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Factors affecting Water Conservation Potential of Domestic Rain Water Harvesting- A Study on Bengaluru Urban

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Abstract

The exponential growth of population, dynamics of industrialization, and expanding real estate business in Bengaluru have put high pressure on water resources and the demand-supply gap is ever widening. The loss of open lands, lakes, and ponds resulted in the depletion of groundwater and the city has no option but to resort to water conservation. Ever since Bangalore Water Supply and Sewerage Board (BWSSB) passed the Rainwater Harvesting Regulation in 2009 a policy-driven initiative has started to popularize Rain Water Harvesting in Bengaluru city. This study examines the technical and non-technical factors affecting the water conservation potential of the Domestic Rain Water Harvesting system (DRWH) in the independent houses in the city of Bengaluru. Using the OLS regression model the main determinants of water conservation potential of the DRWH are identified as catchment area, type of roof, number of water sources, and house area. The study finds that there are 13.76% water savings per household per year with DRWH structures.

Keywords: Water conservation, Domestic Rain Water Harvesting

JEL Classification: Q24, Q53

Factors affecting Water Conservation Potential of Domestic Rain Water Harvesting- A Study on Bengaluru Urban

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Introduction

Over the years, industrialization, increasing population, expanding agriculture, and high standards of living have increased water demand against the static level of water supply. The cities as the hub of the major economic activities are likely to face water shortages which will deteriorate the quality of life. India portrays a rather alarming picture of the future when it comes to water stress. Five of the world's twenty largest cities under water stress are in India and the average per capita water availability is expected to reduce further to 1341 m^3 by 2025 and 1140m^3 by 2050 (NITI Aayog, 2019).

The estimates show that the state of Karnataka experiences 40 to 80 % water stress and Karnataka is ranked fifth on the Composite Water Management Index for the financial year 2017-18 (ibid). Water supply infrastructure in Bengaluru city like other metropolitan cities in the country is unable to meet the needs of the ever-growing population. The growth in the population in the city has put immense pressure on potable water and water for other purposes. According to the estimates of Bangalore Water Supply and Sewerage Board (BWSSB), the city needs around 1125 MLD and supplies only 900 MLD and the demand-supply gap (after leakage losses) is 585 MLD (CSE, 2011). Chennai faced “Day Zero” or acute water shortage in 2019 and it is speculated that Bengaluru would be the next city to face a similar problem (NITI Aayog, 2019). United Nations Sustainable Development Goal (SDG) six considers the improvement of water quality by treating the wastewater, increasing water recycling, and safe reuse (Tortajada, 2020). This will result in the availability of more clean water for all uses, and enormous progress on sanitation and wastewater management.

The location of Bengaluru in the semi-arid peninsular region makes it scarce in the presence of large water bodies. Cauvery and Arkavathi rivers are the two sources of surface water in the city of Bengaluru. The city also has a rich lake cover which occupies nearly 4000-hectare and they have been instrumental in recharging the groundwater as well. An increase in the number of borewells for residential and commercial use, growth in the number of private water tankers, and decline in the number of water bodies led to the shrinking water table (CSE, 2011).

