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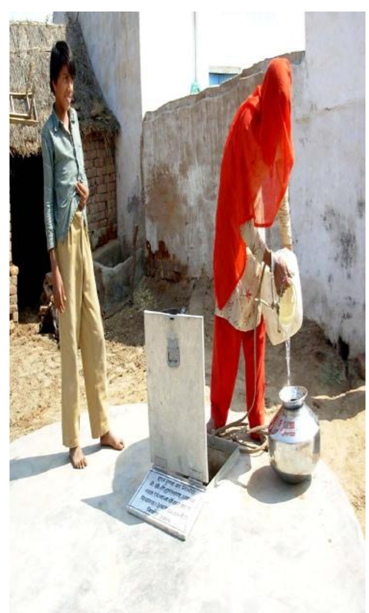
A STUDY ON RISK ASSESSMENT OF DOMESTIC ROOF WATER HARVESTING PROJECT IN CHURU DISTRICT OF RAJASTHAN USING FAILURE MODE AND EFFECTS ANALYSIS (FMEA) FRAMEWORK.





Introduction to the Authors

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Dr. Monika Chaudhary has a background in Economics and Finance. She has done Masters in Economics, MBA in Finance and Ph.D in International Trade and Finance from University of Rajasthan. She is a National Scholarship holder and was selected for Rajasthan State Administrative Services. She has presented research papers in National and International conferences and has won awards. She has worked in the area of Exchange Rate Forecasting, Public Expenditure on Health and Education and Water and Sanitation. She has done Corporate Consultancy in the areas of Capital Restructuring. She has published various articles in magazines and Journals.

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Mr. Goutam Sadhu, PGDRD, MBA, DHSM (Israel) is specialized in Water, Sanitation, Health, Community management and NGO management. He was trained in designing and training methodology in International Resource Center, Netherlands and Health System Management from Galileo College, Israel. He has more than two decade of long experience in successfully implementing the community based project, designing and conducting training programme for senior and middle level civil servant and NGOs. He has contributed towards policy design, planning (micro planning), program implementation. He is also been associated with CAPART as a Monitor, and has been consultant in different projects funded by national and international agencies. He has been honored with several prestigious awards. Mr. Sadhu has presented several papers on water and health in international and national conferences. His current research and teaching interests are in the application of community based model in the area of water, sanitation and in public health.

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Manglika Tripathi is a Post Graduate in Health Management and has worked in the areas of Reproductive Child Health, HIV AIDS and Water and Sanitation. She is currently associated with Institute of Health Management Research (IIHMR) as Project Officer for Roof Top Rain Water Harvesting Project in partnership with Safe Water Network USA in Churu District of Rajasthan. She earlier worked with Hindustan Latex Family Planning Promotion Trust (HLFPPT) as State Program Officer for 1 year under Female Condom Social Marketing Program funded by NACO and with National Rural Health Mission for 2 years as State consultant Village Health Planning.

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1. Introduction :

Rainwater harvesting is the accumulating and storing, of rainwater. Rainwater harvesting' is a widely used term covering all those techniques whereby rain is intercepted and used 'close' to where it first reaches the earth. Arrangements to cause rainfall to percolate the roof (as a form of flood control) into the constructed small reservoirs which captures the run-off water so that it can be used for cattle or micro-irrigation. Thus, roof water harvesting is a subset of rainwater harvesting, albeit an important one.

Domestic Roof Water Harvesting (DRWH) provides an additional source to meet local water needs. In recent years,DRWH systems have become cheaper and more predictable in performance. Rainwater harvesting systems deliver water directly to households, relieving the burden of water carrying, particularly for women and children. This labour saving feature is especially crucial in communities where households face acute labour shortages or their man-hours can be used in a productive outcome.
The DRWH technique is approaching maturity and has found its major applications where:

- Other water techniques are less effective, for example due to deterioration in groundwater sources.
- Water collection drudgery is particularly severe.

In India, DRWH has been strongly linked with aquifer replenishment programmes. Elsewhere it is seen as an attractive technique, in part because it fits with the decentralization of rural water supply and is suitable for household management.

DRWH is reasonably priced technique that is 'affordable to the beneficiaries'. Providing domestic water in rural areas via 'point sources', such as protected shallow wells, springs, boreholes and gravity schemes, DRWH gives a better water service than do point sources, because it entails no fetching or queuing.

2. Purpose of the Study

The purpose of this study is to do a Risk Assesment Study and presnt the result in a form, suitable for practitioners to apply directly. The objective of this study is to assist NGO and government staff responsible for implementing domestic roofwater harvesting systems or programmes. Finally, it could be used by individual householders or masons literate in local language to design single roofwater harvesting systems.

