million liters per day) as against the demand of 1358 MLD and the gap is 298 MLD. There are only three ULBs (Tirupati, Narsaraopet and Vizianagaram) in which water supply is at the rate of 135 lpcd and above as per available statistical data.

In 73 ULBs the supply is between 70 and 135 lpcd while 45 ULBs are supplying less than 70 lpcd. To the areas which do not have the piped systems and bore wells, about 627 water tankers are supplying water in 96 ULBs. So it is essential to work out a sustainable frame work with respect to pervious and impervious geo morphological character of the settlement with regard to Micro-zoning of the city for assessment of rainwater runoff with so as to assess the potentiality of the settlements, appreciation of water conservation strategies for rain water and its applicability to supply safe water for the users for various uses. Besides, it is felt essential and investigated the ‘water supply and demand chain of the study pockets in Guntur to appreciate the rainwater quantity assessment with reduced the gap of 15 LPCDs to up to 100 sqm plots, 20 LPCDs to plots of (100-200), (200-300), and (300-500)sqm. Whereas the plot sizes of (500-800) and 800sqm amounts average 26 LPCDs. A case study of Guntur has been proposed as it falls closer to river Krishna and having annual rain fall of 906mm, and with due consideration to potential rainy months and post monsoon, with derived correlation among the study pockets lead to work out the sustainable frame work with a feasible solution through modular approach of pocket level considerations to distribute the community level harvested rainwater to all residents as shown in the figure 10

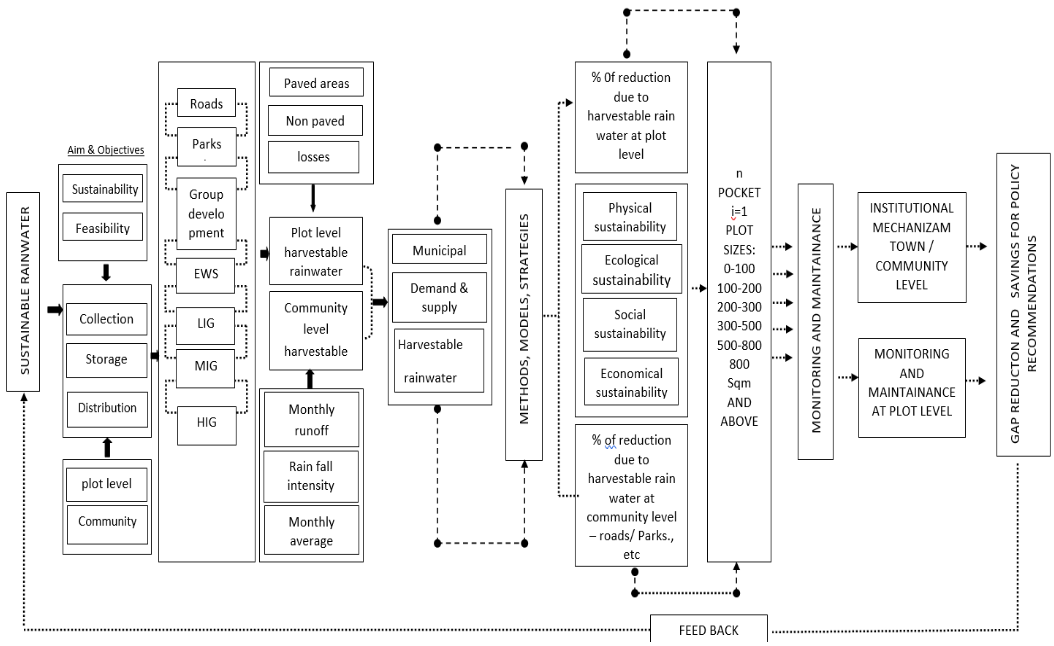

Figure 10: Sustainable frame work for appreciation of harvested rainwater to reduce the stress on water supply.

The Sustainable frame work has various tasks and adressing the challenges sequentially to bring the fesible solution with respect to the macro level through the correlated appreciation to 8 study pockets of considered data sets to reduce the water stress in terms of demand and supply.

1. The identification of sustainable parameters to strengthen the aim of reducing water stress.
2. Working out the storage potential of rain water through its rain intensity, number of rainy days, surface runoff and also slope and collection with due consideration to evaporation with respect to time and metrological conditions.
3. Significance and irrelativeness at plot level and neighborhood level i.e community level
4. Identification of different land uses such as residential use related plots, parks, play ares, roads and categories of plots.
5. Assessment of rainwater potentiality month wise with respect to paved, non-paved and losses to work out the harvestable rainwater at community level and residential use zone level.
6. Appreciating different sources of water supply and its planning, engineering and supply mechanism and demand in different pockets of the town.
7. Identification of suitable model / method / strategy to applicable to the given context and conditions.
8. Analyzing the harvestable rainwater with respect to the physical sustainability, social sustainability, economical sustainability and ecological sustainability t varying plot levels and community level of different pockets of the existing and proposed new development areas of the town.
9. Assessment of gap reduction and water stress relief of municipal supply and avoiding underground water usage and enhancing the supply augmentation.
10. Monitoring and maintenance of the proposed supply system of harvestable rainwater of community level and reviewing of the plot level mechanism of usage of stored harvested rain water.
11. Working out the efficient Institutional mechanism at Local body level and monitoring the harvested rainwater storage , sump and pump , distribution to dwelling units at varying plot levels in the neighborhood.
12. Policy recommendation for ‘Demand and supply Gap reduction’ and providing natural rainwater storage mechanism for sustainability considerations.
13. Review feed back to verify the frame work aims and objectives of Sustainable Rainwater harvesting.

11. Conclusion

The comprehensive study of its impact will throw more light on RWH scenario and its future implication. Consequently, this study aimed to develop a framework to assess demand and supply gap and worked out a sustainable solution with due consideration to potentiality of rainwater harvesting. The specified objectives of the study are to investigate the plot level and community level considerations to derive a model to reduce the water stress on municipal supply and avoiding the usage of underground water. The sustainable frame work evolved to Guntur town through conscious direction and collecting integration of rainwater related parametric model, the same framework can be a model to utilize the towns having similar conditions broadly and with minor modifications to the context specific parameters.

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