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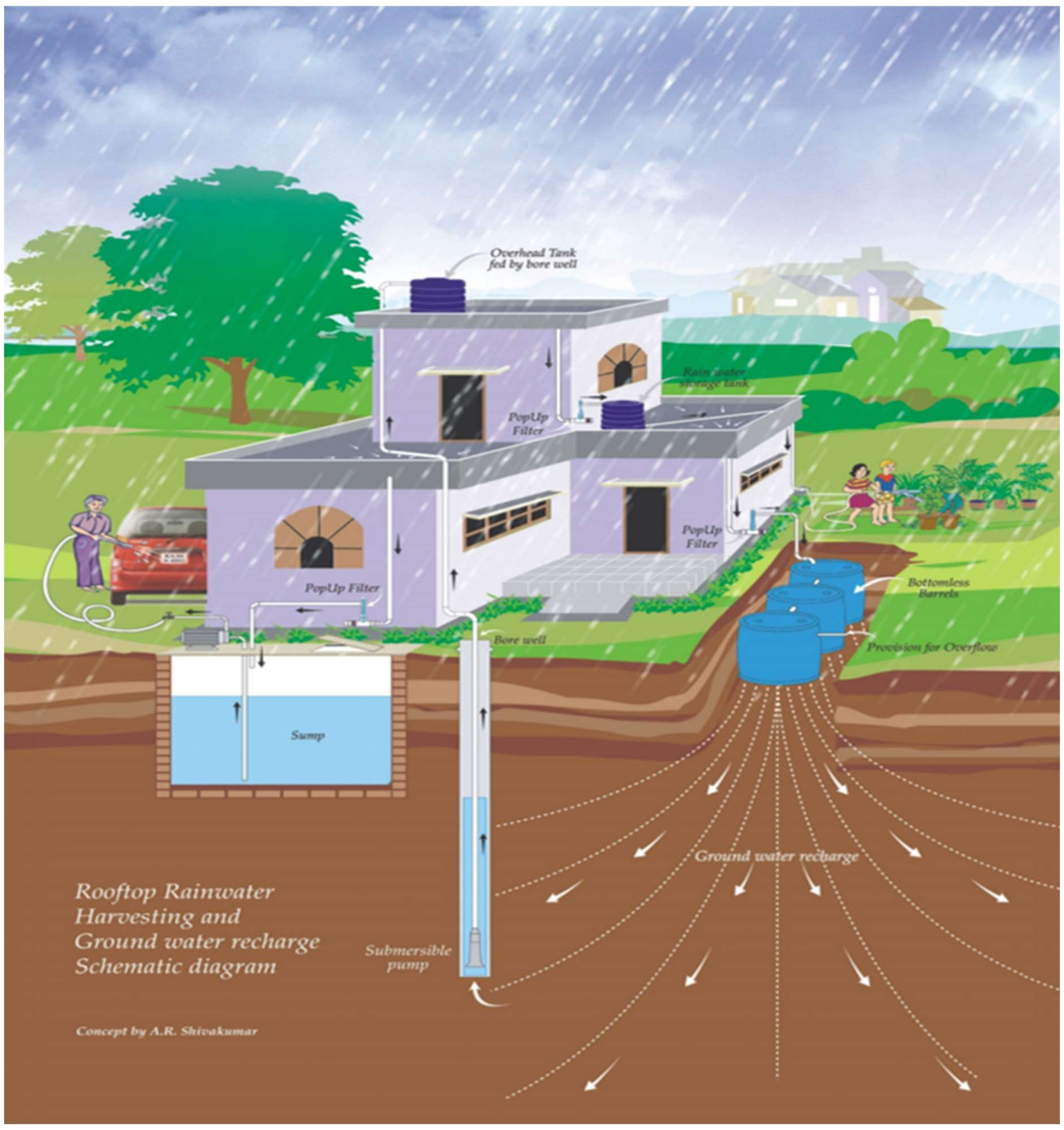
The population of Bengaluru is dynamic and ever-changing adds to the pressure on the government to allocate water resources to meet the increasing demand for water due to the increasing population. If the population of Bengaluru continues to grow at the current rate, the city will undergo a drastic change due to depletion of groundwater and inculcation of water conservation attitude is the way forward policy (Ramachandra et al, 2016).

Lack of water conservation measures potentially puts the Bengaluru water supply infrastructure city at risk. Water Conservation means using less water or using recycled water and Rainwater Harvesting (RWH) is a popular method of water conservation wherein rainwater is collected or stored in manmade catchments or subsurface aquifers. RWH as a method of water conservation is receiving immense attention in recent decades as it proves to increase water availability in the aquifers and provide water security. RWH is a popular sustainable strategy in many countries like China, Brazil, Australia, and India (Yannopoulos et al, 2019); that faces immense pressure on water resources owing to rapid urbanization and population growth.

