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Role of Roof – top Water Harvesting to Manage Drought in Bankura District of West Bengal

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ABSTRACT

In the present work, draught prone region of Bankura district is selected for the analysis of feasibility and sustainability in developing participatory and coordinated systems of roof-top water harvesting. In the present study area, subsurface sources of water are not equally accessible to all. Withdrawal of subsurface water requires huge investment and technology to get access to deeper aquifers. Dug wells at shallow aquifers become dry in lean season and most of them have to experience the hardship of collecting water. A detailed survey with structured questionnaire is made for analyzing the extent of problem and to estimate the demand for water per household per day through the assessment of adult and minor constituents of population, family composition etc. The feasibility of roof top water collection is assessed through examining construction-materials of roofs and calculating the daily yield of water-discharge from roof top of average size (calculated from sample survey) in relation to daily rainfall as an average of past 35 years (1969-1991; 1995-1996; 2006-2011). Survey shows that as much as 83% of surveyed houses have either tin, tiles, asbestos or cement roof, having a yielding capacity of more than 90%. The daily amount of water yield from roof top and that of daily demand are plotted in a graph to construct Mass Curve for calculating the reservoir size for a family of four members to meet average demand in dry period Mass curves are constructed by plotting cumulative demand of domestic water for drinking and cooking (60 L/Household/Day) and cumulative supply from the average roof top of 10mx5m size from average daily rain. Considering the possibility of climatic fluctuation, the effective reservoir sizes are designed to meet the demand of worst drought in certain recurrence interval. Log probability analysis shows that the reservoir size of 4025, 5130, 6445 and 7835 L may serve the demand that may recur at recurrence interval of 2, 5, 20, 50 and 100 years.

INTRODUCTION

In the context of global climatic change, irregularities and concentration of rainfall seem to be spectacular and important in controlling regional hydrology in general and water availability in particular. Intergovernmental Panel on Climate Change (IPCC) predicts that by 2025, 1800 million people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be under stress conditions. In India per capita availability of freshwater was 1816 m^3 in 2001 and that has been reduced to 1588 m^3 in 2010 due increase in population and decline in freshwater availability. According to CWC (2010) total estimated utilisable water in India is 1123 BCM of which Surface water amounts to 690 BCM and Ground water is of 433 BCM. Projected water demand from different sectors shows that by 2050, India will come under absolutely water deficit condition. In these circumstances, it is essential to formulate strategy to be adopted by the communities for building resilience to cope with the situation. Rain water harvesting is the best among the alternative options to manage water scarcity in the potential water scarcity regions (Myres, 1967; Rao, (2007).

The term water harvesting refers to collection and storage of natural precipitation. It also involves other activities for prevention of losses through evaporation and seepage and incorporates all other hydrological studies and engineering interventions, aimed at conservation and efficient utilization of the limited water endowment of a physiographic unit, such as a watershed.

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The term Rain Water Harvesting refers to direct collection of precipitation falling on the roof or onto the ground within passing through the stage of surface runoff on land (Athavale, 1991, 2001 & 2003). To mitigate the hardship of residential population due to water crisis, the best and cost-effective method may be the roof-top water harvesting (Babu, R. A., 2007 and Muralidharan. D., 2007). In the hilly regions roof top water harvesting is carried out traditionally and it is a significant alternate source of water (Pandey, 2002; Moitra Maiti, 2008; Mishra et al 2007).

In the present work, attempt has been made to analyse the feasibility and effectiveness of roof-top water harvesting in an attempt to formulate a strategy for water management at domestic units through community participation in an area that presently suffers from acute water scarcity and may also experience intense crisis in future. Specific objective of the present work is to calculate the rational reservoir size for a standard family considering average roof size, average rain, amount of water demand and probability of drought.

STUDY AREA

Hirbandh, the western most block of Bankura district running along the border of Purulia district, is selected for the present study. On an average, the elevation of the region ranges from180 to 120 m with an average gradient of 1:100. Geographically the area is situated on the wide interfluve between the river Shilabati and Knagsabati. The concerned area represents the undulating topography and considerable gradient that favours easy drainage and soil erosion thus belongs to the soil and water source zone of the Shilaboti drainage basin. The hypsometric analysis shows the younger stage of erosion indicating huge potentiality of further erosion. The concerned area falls in the drainage basin of an unnamed right hand tributary of the river Silabati and the drainage systems are mainly composed of first order seasonal streams. This region experiences sheet wash where rain drop impact and sheet flow is active for the displacement of matter.

