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   FACTORS OF BIOLOGICAL CONTAMINATION OF HARVESTED RAINWATER FOR RESIDENTIAL CONSUMPTION

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Abstract:

The purpose of this study was to examine the factors affecting the biological contamination of rainwater harvested from the rooftops of single-family residences in Bryan and College Station, Texas. It was conducted to identify the presence of total coliform bacteria and turbidity, and the factors that affect the presence of such contaminants in rainwater collected from rooftops for the purposes of potable and non-potable uses. Samples of rainwater were collected in sterilized containers from sixty randomly selected residences, thirty each with metal and asphalt shingle roofs, on ten different rainfall days. The data was analyzed using multiple and probit regression techniques. The results from the study indicated that the level of turbidity in roof rainwater runoff was directly affected by the area of the roof and by the period of dry spell. It was also found that the intensity of rainfall greatly affected the presence of total coliforms in the harvested rainwater. The findings of the study would facilitate effective design of rainwater harvesting systems for residential buildings through specification of the level of treatment and quantification of water to be diverted as first flush.

Key words: Construction Technology, First Flush, Rainwater Contamination, Rainwater Harvesting, Residential Design.

Factors of Biological Contamination of Harvested Rainwater for Residential Consumption

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Statement of the Problem

Water is essential for all forms of growth and development and is a fundamental basic need for sustaining human economic activities. Availability of water in the desired quantity and quality is extremely important for the survival of everybody Increase in human population, economic growth, and a desire for high standards of living will increase the demand for large sources of clean water ((Vasudevan & Pathak, 2000). Water is a renewable source but its availability is limited. Increasing water demands has led to crisis situations in many parts of the world and the amount of water being consumed has exceeded the annual amount of renewal, creating a non-sustainable situation. It is projected that Texas will face water shortage in the coming years (Varma, 1986). Although Texas has a large amount of groundwater, more of it is used annually than is replenished by recharge. Groundwater used in 1980 was 10.8 million acre-feet; this exceeds the average annual effective recharge rate by some 5.7 million acre-feet (Knowles, 1982).
Rainwater harvesting has been practiced since the early days of civilization. It is the principle of collecting and using precipitation from a catchment area (Pacey & Cullis, 1986). The system involves collection, storage and use of rainwater. The use of rainwater to satisfy the domestic demand is very attractive because of the independence from centralized distribution systems which are beginning to restrict volumes of water usage to individual usage, the low mineral content and high quality of rainwater prior to collection and the economics of rising water costs (Lye, 1998). This technique can be used to satisfy the complete domestic water requirements of single-family residences based on average rainfall of an area. A reinvention of the system is witnessed in many parts of the world as an alternate source of water due to the great emphasis on water conservation and quality (Woods & Choudhury, 1992). Since 1996, rainwater harvesting has received renewed interest in the United States in the areas of rural and urban residential and small to medium commercial construction (Lye, 1998). The gradual depletion of groundwater sources, the average annual precipitation in Texas, the flexibility of the system, and the modern methods of treatment provide an excellent opportunity to harvest rainwater for domestic use. Biological contamination of drinking rainwater may occur from water pollution by faecal waste and excreta of various animals (Vasudevan & Pathak, 2001). It is important to ensure that the harvested rainwater meet the drinking quality standards.

Current sentiment is to classify collected rainwater as a type of raw surface water (Lye, 1998). Rainwater could get contaminated by the roofing materials, overhanging trees, debris collected on roofs, bird droppings all could cause sediment deposit in rainwater. The storage tanks could be a source of pathogens and contaminants if not designed or maintained well (Roofwater Harvesting Research Group).

This study was conducted to identify the presence of biological contaminants particularly total coliform bacteria (TCM) and turbidity and the factors responsible in rainwater collected from rooftops of buildings in Bryan and College Station, Texas. The coliform test has generally been considered as a reliable indicator of the presence of pathogens that cause water-borne diseases (DeZuanne, 1990). Turbidity is considered to be a microbiological parameter because it may harbor pathogens. Low turbidity can be correlated with low level of bacteriological contaminants before bacteriological examination (DeZuanne, 1990).

The purpose of this study was to examine the factors affecting the level biological contaminants in rainwater collected from the rooftops of single-family residences for Bryan and College Station in Texas.

Hypotheses

1. The level of total coliform bacteria in rainwater collected from the rooftop of single-family residential dwellings is affected by dry spell, catchment area, intensity of rainfall, and type of roof material.
2. The level of total turbidity present in rainwater collected from rooftops collected from the rooftop of single-family residential dwellings is affected by dry spell, catchment area, intensity of rainfall, and type of roof material.

