Identification of Acceptable uses of Rooftop Rainwater Harvesting to Facilitate Reclaimed Water Systems

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Abstract - *The study is done for assessment of Rooftop Rain Water Harvesting (RRWH) for non potable uses in a humid urban catchment. In this study, an user response survey was conducted, with 390 sample size, in five types of building uses; Residential, Educational, Medical, Institutional and mixed use Commercial, with variable roof sizes and situated in four different zones of KMA, having wide variation in piped water supply. A database of 32 years of daily rainfall data has been analyzed , in order to find out demand for different end uses for various building, supply from roof runoff, demand supply ratio, priority of different socio-economic factors for each type of building using AHP analysis, user's opinion on choice of end-use using regression analysis and finally developed a DSS model. Analysis also revealed that the highest acceptance of RRWH are in favor of the Medical uses building, the lowest being mix-Commercial building. Further factors like toilet flushing is found to be most potential end use options, followed by landscaping and cleaning. The regression model clearly show that the variables like ground condition, scale of development, degree of contact, storey's of building and water scarcity are key to decision making.*

***Key Words*: Roof top Rain Water Harvesting (RRWH), non-potable use, Decision support system (DSS), Analytical Hierarchy Process (AHP), End-use potential, Urban Local Bodies (ULB).**

1. INTRODUCTION

Historically water has been perceived as a plentiful resource and its availability and quality was not considered as major problems till first half of the last century (Cullet, 2009). As discussed in the previous chapter net amount of water requirement in the cities has been increasing day by day with the advent of urbanization. A large number of cities with even higher levels of water consumption and huge population base need more water than the neighbor non-urban area. A recent study shows that the total water consumed in 22 metropolitan cities of India was about 13014 mld (through formal supply system) for an estimated population of about 70 million. Water supplies in three largest cities Mumbai, Delhi and Kolkata (in municipal area only) was over 6600 mld for an estimated population of about 29 million (Mekala et al. 2008)

Cities have interwoven water supply network systems with its ecosystem that deliver water supply to a large dense settlement along with the floating population (Lee 2006, Hadsler et al. 2004). In the light of this, water demands may be broadly classified into domestic and non-domestic. Domestic demand includes potable and non potable uses like washing, cleaning and several others. Non-domestic use of water would include industrial, commercial and institutional uses, and water used for public purposes such as firefighting, street washing, and watering trees/public gardens etc. The real estate boom of this country had given rise to several water stressed region and West Bengal holds plenty of them (Shaban, 2008). The shrinking amount of fresh water resources had led to rise in cost of treated water supply (Gardner- Outlaw, Engleman 1997). Meeting that increasing water demand within geographical constraints has been proved to be a difficult task. Alternative water supply would be explored to meet the demand. This thesis work argues that the implementation of Rain Water Harvesting (RWH) at plot level has to be justified economically as well as socially and environmentally (Sharma, 2012).

1.1. Conventional Water Systems

Decision makers privileged water resources assessment is the first priority for providing the potential solution for shortages and deterioration of water resources. The assessment would identify the current status to plan and design the trend of water supply in coming years (Blunt, 2007). In the Twelfth Five-Year Plan (2012-2017), Norms fixed by the CPHEEO Manual (2010) was 135 lpcd (+ 15% for leakage) for the cities provided with piped water supply where sewerage system exists/planned. However the expenditure that the city incurs in bringing water to its people was high. A large share of the municipal budget for water supply is spent on the electricity bills for operation of pumps. A considerable amount of water is lost in course of transportation of water supply (Vijaya,2006). In this context it is worth to mention that rainwater runoff could supplement the conventional water supply to a large extent. The water bodies within city limits act as a catchment for rainwater and storm water runoff and further channelize them to rivers and underground water aquifers, which are primary sources of municipal water supply. All these had been neglected, desecrated and decimated – lakes and ponds willfully destroyed for land and groundwater over-extracted because there was no treated water for use (Flower et al, 2007). As per Development plan, KMA, 2005-2009, under KUSP current urban water system harvest large quantity of water from nearby and as well as remote surface water sources. At the same time ULB also delivers potable water to all urban potable and non potable uses and subsequently collects wastewater through piped network within its jurisdiction. Each city produces a large amount of wastewater which required to be transported to urban fringes for treatment for further discharging it to the surrounding environment. Large volumes of storm water were also generated within urban areas due to the increased imperviousness of urban catchment.