The water divide between the mighty Silabati and Kangsabati suffers from water scarcity for the easy and immediate drainage of both surface and sub surface water down the steep slope just after the rainfall. The sharp increase of water demand due to faster growth of population and improved life style on one hand and no major water storage facility, on the other essentially created the acute crisis. The increased tendency of concentration of annual rainfall in the monsoon months and reduction in the storage of soil water by indiscriminate slope clearing intensify the problem. The crisis becomes acute during dry summer when maximum of the channels and the ponds become dry. The agriculture remains at the rudimentary level entirely depending on the natural supply and without having any irrigation facility. The traditionally practiced gender difference in work participation imposed the responsibility of maintenance of households and collection of water to women sector and thus they have to suffer more than their male counterpart. People, specially women have to cover longer distance to collect water from remote sources. The social and economic processes are disturbed as they have to spend a long time for water collection. During acute crisis period, almost all the villagers are gathered at one or two alive but almost dying ponds for bathing, sanitation and washing. Huge pollutant pools make the water non-suitable for use in the ponds.

MATERIALS AND METHODS

Primary data on the population composition, rate of increase, damand of water for domestic use specially cooking and drinking, roof size, roof composition etc. are collected by surveying 231 sample households with structured questionnaire from 16 villages. Samples are selected randomly from different social and economic strata. Secondary data on daily rainfall and temperature for duration of 35 years (1969-1991; 1995-1996; 2006-2011) is collected from IMD, Pune. Collected data are analysed by SPSS software.

The necessity of roof-top water harvesting is examined through

- The study of water demand of a family through intensive field survey with structured questionnaire,
- The source of water and distance during normal period and that in crisis period and the hardship involved in collection of water from distant sources are studied in details.

The scope of roof-top water harvesting is examined through

- The study of constituent materials of houses specially the roofs.
- Roof sizes of the houses are measured during field study to get the average roof size for calculating yield of water from a rain of certain intensity

The feasibility study is made through quantification of water yield and required reservoir size

- The yield of water for every rainy day from average roof top is calculated for a duration of last 35 years (1969-1991; 1995-1996; 2006-2011) considering a loss of 10% during conveyance.
- Mass curves for last 35 years (1969-1991; 1995-1996; 2006-2011) are constructed after Weiner and Matthews, 2007 for calculating the size of reservoir for each of these years sufficient to store water for a family with an average demand of 60 L per day.
- Considering the variability of rainfall, the reservoir sizes sufficient for the drought of a 5, 20 and 100 years' recurrence interval were calculated following log probability law after Chow (1954, 1964) & Schwab (2002).

RESULT

Month-wise Average Rainfall Distribution

The analyses of rainfall data confirm the concentric character of the monsoonal rain. Daily rainfall data of past 35 years available from IMD (1969-1991; 1995-1996; 2006-2011) shows that about 79% rain is received in the monsoon months during June to September. Some moderate amount of rain is received in May (92mm) and October (81mm) as pre and post-monsoon rain respectively. The dry period of six months (November - April) receives very meagre amount of rain (Fig. 1). This seasonal concentration is mainly responsible for water scarcity.