Definition of Terms

1. Catchment area: Net roof surface, in square feet, from which rainwater is collected.
2. Potable water: Water that is fit for human consumption
3. Water quality standards: The quality standards that are set by the Safe Drinking Water Act (SWDA) of 1996 promulgated by the Environmental Protection Agency
4. Dry Spell: Number of days since it rained last.
5. Effective Roof Area: Area of the roof in square inches that is served by the downspout from where samples are collected.

Limitations

1. This study was confined only to single-family residential dwellings with guttered roofs in Bryan and College Station, Texas.
2. This study was confined to single-family residential dwellings with sloping roofs.
3. This study was confined to single-family residential dwellings without tree cover over the rooftops.

4. The study was confined only to biological contaminants in rainwater harvested from the rooftops.

Methodology

Data Collection

A total number of 60 (sixty) single-family residential dwellings in Bryan-College Station, Texas were randomly selected for the purpose of the study—30 (thirty) with asphalt single roofs and the other 30 (thirty) with metal roofs. The roofs for all the buildings in the sample were sloping with roof drains and downspouts for ease of rainwater collection. A total of sixty samples were collected on ten 10 (ten) different rainfall days. The different between two consecutive rainfall days was measured as a dry spell. Thirty samples were collected from dwellings with metal roof and the other thirty samples were collected form dwellings with asphalt shingle roofs. The samples were collected in standard 100 ml sterilized bottles provided by the laboratory that conducted the tests. The samples were tested to identify the presence of total coliform bacteria and turbidity in the collected rainwater.

The roof area covered by each downspout was calculated using the total area of the roof of a dwelling and the total number of downspouts that served that particular roof. Data on the intensities of rainfall during the period of sample collection was obtained from the meteorological center located at the Easter wood airport in College Station, Texas and from the web page on private weather stations, www.weatherunderground.com.

Variables

Total Coliform Bacteria (TCB)

It is an indication of the microbiological quality of water and indicates the presence of bacteria in the water sample. Standards require potable water to be completely free of TCB. It is a dummy variable and was operationalized by assigning a value of 1 when coliform bacteria was present in a sample, and value of 0 if there was no such bacteria in the sample.

Turbidity (TURB)

Turbidity is the measure of the fine suspended matter in water, mostly caused by colloidal matter. It was measured using nephelometric turbidity unit (NTU).

Roof Type (ROOF)

It indicates the material used for the construction of the dwellings included in the sample. It is class variable having two classes: (1) Asphalt and (2) Metal.

Roof Area (AREA)

It is the area of the roof that is served by one downspout for roof drainage. It was measured in squared feet.

Intensity of Rainfall (RAIN)

It is rate at which it rained at the time when the rainwater samples were collected. It was measured in inches.

Dry Spell (DRY)

Dry spell is the number of dry days between two consecutive rainfall events. It was measured in number of days.

Results

Hypothesis 1

The level of total coliform bacteria in rainwater collected from the rooftop of single-family residential dwellings is affected by dry spell, catchment area, intensity of rainfall, and type of roof material.

The hypothesis was tested using probit regression analysis with stepwise option. This is a useful statistical tool for studies dealing with dichotomous dependent variables. It provides a Chi-Square value of the predictor variables that is useful for interpreting the relationship of these variables with a dichotomous dependent variable. The value of the Chi-Square is checked against a critical value at a specified statistical level of significance. Regression analysis is a modeling technique for identifying a function that describes the relationship between a dependent and one or more independent variables. A stepwise procedure searches for the “best” model by selecting independent variables that are statistically significant at a specified *p*-value. The following model was used for the analysis:

$$TCB=\beta_0+\beta_1 TYPE+\beta_2 AREA+\beta_3 RAIN+\beta_4 DRY+\xi \qquad (1)$$

where β_0 = intercept,
$\beta_1, \beta_2, \beta_3, \beta_4$ = regression coefficients, and
ξ = error term in the model.

The results indicated that out of the four independent variables, only intensity of rainfall (RAIN) has a statistically significant effect on the total coliform content (TCB) of collected rainwater.

The results of the analysis are shown in Table 1.