Increasing demand for water to meet the growing population pressurises authorities to address groundwater depletion and on options to recharge groundwater. Groundwater is defined as the water available below the ground in the ‘zone of saturation’ and groundwater recharge means the water put below the ground to charge groundwater table by artificial structure or pit. Domestic Rain Water Harvesting (DRWH) is a broad category of RWH technology in which rainwater is captured from courtyards, rooftops, or other kinds of surfaces which help to recharge groundwater that would otherwise go to waste. This technique is simple and robust in water resource management and the water harvested is potentially useful for primary or secondary purposes. (Ganjali & Guney, 2017; Umamani & Manasi, 2013)

RWH technique can be broadly classified into 1) Storage of Water on Surface and 2) Groundwater Recharge. The first technique includes Rooftop RWH in which downward water pipes are fixed to the rooftop where there is maximum rainwater runoff and it is connected to a storage tank. The stored water can be used for secondary purposes and also for drinking if treated properly. It helps in achieving sustainability and it helps to avoid depletion (Ganjali & Guney, 2017). Another method of storage of rainwater on the surface is rooftop rainwater for recharging open wells. The downward pipes are connected to open wells or bore wells. The second technique of RWH is an artificial recharge of groundwater and through this technique, the excess rainwater is infiltrated into the subsurface (Umamani & Manasi, 2013).

Figure 1: Schematic Diagram of Domestic Rain Water Harvesting System



Source: (Basavaraju, 2020)

Figure 1 is a schematic diagram of the rooftop RWH system and how it helps in groundwater recharge. There will be catchment area, gutter and downpipes (for conveyance), flush systems, components to filter the water and debris, storage tanks and delivery system and recharge mechanisms for the RWH system. With good rainfall density, optimum rooftop area, and minimum runoff coefficient, RWH is feasible (Dadhich & Mathur, 2016).

Bangalore Water Supply and Sewerage Board has taken up measures to improve water conservation to combat water problems through its services. BWSSB came up with Rain Water Harvesting Regulations (2009) making every owner or occupier of a building having site area of not less than 2400 square feet on or before 2009 or every owner who proposes to construct a building on a site area of not less than 1200 square feet shall provide Rainwater Harvesting structure for storage for use or for groundwater recharge within 31st December 2011 notified by the State Government in such a manner and subject to such conditions as may be provided in the regulations and guidelines issued by BWSSB (Bangalore Water Supply and Sewerage Board, 2019). This study tries to examine the factors affecting water conservation by DRWH in Bengaluru Urban.

The serious issue of water scarcity has increased the demand for any water conservation methods and several parts of the world have adopted systems like rainwater harvesting as part of their policy framework. Before only arid and semi-arid regions used to practice them however as the concerns on water stress puts demand for rainwater harvesting systems in humid and semi-humid regions as well (Yannopoulos et al, 2019).

Literature shows that RWH is not at all a new technology and establishes that some of the ancient and medieval civilizations also have practiced it. These practices have been blended with modern technology and customised according to the geographical area. A lot of technical studies have been done of the advantages and disadvantages of the various RWH methods in different parts of the world. Some studies are also done of the experience of RWH in Bengaluru. This study is done in the context of the mandatory regulation made by BWSSB (2009) which made installation of RWH compulsory in Bengaluru houses. The research is looking into the technical and non-technical factors which determines the effectiveness of DRWH systems.

Objectives of the Study

Following are the objectives of the study:

1. To identify the technical and non-technical factors that affect water conservation in the households which installed Domestic Rain Water Harvesting Systems and to check the private benefits of the system.
2. To check whether the ‘stick policy’ of regulation influenced water conservation goals.