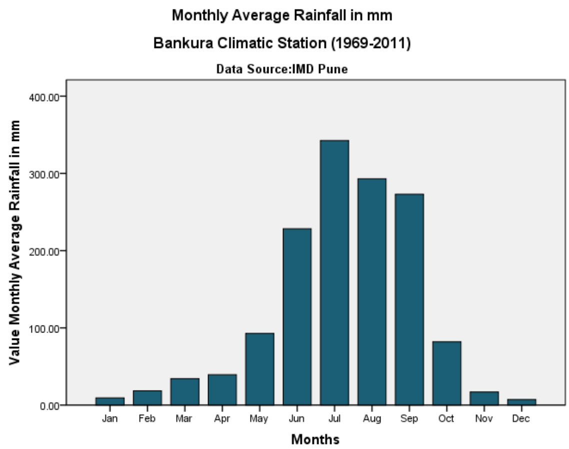

Fig. 1: Average monthly distribution of rain

Distribution of Rain in Dry and Wet Period

It is essential to understand the distribution of rain in wet and dry period (Linsey et al.1982). The period from June-October is considered as the wet period. Analysis shows that a major share (ranging from 70 to 91%) of annual rain is received in this period of five months. Again 16.44% of annual rain is concentrated to a single storm of average 7-8 days. Prolonged dry period of 7 months receives very meagre amount of rain that may be as low as 9% of the annual total (i.e. in 1984; Fig. 2). Rain in the dry period are so less that in maximum cases almost all the rain received are either evaporated or adsorbed by vegetation or soil and are dried down in the next day. So, the rain water in the wet season is the effective input that is to be retained in situ for availability in longer dry period.

Concentration of Rain in Few Intensive Storms

Concentrated Rain in storms of few days' duration is one of the main characters of rain in the area under study (Moitra Maiti, 2008). This tendency is increasing at present, may be due to global warming (Fig. 3). Rain is increasingly associated to such extreme events. This rain may amounts to even 643 mm being concentrated within eight days (August

27-30, 1987-88). Almost every year since 1969, experiences such concentration of rain in storm periods that receives on an average 239 mm of rain. Studies on the storm periods of 20 years show that, on an average, 16.44% of annual rain is received within a single storm of 7-8 days' duration. This concentrated rain causes high percentage of surface runoff in saturation condition and this huge immediate runoff causes extreme flood in the lower catchment of the mighty Silabati. Flood at the lower catchment in the Silabati is thus an annual event. This rain of concentrated duration is neither retained in the soil, nor infiltrated down to recharge ground water and so no water is available in prolonged dry period. Rather, it causes enormous soil erosion during this period of concentrated flow. The main challenge of water harvesting is to arrest this concentrated flow of surface runoff arising out of storm-rains of few days' duration (Moitra Maiti et al. 2012, Moitra Maiti, and Maiti, 2009).

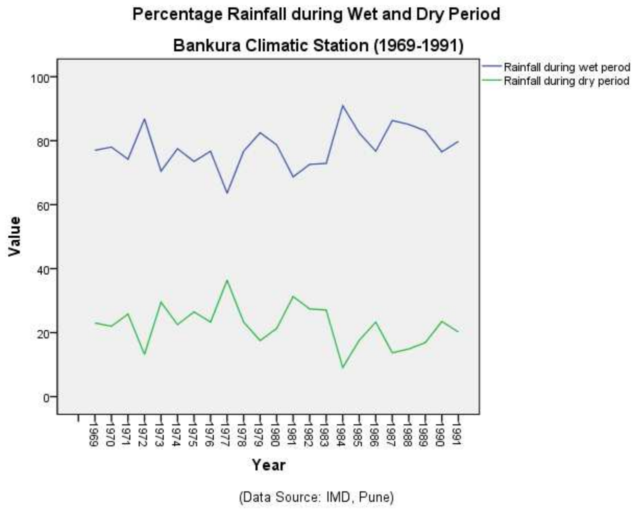

Fig. 2: Distribution of rain in dry and wet season

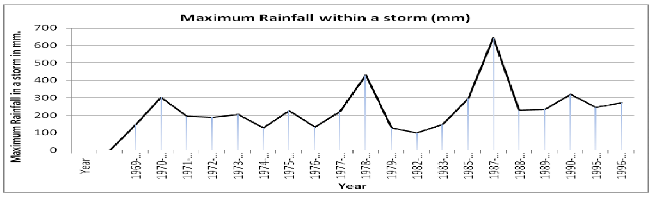

Fig. 3: Concentrated rain received in the storm periods.

Duration of Storm Period

The storm periods may last for 2 to even 18 days (Fig. 4). The contiguous days with some rain is considered as a storm generated mainly by low pressure situation. Almost all the rain of the study area is of cyclonic nature. Effective watershed management should adsorb the rain received in those days for making available in dry period.

Characters of Dry Periods

Analyses of the daily rainfall data reveals that the stretch of continuous duration of no rain i.e. the dry spell varies from 25 days to 88 days with an average of 62 days. That means any effective management should have the arrangements for water supply for at least 3 months in the area under study.