Table 1

Summary of Probit Regression Analysis for TCB

Parameter	Degree of Freedom	Regression coefficients	Chi-Square	*p*>Chi-Square	Critical value of Chi-Square *p*<=0.5
Intercept	1	-2.3787	20.9497	<0.0001	3.84
RAIN	1	3.2465	12.2858	0.0005	

The results indicate that the Chi-Square statistic for rain was much higher than the specified critical value at the level of significance of 0.05. This indicates that the level of total coliform bacteria present in rainwater collected from a roof catchment increases with the intensity of rainfall. None of the other predictor variables included in the model has any effect on the presence of total coliform.

Hypothesis 2

The level of total turbidity present in rainwater collected from rooftops collected from the rooftop of single-family residential dwellings is affected by dry spell, catchment area, intensity of rainfall, and type of roof material.

The hypothesis was tested using a General Linear Model with roof type (ROOF) as a class variable. The following model was used for the analysis:

$$TURB=\beta_0+\beta_1(TYPE)+\beta_2(AREA)+\beta_3(RAIN)+\beta_4(DRY)+\xi \quad (2)$$

where β_0 = intercept,
$\beta_1, \beta_2, \beta_3, \beta_4$ = regression coefficients, and
ξ = error term in the model.

The results of the analysis are shown in Table 2.

Table 2

Summary of General Linear Model Analysis for TURB

Variable	Intercept	Regression coefficients	*T*	*p*>|*T*|	Critical value of |*T*| @ *p*<=0.5
Intercept	-6.9362		-2.63	0.0111	2.39
DRY		0.4895	9.41	<0.0001	
RAIN		3.4551	1.07	0.2891	
AREA		0.0104	4.99	<0.0001	
ROOF		1.7557	0.82	0.4139	
F-value of the model			p>F		Model R^2
28.68			<0.0001		0.67

The *F*-value of the model used for the multiple regression analysis was found to be statistically significant at a level much lower than 0.05. This statistic basically tests how well the model, as a whole, accounts for the dependent variable's behavior. The predictive efficacy of the model was found to be moderately high with an R^2 of 0.67. The larger the value of R^2, the better the fit of the model, and higher is its predictive efficacy.

The results indicated that turbidity (TURB) present in rainwater collected from a roof catchment is affected by only dry spell (DRY) and roof area (ROOF) at the level of significance of less than 0.0001. Longer the period of dry spell and larger the area of roof, the more is the quantity of suspended particles in collected rainwater.

Conclusions

The results from the study indicate that the level of turbidity in roof rainwater runoff is directly affected by the area of the roof and by the period of dry spell. The longer the dry period in between rainfall events, greater is the amount of turbidity in the rainwater. Larger the roof area, higher will be the level of turbidity in the water collected. Rainfall intensity does not affect the level turbidity in the roof run-off. The study does not show any evidence of the effect of roof type, in terms of material, on either turbidity or on presence of total coliform bacteria. The results from the total colifrom tests indicate that the intensity of rainfall greatly affects the presence of total coliforms in the run-off. More the intensity of rainfall, the more efficient is the cleaning process and greater is the presence of pollutants in the run-off. The binary nature of the results of the total coliform test has made it difficult to show conclusively the effects of the predictor variables.

The reliance on ground water has been rapidly increasing to meet our increasing demands. There has been a great increase in municipal and industrial requirements that will be expanding even more in future. Most of the water needs in the Texas come from ground water supplies. More of it is used everyday than is replenished by recharge. It is, therefore, necessary to explore possibilities and alternate sources needed to cope with water shortage problem. Rainwater harvesting seems to be an excellent alternative.

For rainwater to be used as a potable source of water supply, it is imperative that it meets all the standards developed by the Environmental Protection Agency. Once rain comes into contact with a collection system it could become biologically contaminated (Todd & Vittori, 1996). It thus becomes necessary to quantify the presence of pollutants in rainwater from catchment areas and to identify the reasons behind the presence of these pollutants. This study examines and identifies the factors that affect the level of biological contamination of harvested rainwater. The treatment facilities when constructing building structures with rainwater catchment facilities can be optimized based on the findings of this study. This results of the study will hopefully help in designing appropriate and economical treatment systems based on the design factors identified that effect the quality of rainwater using the roof as a catchment surface. The study indicates that roof material does not have any affect the level of on total coliforms and turbidity present in collected rainwater. Therefore, design of treatment systems for rainwater collected from different types of roofs may be the same. The study also indicates that dryness of roof affects the level of turbidity, signifying the importance of first flush to be rejected and not as potable water. Since roof size is factor that affects turbidity, it will be necessary to increase the efficiency of a rainwater treatment system with increase in roof area per down spout.

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