3. Methodology

This study was done in two stages –

3.1 First Stage – In the first stage the primary data was collected from 40 villages of churu district. The nature of data was technical as well as non technical. Data pertaining to water quality, available infrastructure and practices was technical in nature. Data pertaining to economic status of people, their paying capacity and behavioral practices was non technical in nature. Technical data was collected by technical tools and non technical data was collected by structed schedule.

3.2 Second Stage – In the second stage the technical and non technical data was tabulated and recorded. An analysis of this data was done on FMEA framework.

4. FMEA method:-

A failure modes and effects analysis (FMEA) is a procedure in product development and operations management for analysis of potential failure modes within a system for classification by the severity and likelihood of the failures. *Failure modes* are any errors or defects in a process, design, or item, especially those that affect the customer, and can be potential or actual. *Effects analysis* refers to studying the consequences of those failures.

Step 1: Severity

The first step is to determine all failure modes based on the functional requirements and their effects. In this case the failure mode is taken as a risk factor in rain water harvesting . A failure mode in one component can lead to a failure mode in another component; therefore each failure mode should be listed in technical terms. Also, the ultimate effect of each failure mode needs to be considered. A failure effect is defined as the result of a failure mode on the function of the system. In this way it is convenient to write these effects down in terms of what one might see or experience. In case of RWH, if we take the example of failure effect as the presence of fluoride in water. The severity of this risk can be judged on the basis of given parameters :-

Table 1: Rating of severity of effect of risk factors.

Rating	**Severity of Effect**
10	May result in a complete disruption of the system permanently
9	May result in a partial disruption of the system permanently
8	Project turns unviable due to financial constraints
7	May result in a complete disruption of the system temporarily
6	May result in a partial disruption of the system temporarily
5	Water contamination resulting in serious illness
4	Water contamination resulting in a mild illness
3	Large impact on efficiency of the system
2	A little impact on the efficiency of the system
1	Little to no impact

Each effect is given a *severity number (S)* from 1 (no danger) to 10 (critical). These numbers help to prioritize the failure modes and their effects. If the severity of an effect has a number 9 or 10, actions are considered to change the design by eliminating the failure mode, if possible, or protecting the user from the effect. A severity rating of 9 or 10 is generally reserved for those effects which would cause injury to a user or otherwise result in litigation.

Step 2: Occurrence

In this step it is necessary to look at the cause of a failure mode and how often it occurs. This can be done by looking at similar products or processes and the failure modes that have been documented for them. A failure cause is looked upon as a design weakness. All the potential causes for a failure mode should be identified and documented. Again, this should be in technical terms. For example if the cause is taken as Nitrite content in water. A failure mode is given an *occurrence ranking (O)* between 1–10. Actions need to be determined if the occurrence is high (meaning > 4 for non-safety failure modes and > 1 when the severity-number from step 1 is 9 or 10). This step is called the detailed development section of the FMEA process. Occurrence also can be defined in percentage. If a non-safety issue happened less than 1%, we can give 1 to it. It is based on your product and customer specification.

Table 2: Rating of occurrence of severity

Rating	Chance of Occurrence in percentage terms
10	90
9	80
8	70
7	60
6	50
5	40
4	30
3	20
2	10
1	0.0005

Step 3: Detection

When appropriate actions are determined, it is necessary to test their efficiency. In addition, design verification is needed. The proper inspection methods need to be chosen. First, the current system should be examined, that prevent failure modes from occurring or which detect the failure before it reaches the customer. Next one should identify testing, analysis, monitoring and other techniques that can be or have been used on similar systems to detect failures. From these controls it can be learnt how likely it is for a failure to be identified or detected. Each combination from the previous 2 steps receives a *detection number (D)*. This ranks the ability of planned tests and inspections to remove defects or detect failure modes in time. The assigned detection number measures the risk that the failure will *escape detection*. A high detection number indicates that the chances are high that the failure will escape detection, or in other words, that the chances of detection are low.
After these three basic steps, risk priority numbers (RPN) are calculated.

Table 3: Rating of likelihood of detection of severity.