Probability of Rain in Dry Period

Probability of rain in dry period since 1969 was calculated (Table 2) and are arranged in descending order for calculating return period after Gumbel's law (1954). On an average, 323 mm of rain may be expected within this period of 7 months. This rain has a huge variability characterised by the value of standard deviation 102 mm. The rain of 513mm may occur at a recurrence of 24 years and that of 493mm may recur at every 12 years.

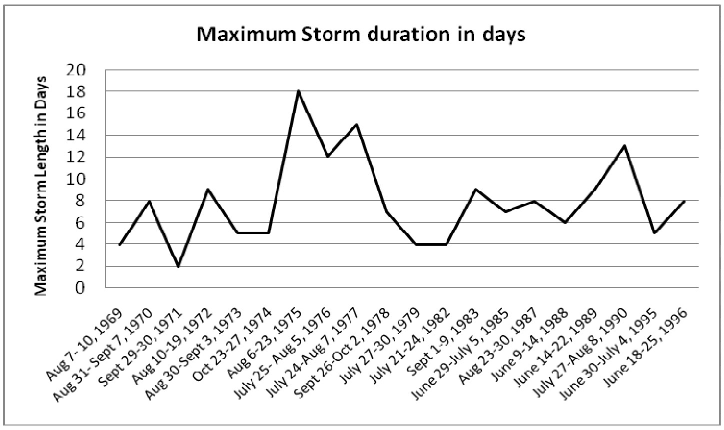

Fig 4: Storm duration in days since 1969

For the better understanding of the recurrence interval of such prolonged dry period and to propose long-term management plan, Log-Probability analysis seems to be important following Chow (1954) and Schwab et al. (2002). Analysis shows that a maximum drought length of 95 days may recur at 20 years' recurrence interval at 5% probability. This length may be 115 days at 100 years' recurrence interval (Table 1).

Table 1: Drought duration at certain recurrence intervals

Calculation of Magnitude of Droughts in Days			
P (%)	T (Years)	K (Frequency factor)	Xc (Magnitude of Drought Length in Days)
99	1.01	-1.633	31.43
50	2	-0.141	58.84
20	5	0.742	75.05
5	20	1.837	95.168
1	100	2.922	115.1

Roof-top Water Harvesting

Roof-Top water harvesting may be an efficient management of water scarcity in the area of concern. This area receives sufficient water as rain, but due to inefficient retention, water scarcity results. The feasibility of roof top water collection is assessed through examining construction-materials of roofs and calculating the daily yield of water-discharge from roof top of average size of 10m X 5m (calculated from sample survey) in relation to daily rainfall. The daily amount of water yield from roof top and that of daily demand are plotted in a graph to construct Mass Curve for calculating the reservoir size for a household. The average household demand in the study area is calculated from the data collected from field survey. The demand per day per household for drinking and cooking is 63.3L. It is considered to be 60L for the convenience of calculation. Considering the possibility of climatic fluctuation, the effective reservoir size has to be designed to meet the demand of worst drought in 20 years.

Roof size

It is essential to analyse the roof size as the discharge yield from a roof depends on its size. Survey shows a greater variation in the size of the roofs. Among the results, the size of 10m X 5m seems to be the best representative of the study area. In all the calculations this size is considered. A loss of 10% discharge is considered during conveying from roof to reservoir.

Table 2: Rain during dry period

Year	Rainfall in dry period(mm) [Oct-May]	Calculation of Return period after Gumbel (1954)	
		Rank in descending order	Return periods in Year (T)
1969	262.1	18	1.333333333
1970	321.5	10	2.4
1971	493.7	2	12
1972	152.6	23	1.043478261
1973	449.6	5	4.8
1974	311	11	2.181818182
1975	303.7	12	2
1976	204.5	21	1.142857143
1977	513.4	1	24
1978	462.4	4	6
1979	208.14	20	1.2
1980	271	15	1.6
1981	393	7	3.428571429
1982	299	13	1.846153846
1983	367.8	8	3
1984	166.94	22	1.090909091
1985	262.6	17	1.411764706
1986	338.2	9	2.666666667
1987	267.4	16	1.5
1988	221.9	19	1.263157895
1989	296.17	14	1.714285714
1990	472.83	3	8
1991	409.6	6	4
Mean 323.8730435			
Standard deviation 102.9423203			
Variance 10597.12132			
Skewness 0.284470893			
Kurtosis -0.868472351			
(Coefficient of Variation) Cv 0.32			

Constituent materials of Roof

Intensive household survey shows that a considerable percentage of the roofs are constituted of tin, tiles, asbestos or cement. The percentage ranges from 83-25%. These materials yield sufficient discharge from rain and are suitable for roof-top water harvesting (Table 3).