Literature review

Water conservation attitudes of individuals assessed as a response to the environmental concerns revealed that end-use water consumption in households will be low if the concern for the environment is high (Wills et al, 2011). RWH has proven to substitute dependency on the mains water supply to some extent (Thomas, 1998, Mou 1995). Several types of research have been carried out on RWH of a region, time, or so on as a solution to the mentioned concerns. Case studies were done on arid, semi-arid regions; urban, peri-urban, and rural areas reveal that the success of RWH varies from one region to another. Micro-level management of water sources leads to sustainable management of common property resources. The research was carried out on the campus of an educational institution in Chennai reported the response of groundwater to artificial recharge through rooftop RWH methods. The findings show the effectiveness of RWH in increasing the level of the water table in the study area (Sayana et al, 2010). Parameters that influence the effectiveness of RWH are the climatic condition and the magnitude of rainfall in the area. A case study conducted in Dhule, a district in the north-west part of Maharashtra shows the ineffectiveness of the RWH system due to less annual rainfall and negligible non-monsoon rainfall (Dwivedi & Bhadauria, 2009). Another research conducted in Ahmedabad and Radhanpur (urban and rural area) found RWH could only provide water security to independent bungalows and flats in the dry season in Ahmedabad but the physical feasibility of RWH was doubtful. This study also reveals that RWH as a supplementary source of water is Ahmedabad is not economically viable but Radhanpur is viable (Kumar M. D., 2004). Research done on economic analysis and feasibility of RWH in Australia and Kenya points that RWH can save a large quantity of quality water at very reasonable costs but changes with the change in variables like life cycle cost analysis (acquisition cost and ownership cost), water price, interest, inflation, time of analysis, costs (capital costs, maintenance costs) and benefits. Australian states have policies promoting and encouraging RWH whereas it requires a policy shift in Kenya because in some parts of Kenya RWH is prohibited (Amos et al, 2016). Research conducted in South Africa on RWH studies the impact of domestic rainwater harvesting and how it can lead to water-borne diseases caused by contamination and breeding of mosquitos especially through open pits. The paper made suggestions that consideration must be given to density of rainfall, location, quality, and other factors (Kahinda et al, 2007). Contrarily, Bouma et al. (2011) argue that the externalities of watershed development investment are unlikely to enhance welfare at a sub-basin scale. The aggregate effect of several small investments in rainwater harvesting will reduce the availability of water downstream and thus reduce welfare. The impact on downstream is significant and the net benefits will not be able to repay the investments. The energy required to pump rainwater in a single storey building may be more. Thus, it is not right to assume that rainwater harvesting systems will have a positive impact on the environment (Vieira et al 2014). There also comes health risk with the usage of untreated harvested rainwater due to microbial pollutants, contamination, etc. entering into the tanks (Wesaal et al. 2013). RHW system must be designed in a way that reduces breeding of mosquitos, contamination, and pollution (Kahinda et al. 2007). Angrill, et al. (2011) suggest the best rainwater harvesting strategy with the least impact on the environment is the roof tank rainwater harvesting in Mediterranean climatic conditions. In conclusion, literature affirms that rainwater harvesting techniques can address and tackle the water scarcity problems. However, effectiveness varies from urban to rural, dense to diffused urban settlements. The water collected through RWH can be used as potable water only after proper treatment. However, it can be used for secondary purposes of water. RWH promotes sustainability and provides water security and also reduces the risk of floods in dense urban settlements, recharges groundwater, and leads to sustainability and it comes as a boon in handling the water crisis.

Bengaluru is the third most populous city in India (Government of Karnataka, 2019). It is one of such cities whose urbanization process has been alarmingly fast. Bengaluru does not have any perennial water sources and depends mainly on the Cauvery River. Water from the river is pumped into the city from a distance of 100kms which is an expensive task for the water supply authorities (Suresh, 2001). Apart from the Cauvery River, Bengaluru has been dependent on lakes and tanks. But due to dumping and encroachment problems in lakes, the lake water has been contaminated or is drying up. The water table levels are depleting due to the construction of houses, roads, footpaths that have left little earth exposed for rainwater to seep in and replenish the groundwater levels. The demand for water per person in Bengaluru city is nearly 150 to 200 lpcd (liters per capita per day) but the average supply is only about 100 – 125 lpcd (Ramachandra et al, 2016). This leads people to resort to alternate water sources by using groundwater (Raju, Manasi, & Latha, 2008).

Looking from the policy framework, voluntary or incentive- based scheme and mandatory regulation are the two approaches which can be adopted to promote RWH implementation. BWSSB has taken up measures to improve water conservation to combat water problems through its services and this study looks into the BWSSB mandate of 2009 and its effect on implementation of DRWH systems in the city of Bengaluru. BWSSB came up with Rain Water Harvesting Regulations (2009) making every owner or occupier of a building having a sital area of 2400 square feet and above or every owner who propose to construct a building on a sital area of 1200 square feet and above shall provide for rain water harvesting structure within 31st December 2011 (BWSSB Amendment Act, 2009). According to BWSSB, with RWH, 107280 litres of rainfall can be captured in a year from one household and domestic harvesting of rain water can be to the city's advantage in several respects given the urgency of lessening the current water crisis. This was the rationale behind the selection of this topic and this research limits its study to DRWH in Bengaluru Urban in those independent houses have already installed this system.

Description of data

Our sample consists of 54 houses that have adopted rainwater harvesting systems. Around 57 percent of the sample lived in site area more than 1200 sq. ft and 43 percent lived in a site area which is less to 1200 sq. ft. The average age of the respondent is 45 years and 53 percent of the respondents owned the independent houses they occupied.