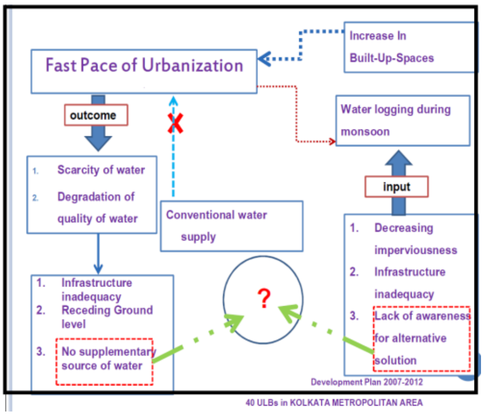

Fig. 1.1. Present water scenario in the Urban Local Bodies of Kolkata Metropolitan Area

Source: Development Plan 2007-2012, Kolkata Metropolitan Area

The majority of that storm water flows out of the urban area, with almost no planning and management. That large amount of low quality runoff could be reused for non-potable uses, if planned beforehand (Radcliff, 2003). As a result, the adverse impact of conventional urban water management on the water balance of these areas has been reported substantial (Mitchell et al., 1997; Mitchell et al., 2004).

1.2. Urban water supply issues

In most cities, water is collected from distant surface water sources and thereafter is transported to the city after treatment. It has been found that the supply of water has been only available for a few hours per day, with irregular pressure in most of the metropolitan cities in India (Shaban, 2008). In that process of bringing water from far and distributing it within the city, the length of the pipeline increases with directly proportionate to the cost of infrastructure and its maintenance. A standard indicator of inefficiency was the percentage of water accessibility by the citizen, does not reach to all parts of the city (McKenzie et al, 2009). In addition to the higher financial costs to the water utility, high levels of unaccountability of water has been a major issue in the supply of water, since leaks and illegal connections lower water pressure in the distribution system (Egunjobi, 1985). In India, the consequence of overstaffing, underpricing, high levels of unaccounted for water was that, most urban water utilities had been unable to cover even operating and maintenance costs out of revenues from tariffs, let alone provide capital for the expansion and improvement of the network (McKenzie et al, 2004). The analysis of cost was not computed or understood when cities map out the current and future water scenario. Data suggests that most cities spend anywhere between 30-50 per cent of their water supply accounts for electricity to pump water (Working Group on Urban and Industrial Water Supply and Sanitation for the Twelfth Five-Year Plan,2010). As the distance increases, the cost of installation and then maintaining the water pipeline and its distribution network also increases. The situation worsens with respect to increased water losses as a result of poor maintenance of the network. All these aspects results in authority to pay more for lesser amount of water supply. The end result was that, the cost of water increases and the state was not able to subsidize the supply of water to all (Hellstorm, 2000).

1.2.1. Water scarcity

Water shortage has become a serious problem all over the world (Zhou et al., 2008). According to Su et al 2005 rapid urbanization causes upliftment of social and economic development status, and henceforth an increasing requirement for water in industrial and commercial developments came into the picture (Falkenmark, 1997). Moreover climate change; a global phenomenon with impacts felt locally (Hein et al 2009) results in irregular precipitation patterns and temperature fluctuations, which further had impact on incomes (IPCC 2007). Sham et al, 1997 found that water scarcity evokes issues of environmental concerns, economic efficiency and social equity.