Rating	Likelihood of Detection
10	Absolutely uncertain that failure will be detected
9	Very remote chance that failure will be detected
8	Remote chance that failure will be detected
7	Very low chance that failure will be detected
6	Low chance that failure will be detected
5	Moderate chance that failure will be detected
4	Moderately high chance that failure will be detected
3	High chance that failure will be detected
2	Very high chance that failure will be detected
1	Almost certainty that failure will be detected

Risk priority number (RPN)

RPN does not play an important part in the choice of an action against failure modes. They are more threshold values in the evaluation of these actions.
After ranking the severity, occurrence and detectability the RPN can be easily calculated by multiplying these three numbers: RPN = S × O × D
This has to be done for the entire process and/or design. Once this is done, it is easy to determine the areas of greatest concern. The failure modes that have the highest RPN should be given the highest priority for corrective action. This means it is not always the failure modes with the highest severity numbers that should be treated first. There could be less severe failures, which occur more often and are less detectable.
After these values are allocated, recommended actions with targets, responsibility and dates of implementation are noted. These actions can include specific inspection, testing or quality procedures, redesign (such as selection of new components), adding more redundancy and limiting environmental stresses or operating range. Once the actions have been implemented in the design/process, the new RPN should be checked, to confirm the improvements. These tests are often put in graphs, for easy visualization. Whenever a design or a process changes, an FMEA should be updated.

This can be done by following ways :

- Try to eliminate the failure mode (some failures are more preventable than others)
- Minimize the severity of the failure
- Reduce the occurrence of the failure mode
- Improve the detection

5. Components in Roof Water Harvesting System :-

The basic roof water harvesting system :- Rain falls onto roofs and then runs off when there is no rainfall run off flow is zero. However if the run-off is channelled into a water storage tank or jar, water can be drawn from that store whenever it is needed even months after the last rainfall. Moreover, as the water storage tank is generally located next to the building on the roof of which rain fell on, roof water harvesting is used to supply water to that very building. This abridged the chances of going out to fetch water.

The roof :- To be ‘suitable’ the roof should be made of some hard material that does not absorb the rain or pollute the run-off. The larger the roof, the bigger the run-off flow. In case of small roof, either the roof must be extended, or roof water harvesting can only be one of a number of sources of drinking water to meet the need.

The water-store :- A RWH system with a large water store will perform better than one with a small store. A small store such as a 500-litre water storage tank will often overflow in the wet season wasting up to 70% of the annual run-off. It will also run dry before the end of the dry season.

a) **Very cheap system** (e.g. only 250-litre store)
   Annual water yield in litres=25% of annual rainfall (mm) x roof area (sqmeters)
b) **Cheap system** (e.g. 1,000-litre store)
   Annual water yield in litres = 40% of (annual rainfall x roof area)
c) **Normal system** (e.g. 5,000-litre store)
   Annual water yield in litres= 65% of (annual rainfall x roof area)
d) **Expensive system** (e.g. 15,000-litre store)
   Annual water yield in litres = 85% of (annual rainfall x roof area)

Guttering :- The arrangement for leading water from the roof to the water store is usually called ‘guttering’ or ‘gutters and downpipes’. Gutters are open channels carrying water sideways under the edge of the roof to a point just above the water storage tanks.

6. Risk assessment of domestic roof water harvesting

Table 4 : Risk assessment of domestic roof water harvesting

S. No.	Risk variables	Potential effect of failure	Potential causes of failure	Recommendation
A	**Water Quality**	• Rainwater itself is of excellent quality and is only surpassed by distilled water-it has very little contamination, even in urban or industrial areas, so it is clear, soft and tastes good. Contamination however, is introduced into the system, after the water has fallen on to a surface. The primary means of tank contamination is through water washed in from the roof, although the main reason for most outbreaks of reported disease is direct entry to water in the tank either via a vector, such as a rat, lizard or insect, or because of an accident. • Water quality is detoriated by the presence of some chemicals like nitrite ,fluoride. Nitrite content in water is a result of leakage in sewage line , the water of the sewage tank contaminates the water in drinking water tank as a result of which people get water-borne diseases like diarrhea, blue baby syndrome. • It was noticed that water has fluoride contents in it which causes	• Water quality is detoriated by contamination of water,nitrite is found in water if there is a leakage in either drinking water tank or the sewage tank and both the tanks are adjoining. • Ph value of water decreases as water contains toxic metals. • Presence of bcteria like e-coli in water causes bloody diarrhea.	• Treatment of water using water filters, chlorination etc. • Finding the source and trying to stop the contamination and treatment of water.