The policy of BWSSB which made it mandatory to adopt RWH according to the 2009 regulation insisted many households to install them. Figure 2 shows that around 53.7% percent of our sample installed DRWH due to the compulsion from BWSSB. Nearly 35% adopted it as they were convinced of the benefits of the rainwater harvesting techniques.

Figure 2: Motivation for installation of DRWH system in the house

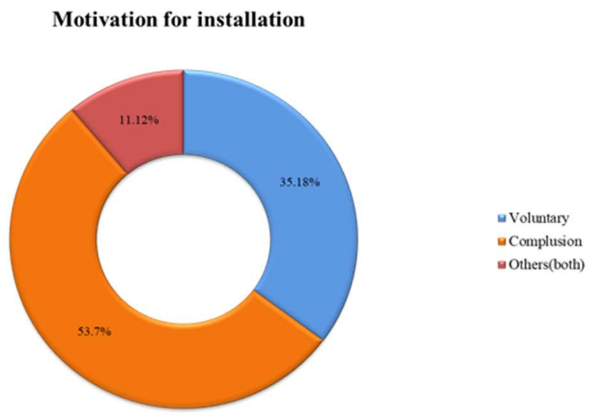


Figure 2 reveals the reasons for the adoption of DRWH systems in the households. More than half of the respondent households installed it because of compulsion of the BWSSB regulation whereas 35 percent admitted doing it voluntarily.

Table 1 shows that the most popular technique of RWH among the respondents is underground recharge of rainwater. This technique seemed to be the most convenient technique since it does not require much maintenance, capital and also takes less space. 32 out of 54 respondents adopted underground recharge technique of RWH. The second most popular technique among harvesters of rainwater was storage for reuse which was adopted by 13 respondents.

Table 1: Uses of Harvested Rainwater by households

Technique of RWH	Number of Houses	Percent
Storage for reuse	13	24.07
Underground recharge	32	59.26
Directly to bore well	5	9.26
Directly to open well	0	0
Reuse and recharge	4	7.41
Total	54	100

Rainwater harvested is used for different purposes like groundwater recharge, recharging the bore well, cleaning, gardening, cooking and drinking, washing, flushing, and so on. Many used it solely for secondary purposes and few used for primary purposes like drinking and cooking too. 11.11 percent of respondents used the harvested rainwater for primary and secondary purposes as well as for recharge. Respondents with underground recharge technique of RWH have placed plants near the recharge pits so that the excess water coming from the recharge pit does not go to waste.

Methodology

Primary data was collected from households in Urban Bengaluru which have installed RWH systems to understand the perception and attitude of households on water conservation and water savings with the help of scheduled questionnaires. The study was conducted in Bangalore from December 2019 to May 2020 and based on discussions with the officials of the BWSSB, the area for the survey was identified.

A structured questionnaire covering various aspects on perceptions, usage, problems, cost incurred on installing RWH, maintenance costs, water savings, house area, features of the roof were designed and canvassed. This study only included the independent houses in Bengaluru Urban which have installed DRWH after the BWSSB mandate in 2009. The rented houses and apartment complexes did not fall under the scope of this study.

There are 54 responses from houses with RWH installed and respondents are residents of independent houses from East Bengaluru. Random sampling was used to include the households which are engaged in RWH harvesters and the list was provided by BWSSB and all the houses in the sample have installed RWH systems after the water conservation policy of BWSSB was announced in 2009. Statistical and econometric tools are used for analysis and the software package STATA was used for the data analysis. The study uses cross-sectional data to assess the impact of independent variables on the dependent variable and anecdotal evidence also reveals into the working and shortcomings of the system.

Conceptual Framework

The water conserved by the houses that adopted RWH systems depends upon several technical and non-technical factors. The amount of water conserved is the result of the set of attributes of the technology and socio-economic characteristics of the respondent households. The household's water conservation function takes the form as expressed in equation 1:

$U_i=V(T, S_i) + e(T, S_i)$ ………………………… (1)

Water conservation potential depends on the attributes of the chosen form of RWH (T) and the socio-economic variables (S_i) of the respondent household 'i'. Utility U is comprised of a deterministic component (V) and an error component (e) which follows a predetermined distribution.