Demand for water was increasing to an extent since later half of the last century that it would not be available for basic requirements of individuals in another 40-50 years (UNEP, 2009). Short term major investments would therefore be required in for upgrade of ageing water mains and sewer systems in particular. In India water has been considered a highly subsidized commodity leading to market inefficiencies and hence inefficient use of the already scarce resource (Mekala et al, 2007). The urban water authorities, usually known as Water Supply and Sewerage Boards (WSSB), had been responsible for the city's water supply and sewerage services. Since urban water supply was subsidized, these institutions constantly incur losses and had no funds to invest in repairs and maintenance of existing water supply infrastructure, wastewater treatment and expansion of their services (Sekhar et al, 2005). City water supplies have been controlled by these boards and are depended on ground water resources. Absolutely no records were found of the amount of groundwater, which was extracted at the individual plot level in the city (Ramachandran, 2009). Today no city values its local water bodies as the function of its water supply. Instead, these water bodies were seen as lucrative options for land, was first filled with garbage and then taken over as real estate for housing and other developments. As a matter of fact ground water depletion had become a common issue in most of the cities as in Kolkata (KMDA Perspective Plan 2025).

There is a wide range of tools which are employed within Integrated Urban Water Management (IUWM), including, but not limited to the following;

1. Water conservation and efficiency;
2. Water sensitive planning and design, including urban layout and landscaping;
3. Utilization of non-conventional water sources including roof runoff, storm water, grey water and wastewater;
4. The application of fit-for-purpose principles; storm water and wastewater source control and pollution prevention; storm water flow and quality management;
5. The use of mixtures of soft (ecological) and hard (infrastructure) technologies; and
6. Non-structural tools such as education, pricing incentives, regulations and restriction regimes (coombes et. Al, 2002; Mitchell, 2004).

According to Cheng et al 2006 Rooftop Rainwater Harvesting (RRWH), promoted by donors and governments, was an optional appropriate technology to reduce water shortage in rural user. To provide an insight into the water scarcity issue, the relationship between harvested rainwater and other related factors is to be explored.

1.2.2. A shift in paradigm

Cities that had developed according to conventional master plan for the urban area do not generally consider the impact of urbanization on runoff and the associated problems with flooding. Neither the growth of impervious areas nor storm water flows were regulated. Thus each rainfall series had become an urban nightmare as roads are being flooded and remained waterlogged for long (Ramachandran, 2009). Scientists had predicted that climate change threats will manifest in more extreme and variable rainfall – it will rain but in shorter number of rainy days (Vialle et al, 2011, O'Hara et al, 2008).

In most of the cases city authority's operation and maintenance departments in a developing country do not have the hydrological data support to cope with such problems through regulation. Meanwhile engineering works, such as channels, pipes and installations, were designed without considering potential impacts of probable rainfall runoff (UNEP, 2009). Urban development in developing country has been unpredictable and often ignores city regulations. As a consequence, private landowners often develop land without the necessary infrastructure. Neither the municipality nor the populations had sufficient funds to provide basic water, sanitation or drainage infrastructure, and there was a general lack of capacity to augment urban water supply using principles of sustainability. The problems of urban development in the tropics were not only the result of climatic conditions; other important factors were density of population, lack of regulations and law enforcement, mainly due to weak institutional capacity and illegal occupation of public or private areas (Pitt et al 2011).

The Working Group had recommendations for the Non-conventional water implementation in the 12th Five Year Plan, India. The integration of urban planning and rainwater management should ideally be based upon preventative action, since the costs would be lower than those of corrective action, and it would be technically simpler to implement. Rainwater harvesting management plans need to be developed within the context of the local environmental, physical and socioeconomic situation (Chakraborty et al, 2009).

Table 1.1: Alternative technologies for water supply, wastewater and rainwater management

Components	Alternative technologies
Water supply system	• Dual water system, where reclaimed and impaired waters were used for no potable application. • Local membrane filtration, which represents possible decentralized systems where raw water was distributed to the consumers and end-point treatment with membrane infiltration, was used. • Aquifer storage and recovery (ASR) system.
Wastewater management	• Source-separating and distributed wastewater systems, that different waste streams were collected and transported separately. • Ecological treatment methods, such as constructed wetlands, living machines, aquaculture, sand filters. • Alternative wastewater collection systems, such as pressure sewer, vacuum sewer and small diameter gravity sewers.
Rainwater management	• Infiltration and collection system, such as permeable pavement, infiltration basins, swales, soak ways or infiltration trenches.