		dieases like fluorosis and premature aging. Soil content in water causes congenital disorder • Water with a low pH (< 6.5) could be acidic, soft, and corrosive. Therefore, the water could contain metal ions such as iron, manganese, copper, lead, and zinc...or, in other words, elevated levels of toxic metals. This can cause premature damage to metal piping, and have associated aesthetic problems such as a metallic or sour taste, staining of laundry, and the characteristic "blue-green" staining of sinks and drains. More importantly, there are health risks associated with these toxins. The primary way to treat the problem of low pH water is with the use of a neutralizer. • Presence of E- coli in water, although harmless, produces a powerful toxin and can cause severe illnesses. Infection often causes severe bloody diarrhea and abdominal cramps; sometimes the infection causes non-bloody diarrhea.		
B	**Construction of an appropriate Tank**	• If a rain water tank is made near septic tank and there is a leakage in any of the tanks then there are chances of water contamination which can cause water-borne	• Poor construction causes failure in this case. • Non availability of tank space can also be a reason.	• The complete tank shall not be underground ; some part shall be above ground. Repair work

		disease.		needs to be done when required.
C	**Size and condition of roof**	• If the roof is thatched or made of mud and bricks, the rain water will pass through this thatched roof and will get contaminated and cause diseases. • If the roof is made of decaying material, it will decay soon and cause problem in the storage of water. • There are possibilities of having dead bodies of animals (like rat, frog, lizard etc)on the roof which will contaminate water.	• Size of roof is inappropriate because of the area of building. • Some people have thatched roof.	• Flushing off the first rain.
D	**Minimum requirement**	• The minimum requirement of roof for household differ from family to family , for small families less water is required so a small roof will do. For large families a large roof is required. • The guttering (guttering implies the pipe which connects the roof with the filter tank) should be proper; otherwise there will be problems in storing water.	• The roof and tank size is inappropriate. • Poor material is used for construction of gutter.	• Consultation with the expert before making the tank. • Cleaning of gutter pipes.
E	**Natural Calamity**	• Natural calamities like flood cause a lot of harm to the RWH system as there is overflow of water so the RWH tanks get contaminated. • Major earthquakes can damage the whole system of RWH. Although the tank will remain safe, the roof	• During floods the tanks overflow so the water gets contaminated. • At the time of earthquake the RWH system gets destroyed. • If there is no rain then this	

		will be destroyed. • When there is drought, the tanks remain empty so the system fails.	system fails.	
F	**Upkeep of tanks**	• In case of uncovered tanks above the ground, there are chances of the water getting contaminated by bird dropping , small children swimming in it and chances of mosquito breeding in it. • In case of an underground uncovered tank there are chances of water getting contaminated by bird dropping and mosquito breeding and as it is open so people can even fall into it in the dark.	• Keeping the tanks uncovered.	• Covering the drinking water tank.
G	**Filteration**	• Water which is not filtered properly is dirty and contaminated and causes diseases.	• Lack of use of proper filter techniques like using cloth to filter water	• Use of good water filter
H	**Economic Viability**	• Many people take loans for the construction of tanks through Microfinance and in the long run they are not able to repay it. • Low cost material used for construction also affects the quality of RWH tanks.	• Inability to pay the taxes.	• Loan shall be given after taking the guarantee from the person that he will be able to pay it back.

7. Self Supply vs Public Supply issues

Self Supply :- 'Self-supply' DRWH is quite common in the Shekawati region of Rajasthan. Especially in rural, households, if they possess suitably hard roofing, often collect roof water with a minimum of equipment like Earthen pots (Matka). From the study it was noted that in the humid tropics there are typically around 100 rainy days per year, although on some of these only a millimeter or two of rain falls, insufficient to fill a storage tanks The average rain fall in the project area was found to be more than 350 mm and hence the rain water harvesting can meet the households demand of 8 liter perday/per person for drinking and cooking.

Any programme to mainstream formal DRWH can build upon householders' experiences with informal DRWH, because this leads to an appreciation of rain- harvesting possibilities, some skill in managing a very limited supply and often a desire to 'upgrade' to a larger and more reliable system.
It is suggested that richer household DRWH can be an important precursor to any form of 11 publicly financed DRWH. It creates a market for both components and specialist installers and it offers a fashionable example for poorer householders to follow.

Public Supply :- Mainstreaming DRWH as a normal option (often as an alternative to further developing groundwater sources) within public or communal water supply poses special problems for water authorities. DRWH is not in its essence a collective solution which can be centrally managed. Nor is it usually suitable as a sole supply, because there is not enough roof area per person to generate a generous annual flow.
Far more than point sources like springs, wells and tap-stands, DRWH requires the cooperation of individual households. It is not easy to monitor water quality or even the quality of installations.

DRWH is generally so unattractive to the owners of private water companies that they have sometimes tried to get it prohibited. In general, a public-private cost-sharing approach is desirable,with households paying part of the cost of their own household systems. Indeed, it is an important attraction of DRWH that it empowers householders and encourages their investment in water infrastructure, putting their water supply on a similar footing to housing itself.