Empirical Model

The OLS regression method is used for data analysis and the empirical model used is specified in equation 2.

$WC_i= \alpha + \beta_1 AoH_i + \beta_2 CA_i + \beta_3 NoR_i + \beta_4 SoW_i + \beta_5 COSTINSTAL+ \beta_6 AI+ \beta_7 DToR +\mu_i$ …(2)

Dependent variable WC_i is the amount of water Conserved by the household 'i' in the year 2019-20 and it is a product of Average Precipitation (2019-2020)[3] in Bengaluru, the Rooftop

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[3] According to BWSSB, the average annual rainfall in Bengaluru Urban has been 929 mm with 57 rainy days (Directorate of Economics & Statistics, 2018).

area of the house concerned and Efficiency factor[4] of the tank which depends upon the slope of the roof (Abdulla & Al-Shareef, 2009;Dadhich & Mathur, 2016)

The independent variables in the model and their probable effect on the dependent variable are explained in table 2.

Table 2: Definition of explanatory variables in the model

Variables	Expected Sign	Explanation
AoH- Area of the house in sq. m	+	Larger the area of the house, the RWH system is also large.
CA- Catchment Area of RWH in sq. m	+	Larger the catchment area, larger is water conservation so it is expected to have a direct relation with the dependent variable.
NoR- Number of Residents	-	More the number increase the demand for water. The relation between the number of residents and water conservation is expected to be direct.
SoW- Number of Sources of Water	-/+	Number of sources of water. This can have either direct and inverse relation with the dependent variable. More sources of water provide water security so the necessity to conserve water is less and the relation of this variable on water conservation is expected to be inverse. Whereas dependence on a greater number of sources increases water expense and house owner have more incentive to install RWH systems to reduce water bills.
COSTINSTAL- Cost of Installation of RWH structure	-/+	Bigger systems can capture more water and enable recharge of higher quantity and the cost of installation also will be higher.
AI - Annual Income of the household	+	Annual income of the household can influence the adoption of the RWH as there are installation costs and maintenance costs.

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[4] It varies between 0 to 1 depending on the type of roof and. It is 0.5 for green grass roof and flat roof is taken as 0.8 and sloped roof as 0.9. The infiltration, evaporation and other losses of rainwater is less in case of sloped roofs compared to that of flat roof and grass green roof.

DToR - Dummy variable signifying the slope of the roof	+	Roof type is taken as a dummy variable. The grass green roof is taken as 0, the flat roof is taken as 1, and the sloped roof as 2. It is expected to have a direct relation to water conservation.

The descriptive statistics of explanatory variables in the model given in the table 3 explain that variables annual Income (AI) and costs of installation (COSTINSTAL) show high standard deviation. Also, area of the house (AoH) varies from 600 sq. ft to 3600 sq. ft and the number of residents varies from house to house. Number of Residents (NoR) in the household also determines the size of RWH system and scale of use and in the sample, it varies from one to ten. All this throws light on the unequal pattern of water consumption between houses. The sources of water varied from one to three which are Cauvery water, bore wells, paid tankers other than the rainwater harvesting systems. Cost of installation varied from one household to another on the basis of size materials, labor cost etc. and also with the technique of RWH adopted by the household. Underground recharge technique is the least costly method and is probably one of the reasons why it is popularly adopted among harvesters of rainwater. The catchment area which is one of the technical determinants of water conservation potential is 89.5 and it varies according to the size of the house and type of roof another technical determinant is a dummy variable.

Table 3: Descriptive statistics of variables used in the model

Variable	Mean	Std dev	Min	Max
WC	66299.63	33861.7	13377.6	167220
AoH	1625.963	617.3694	600	3600
CA	89.5556	38.69263	18	200
NoR	4.1851	1.759868	1	10
SoW	1.7407	.6496787	1	3
COSTINSTAL	23907.41	27635.95	3000	200000
AI	709500	186775.8	100000	1300000
DToR	.8704	.3390495	0	2

Results and Discussion

The focus of the study is to find the determinants which influence the annual water conservation potential of rainwater systems in the houses which installed them. In the empirical model, we have categorised the determinants as the technical and non-technical factors which influence the dependent variable. Area of the house (AoH), number of residents in the house (NoR), sources of water (SoW), Cost of Installation (COSTINSTAL), and Annual Income of the household (AI) are the non-technical factors used in the model. The technical determinants are catchment area (CA) and type of roof (DToR). The variable Storage Capacity of the Tank (SCT) was dropped from the empirical model because of the high positive correlation it had with the catchment area.