	• Detention systems, such as ponds, constructed wetlands, on-site retention systems. • Rainwater harvesting, on-site treatment and used.

Source: Mitchell, 2004

1.3. Rainwater Harvesting (RWH)

Rainwater harvesting systems has three main components: *the supply* (rainfall), *the demand* (end use water requirement), and *the system* (water collection and distribution system). Rooftop rainwater "runoff" refers to rainwater that flows of a roof surface (Liaw et al, 2004). This runoff from the rooftop could be harvested and used immediately to water plants or stored for later use. The amount of rain received, its duration and intensity all effect how much water was available for harvesting. The timing of the rainfall has also considered being important (Syme et al 2006).The rainfall less than 2.5mm is considered for only to wet the surface of the roof top. If a second rainfall occurs soon after the first, more water may run off because the surface was already wet (Waterfall, 2004).

To make the concept of sustainable rooftop rain water harvesting systems meaningful, the clear definition of Rain Water Harvesting System(RWHS) will here be broadened to include not only the technical issues as such, but also the socio cultural dimension representing the organization and the individuals that maintain and develop the integrated systems, as well as the economy (Cook et al,2013). Surrounding the rain water harvesting system, there were other systems that compose the system environment (fig 2.2.). These could of course be grouped in different ways, but here three entities were chosen to represent the context of the Rain water harvesting systems: the environment, society and the urban water system (Coombes et. al, 2002).

The urban water network system that convey water in urban areas includes infrastructures, economy and the organizations, professionals and the water users. The rain water harvesting (RWH) system had been a more or less integrated part of the urban water system. Rain water has been wasted for decades in the same sewers as sanitary wastewater, though there lays huge cry for water within the urban limits of the metropolitan area (Kim et al 2012). Society was all that humans had formed: social systems, governance, economy, infrastructure as well as individuals. The eco-system consisted of the atmosphere, hydrosphere, lithosphere and biosphere, which form the resource basis for human life and macro environment for rain water harvesting in an urban setting. The utilization of natural resources by the society in a sustainable ecosystem niche gives rise to integrated urban water management (Chakraborty et al, 2009).

1.3.1. Rain water harvesting sustainability issues

Many different issues had been raised as sustainability problems for the rain water harvesting systems. An important reason for having a rain water harvesting system (fig 1.3.) at all was to enhance the security of society when handling the variability of the environment in terms of rainfall, which was highly variable in its nature. The ability of the rain water harvesting system to prevent flooding was a contribution to the security of the societal system (Vialle et al, 2011).

Another important issue that was raised in discussions on RWH sustainability was Rain water harvesting pollution. In a systems setting, pollution was connected to several systems. When Rain water harvesting pollutes waterways and soil, there was definitely a problem in the ecosystem (Sharma et al 2012). Rain water harvesting interacts with the eco-system in a negative way (Ellwas et al. 1987; Malmqvist 1984; Pitt 1985). Rain water harvesting pollution is being diffuse, with traffic and building materials as major contributors to pollution. In that sense it was society that affects the sustainability of the RWH, by impairing its coexistence with other systems. Rain water harvesting was also a considerable input of fresh water to urban areas, which could be used in situations of water scarcity, which were increasingly severe in many parts of the world (Niemczynowicz 1999). By providing a local and decentralized water resource, Rain water harvesting could improve the sustainability of urban water systems, by increasing their efficiency and adaptability (Vialle et al, 2011).