Table 3: Constituent Materials of roof

Name of Villages	Roof (in percent)					Roof Suitable for Rain Water Harvesting
	Thatch	*Tin*	*Tiles*	*Asbestos*	*Cement*	
Elora	28.57	*21.43*	*35.72*	*7.14*	*7.14*	*71.43*
Sahardih	37.5	*37.5*	*25*	*0*	*0*	*62.5*
Palashboni	60	*20*	*0*	*20*	*0*	*40*
Deulbera	75	*0*	*25*	*0*	*0*	*25*
Bonsal (Nanda)	33.3	*0*	*33.3*	*0*	*33.3*	*66.6*
Kadia	20	*50*	*20*	*10*	*0*	*80*
Fatepur	37.5	*12.5*	*37.5*	*12.5*	*0*	*62.5*
Gopalpur	16.66	*25*	*25*	*0*	*33.34*	*83.34*
Lachipur	25	*37.5*	*18.75*	*0*	*18.75*	*75*
Batikara	50	*15*	*20*	*0*	*15*	*50*
Dhanalangi	28.13	*28.13*	*28.13*	*12.5*	*3.11*	*71.87*
Tilabaid	57.14	*28.57*	*14.29*	*0*	*0*	*42.86*
Dhaibari	66.66	*33.34*	*0*	*0*	*0*	*33.34*
Saluipahari	28.57	*14.29*	*0*	*14.29*	*42.86*	*71.44*
Bansa	33.33	*16.67*	*0*	*0*	*50*	*66.67*
Bhimpur	40	*40*	*0*	*20*	*0*	*60*

Water demand per household

Demand of water per household for drinking and cooking is estimated by survey with structured questionnaire. The demand varies from village to village. On an average, a household requires 63.3 L of water for the purpose of drinking and cooking. The demand for washing and bathing could not be estimated as they perform those activities in the ponds in a sharing basis. For the purpose of further calculations, the demand of 60 L per household per day is considered.

Estimation of Reservoir Size

Average Daily Rain since 1969

For further calculation of rain water harvesting, daily rainfall of 31years since 1969 has been considered. Daily rainfall recorded during this period has been made total and divided with the duration to get expected rain on the date concerned. This result has been used for calculating reservoir size.

Construction of Mass Curve

Mass curves are constructed by plotting cumulative demand of domestic water for drinking and cooking (60 L/Household/Day) and cumulative supply from the average roof top of 10mx5m size from average daily rain since 1969. As there is continuity in inflow and outflow of water in the reservoir system by supply from rooftop and use for domestic purpose respectively, cumulative of supply and demand is considered. One Mass Curve (Fig. 5) is drawn on the basis of the mean rainfall of 35 years. The graph shows deficit of water in dry period and surplus of it in rainy period. The amount of deficit in each year is calculated in table 4. If the maximum deficit amount is stored, it can serve the purpose for rest of the period.

Table 4 Maximum deficit with their corresponding dates

Year	Date(MM/DD/YY)	Highest Deficit in L
1969	3/19/1969	2889
1970	05/08/1970	5446
1971	04/07/1971	2913
1972	06/12/1972	6244
1973	03/01/1973	3150
1974	3/24/1974	4606
1975	4/20/1975	3063
1976	05/07/1976	5740
1977	3/25/1977	3510
1978	03/11/1978	2980
1979	06/08/1979	5044
1980	05/11/1980	5053
1981	1/31/1981	1860
1982	03/01/1982	3222
1983	04/09/1983	3537
1984	04/04/1984	4496
1985	05/07/1985	2544
1986	6/15/1986	5890
1987	4/25/1987	5955
1988	05/12/1988	2980
1989	5/13/1989	7206
1990	2/18/1990	2940
1991	3/13/1991	3396
1995	05/07/1995	4360
1996	4/21/1996	2355
2006	4/13/2006	2594
2007	4/24/2007	4257
2008	05/02/2008	6079
2009	05/02/2009	5777
2010	4/27/2010	5385
2011	04/04/2011	4628
Mean		4196
SD		1229.69
Coefficient of Variation (C_v)		0.293