Table 4: OLS Estimates of the model

Independent Variables	Coefficient (t-statistics in bracket)	Standard Error
AoH	2.51** (2.27)	1.1069
CA	782.55*** (41.6)	18.7768
NoR	-306.54 (0.89)	345.7066
SoW	2278.41** (2.22)	1025.268
COSTINSTAL	.0192 (0.81)	.0238
AI	.0027 (0.83)	.0033
DRoof	20270.55***(11.41)	1776.133
CONSTANT	-26716.75 (-6.8)	3931.375
R-squared	0.8048	
Adjusted R-squared	0.8007	
Observations	54	

**indicates significance at 5% and ***indicates significance at 1%

The results of the OLS regression model are given in the table 4 and area of the house emerges as a significant factor at a 5% level of significance and one sq ft increase in the area of the house will increase water conservation by 2.51 liters per year. The number of water sources is also significant at a five percent level of significance. More the number of sources of water more the water conservation, this incentivises the household to install water conservation. The catchment area and type of roof are the independent variables that are significant at 1 percent. These two are technical factors that influences the dependent variable. The number of residents in the house (NoR), cost of installation (COSTINSTAL), and annual income of the household (AI) has shown the expected signs but were statistically insignificant.

Table 5 reveals that the houses in the sample had significant savings as the expenditure on the water before and after installation shows a difference. The average annual saving per household using RWH system is nearly 13.76%.

Table 5: Water Expenditure[5] and savings (Before and After Installing Rooftop RWH)

Average annual expenditure on water before installation	₹ 7,975.00
Average annual expenditure on water after installation	₹ 6,794.12
Average annual savings on water expenses after installation	₹ 1129.66

Rainwater harvesting deliver public and private benefits. One way for private benefits to get attention is to publicize them. Public benefits are valued less than private benefits. When an investor makes an investment in such a good with public benefits, she/he always fears free riding and assurance problems which are associated with public benefits of the good. The private benefits of RWH are reflected in the average annual savings in the water expenditure. Individual households may be reluctant to respond to public benefit however they will definitely respond to savings in water expenditure and this will result in further adoption of RWH systems. Technology is an experience good and prior to purchase or use, consumer is unaware of its uses. Buyers of experience goods feature learns the product's attributes after buying and consuming (Benz, 2007). Thus, positive feedback and experience of consumers can be used for further consumption of the product. So, this kind of sustainable technologies which

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[5] This only include water for purposes other than drinking.

ensures water conservation along have to be incentivized along with the imposition of RWH through regulation by a government body. Harvesters of rainwater do not receive any incentive or subsidy from BWSSB for the installation of the structure as it is not feasible for the board since it provides water at a subsidised rate for the entire population in Bengaluru.

Limitations of the study

Some limitations of the study are also worth mentioning here. The size of the sample used for this study is a small fraction of the large population of Bengaluru and only those who adopted RWHs are taken into consideration. It will rather be bold to make assumptions based on a very small sample. This study only focuses on independent houses and the findings cannot be generalised for apartments that are having a burgeoning growth in the city.

Conclusion

Technology is an experience good; people might be inhibited to adopt them due to several institutional, psychological, and financial barriers. After the adoption only they will be able to realise the gains of the technology. Post-use phase the adopters can become agents of change and promoters of the technology. Mandatory policy adopted by BWSSB led to the adoption of the RWH technique in many households in Bangalore. The percent of voluntary adoption of the RWH technique is limited but as this being an experience good, testimonies and feedback of adopters can influence the non-adopters, reluctant adopters, etc. Post-use evaluation, attending maintenance, follow-up, and feedback mechanisms by BWSSB can instil confidence in the general public and can help in maximising the gains of the RWH technique. Adopters quickly respond to private benefits like a reduction in water bills. A mandatory policy can be made effective by proper awareness mechanisms and the dissemination of information on the adoption of the technique. The promotion of a conducive environment for the expansion of the RWH technique has to be supplemented with demonstration programs, provision of soft loans for households to cover more potential beneficiaries.

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