8. Quantity : How much water can be harvested

The quantity of water (Q) that runs off a roof into gutters, in liters per year, is fairly easy to calculate using the rough equation

$$Q = 0.85 \times R \times A$$

Where:
R is the total rainfall in millimeters in that year
A is the guttered roof area in squaremeters

0.85 is a 'run-off coefficient'. It takes into account evaporation from the roof losses between the roof and any storage tank; its value is around 0.85 for a hard roof in the humid tropics, where rain is often intense. It would be lower where rain falls as light drizzle and much lower for a thatched roof.

The amount of this run-off that can be actually delivered to a user by a RW system is U liters per year, where U is less than the run-off Q because the receiving tank sometimes overflows.

In fact $U = E \times Q$

Where E is the 'storage efficiency' (a number never greater than 1) with which we use the water that reaches the tank. This efficiency E varies with:
• the tank size(bigger is better but alsomore expensive)
• the climate (equatorial is best, having a long-dry-seasonis worst)
• the way water is drawn: a higher rate of demand means higher storage efficiency E and so more liters in total but lower reliability (fewer days' supply per year).

The storage efficiency (E) for all of them is usually between 0.4 and 0.8. Taking into account both the run-off coefficient and storage efficiency the water available to a household during a year is between one third and two-thirds of the rainwater falling onto the guttered part of the roof.

9. Conclusion

After doing the FMEA analysis we found the critical risk factors based on "Risk Priority Number" (RPN) scores. These critical risk factors can be managed by taking timely action and correct management decisions. The results of FMEA analysis can be used for further improvements in DRWH technology, including cost reductions, can be expected in the coming decade. *(For Details See Annexure A and B)*

1. **Rain water tank made near septic tank- (RPN- 245) -** Having a septic tank near a water tank is considered to be the highest risk factor. If the two tanks are constructed nearby then there is a chance of contamination of water which leads to increase in nitrite content in water resulting in causing water borne diseases. The reason behind making these tanks nearby may be lack of space. To reduce this risk the water tank can be reconsructed at a place which is at a minimum 10 feet distance from septic tank.

2. **Construction material used for construction of tank – (RPN- 240)-** Second highest risk factor is construction material used for construction of tanks if the construction material used is not of good quality then there may be a risk of failure of the complete system. To reduce this risk a solution has been sought by getting a cost effective construction design from IIT Delhi.

3. **Inability of the beneficiaries to repay the loan raised through Micro Finance – (RPN- 168) -** Inability of beneficiaries to repay the loan raised through Micro Finance is also one of the significant risk factor. If the beneficiary is unable to repay the loan then

the cost of the project will escalate making it financially unviable in some cases. Thus the project will be required to be shelved. However the research study has been done and efforts are being made to improve upon the design of MicroFinance

4. **Roof made of decayed materials- (RPN- 144)-** Another potential risk factor is roof made up of decayed material. If the roof is made of decayed material than there are chances of decaying of roof and the water will also get contaminated. There are chances of choking of gutter. To reduce this risk roof can be covered with a plastic sheet before harvesting or Galvanized Iron Sheets for roof can be used as it will ensure a clean and safe collection of Rain Water. Sensitization of beneficiary is also necessary to reduce this risk.

5. **Dirty and contaminated water- (RPN- 135)-** The chances of water getting contaminated increase at the point when the tank is full and water level touches the roof. There can be various reasons for water contamination like cleanliness status of the roof, upkeep of tank etc. To reduce this risk various steps can be taken like keeping the tank clean and covered , cleaning the roof, flushing off the first rain and using right kind of filter

6. **Nitrite content in water- (RPN- 135)-** It is seen that there is very high nitrite content in the water used in this area, which shows that the water source is near the septic tank or some human or animal waste is getting mixed in water which results in high nitrite. Nitrite in water causes water borne diseases, specifically blue baby symdrome. To reduce this risk the water source should at a place which is at a minimum 10 feet distance from septic tank.

7. **Fluoride content in water – (RPN- 120)-** Fluoride in water is a result of industrial waste and food or gutka getting mixed in water . Fluoride in drinking water results in causing diseases like fluorosis. To reduce this risk water should be filtered using Bone Char technique. Another important thing should be sensitization of people in such a way that food contamination in water is little.

8. **Faulty design of tank – (RPN- 112)-** Faulty design of tank may result in decaying of tank or less storage of water. To reduce this risk repair work and proper research on the technology of tanks should be done using Ferrocement tank design.

9. **Dead animals like mouse, lizard, frog etc on the roof- (RPN-100) -** If the dead animals like mouse ,lizards come to the tank along with water then there are chances of water getting contaminated. To reduce this risk roof needs to be cleaned before storing water and flushing off the first rain.

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