In hydrology the concept of average does not yield fruitful result. For that purpose analysis is made on available daily rainfall data of each year (Table 4). If the decision of reservoir size is taken based on the average deficit of the past years the value becomes 4196 L. This amount will not serve the purpose for more than half of the years. So Log Probability analysis is made to calculate the deficit amount that may arise at recurrence interval of 2, 5, 20, 50 and 100 years using the equation 1. The calculation shows that deficit may become 4025, 5130, 6445 and 7835 L at recurrence interval of 2, 5, 20, 50 and 100 years respectively (Table 5).

X_c= Mean (1+ C_v.K) ------- Eq. 1

(Chow, 1954 and Schwab et al. 2002)

Table 5 Rational Reservoir sizes for different recurrence interval.

Year (Recurrence Interval)	1.01	2	5	20	100
P (%)	99	50	20	5	1
K (After Chow, 1954)	-1.738	-0.139	0.76	1.83	2.96
Xc (Reservoir Size in L)	2059	4025	5130	6445	7835

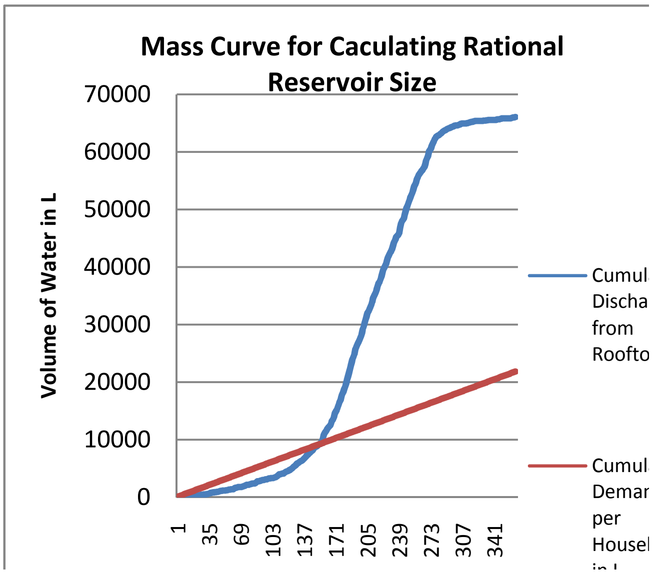

Fig. 5 Mass Curve on the Mean value of 35years Rainfall Data

CONCLUSION

The study reveals that in spite of receiving sufficient rainfall, the region suffers from water scarcity due to lack of proper initiative of retention. Based on decentralised participatory approach targeting at household units, roof top water harvesting may be effective in building resilience against irregular and concentrated rain and resulted water scarcity in the context of global climatic change. Only a reservoir at domestic unit storing a portion of discharge (90%) from the roof top may ensure the supply of total year-long domestic demand. Reservoir may be built either of polythene tank (Myres, 1967) or concrete. These may be set on the open courtyard available at each domestic unit in the area under study. Excess discharge from the reservoir may be directed to recharge underground water table and proper care must be taken to avoid contamination. A recharge pit of considerable size has to be constructed up to a depth of 6-8ft beyond lateritic hard pan. For constructing recharge pit, an elevated place must be chosen away from open toilet and a cemented dyke surrounding it has to be constructed to avoid surface and seepage flow of contaminated water from toilet or waste water drain.

Over all, efficient water management in such drought-prone area must ensure community participation; only initiatives from government may not yield any success. The present practice of state's responsibility of water management has to be changed and community participation in water management must be practiced. Roof-top water harvesting may be initiated as a pilot project at every government school and office buildings to make people aware of the benefits and necessity of it. Again financial assistance from government may be extended as an attempt to encourage local people in adopting rooftop water harvesting as an effective instrument for fighting climate change and water scarcity.

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