2.3.2 Rain water harvesting strategies

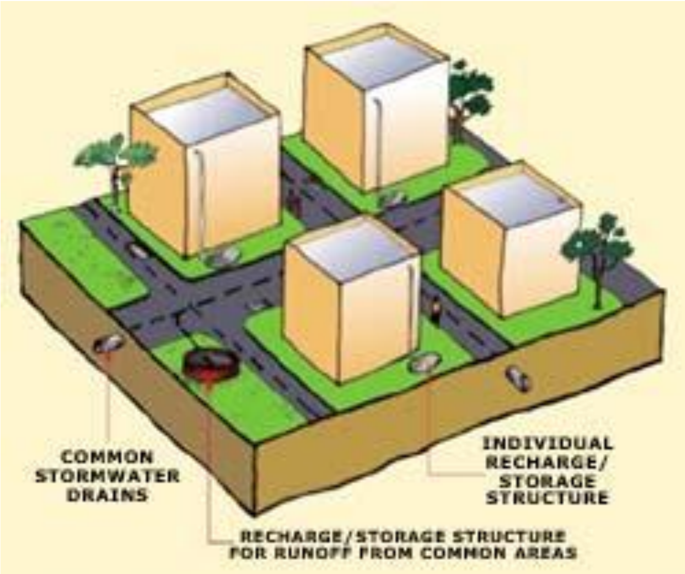

Fig. 2.3 Typical Water Harvesting
Source: CPWD, India Handbook, 2007

Harvested rainwater might have been harvested might have been used in many different ways. In arid regions it was used merely to capture enough water during a storm to save a trip to collect water from a distance for the main water source (Pitt et al 2011). There, only small storage capacity was required, maybe just a few small pots to store enough water for a day or half a day. The main aspects related to water in urban areas in developing countries humid climate, water demand increase based on population growth and Increase in peak and flood frequency due to inadequate drainage management and design (Tucci,2000). There were four types of user regimes in terms of RWH (Gould, 1999) and are listed below:

Occasional – in this process rain water is collected occasionally with a small storage capacity, which allows the user to store enough water for a maximum of one or two days. This system is ideally suited to a climate where there has been an uniform, or bimodal, rainfall pattern with very few dry days during the year and where an alternative water source was available nearby.

Intermittent – this pattern of RWH is the one where the requirements of the user are met for a specific period of the year. A typical scenario is simulated with a single long rainy season and, during that time, most or all of the users' needs are being met. During the dry season, an alternative water source had to be used or, as we see in the Sri Lankan case, water was carted from a nearby river and stored in the RWH tank. Usually, a small or medium size storage vessel is required to bridge the days when there is no rain.

Partial – this pattern of RWH provides for partial coverage of the water requirements of the user during whole of the year. Harvested rainwater is used to meet only the high-quality needs, such as drinking or cooking, while others needs, such as bathing and clothes washing, is met by a water source with a lower quality.

Full – this pattern of RWH encompasses the total water demand of the user is met for round the year through rainwater only. Sometimes precipitation is the only option available for water supply.

A careful water management strategy could always act as a prudent measure. In situations where there has been a strong reliance on stored rainwater, there will be a need to control or manage the amount of water being used so that it does not dry up before expected (Goldenfum et al, 2007). Even where alternative water sources are available, a significant difference to the usage pattern can be observed. If there has been a groundwater source nearby, then a RWHS that could provide a reliable supply of water at the homestead for the majority of the year, and there will be a significant impact to lifestyle of the user(Hellstrom, 2000). Another possible scenario is where rainwater has been stored and used only for drinking and cooking and other higher quality water demands. Whilst a poorer quality water source, which may be near the dwelling, would be used for other activities. There are many factors that determine patterns of usage of harvested rain water (Grandet et al 2010; Madhaorao 2006) as following:

- Rainfall quantity (mm/day)
- Rainfall pattern
- Collection surface area
- Available storage capacity (in liter)
- Daily consumption rate (liters/capita /day or lpcd)
- Number of users.
- Cost

Rainwater harvesting has been proven as a form of source control (table 1.2.) in which water otherwise wasted could be converted to resources. In recent years, due to urbanization and reducing green patches for infiltration,groundwater recharge had decreased and the peak runoff from rainfall and consequent flooding had increased. Therefore it might be necessary that rainwater harvesting should be carried out extensively. That will serve the twin purposes of lowering the peak runoff and at the same time raising the groundwater table. Many urban local bodies in India had already made rainwater harvesting compulsory(Glendenning, 2012; Marsalek,2008).

Table 1.2: Type of disposal of Harvested rain water

Option	Examples	Advantages	Disadvantages
Local disposal	Rain gardens, Soak ways, Infiltration Trenches.	Runoff reduction of minor storms. Ground water recharge.	Capital cost. Clogging.
	Swales, lawns.	Runoff delay. Improved aesthetics. Capital cost.	Maintenance cost.
	Porous pavement/ porous parking lots.	Runoff reduction of minor storms. Groundwater recharge.	Capital and maintenance costs. Clogging.
Inlet control	Rooftop pond.	Runoff delay. Cooling effect on building. Possible fire protection.	Structural loading. Roof leakage. Outlet blockage.
	Downpipe storage E.g. Water	Runoff delay. Reuse opportunities.	Small capacity. Access difficulties.

Option	Examples	Advantages	Disadvantages
	butts.		
	Paved area pond E.g. Gully throttles.	Runoff delay. Possible retrofitting.	Restricts other uses when raining. Storage tank to surface.
On-site storage	All types of water bodies. Detention ponds.	Large capacity. Runoff reduction of major storms. Ground water recharge. Multi-purpose use.	Capital and maintenance cost. Pest breeding potential. Reduced aesthetics. Safety hazard
	Underground tanks.	Runoff reduction of storms. No visual intrusion. Capital cost.	Maintenance cost. Access difficulties.
	Oversized sewers.	Runoff reduction of storms. No visual intrusion. Capital cost.	Maintenance cost. Access difficulties.

Source : Marsalek,2008

Within the urban harvest strategy, whenever rain water is considered as resources, the urban water system had to be modified in certain way that this precious natural resources would be optimally used. To achieve a customize fit for purpose supply ULB authorities need to incorporate decision support system for correct choice of alternative supply (Po et al 2003, Shirley,2002). Stormwater infiltration helps keep the groundwater table at a natural level, which promotes good conditions for vegetation and a better microclimate for the neighbourhood (Jasrotia et al 2009). The haphazard construction in the urban area costs the natural rain water drainage systems with infiltration facilities through grass or other permeable surfaces, and in drainages wales and ditches (Marsalek, et. al. 2008). These technologies were also cheaper than those of conventional systems of storm water disposal.

1.4. Special risks peculiar to RWH systems

Reliability was defined as the probability that the storage tank-catchment combination will supply a required demand for water during a specified time (Baek, Coles, 2011). Available water supply can be calculated by water balance simulation based on catchment size, storage volume, rainfall, water demand, and evaporation losses. The resultant water balance simulation will be applied to estimate the reliability. The result of water balance simulation for the design of a RHS could be affected by the modeling time interval for the water balance simulation such as daily, weekly or monthly calculation intervals (Cowden et al., 2008; Basinger et al., 2010; and Baek, 2010). Practical reliability of the system could be defined using available water supply amount (volume-based estimation, VE) or the time period with water supply failure (period-based estimation, PE) (Baek and Coles, 2011).

There had been a few special health risks associated with RWH, though these were rare and were generally lower than the risks of collecting and carrying water from other sources. Digging underground tanks could be hazardous in certain soil conditions. Users sometimes express the fear that having an outdoor water store makes them vulnerable to malicious poisoning. Underground tanks with missing covers, like open wells, were an obvious hazard to small children or to night walkers. For that reason some above ground walling or fencing was desirable on such tanks. Even above-ground tanks need to be properly covered to discourage children from swimming in them.

The presence or absence of water was only one dimension of the problem and reuse of rain water was influenced by a number of other factors like – the volume of water available relative to existing supply, the timing of availability, the consistency and quality of supply and the desire of suitably skilled and knowledgeable people to invest. In addition to that Kularatne et al. (2005: 19) present a number of social aspects that influence the primary Stakeholders'/ users' decision to accept reuse of rain water.

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