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Potential of Roof Rain Water Harvesting at an industrial setup

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Abstract

This study examined the Roof Rain Water Harvesting (RRWH) prospective at textile mill alongside with the assessment of legal framework on RWH. The following information was analyzed: Decadal rainfall variability, Rainfall probability, Rainwater quality (pH, Total Suspended Solids (TSS), hardness, Iron, Manganese and Lead). The metals were analyzed by Atomic Absorption Spectrophotometer, the rest of the parameters were analysed according to APHA (1997). Volume of rainwater tank was chosen using Rapid Depletion Method. Topographical survey of the site was done using standard Spot Height method. The Weibull formula was applied for plotting positions. The Hydrological Vertical Electrical Survey of the site was conducted with Standard Terresmeter. The average monthly rainfall was found at 91mm, which is higher than 50 mm recommended by Kenya Rainwater Association. Jointly with rainfall probability of 66% it was concluded that RWH was feasible. All the rainwater test results were within the stipulated standards, with exception of TSS, which exceeded the standard by 294%. To address this issue the study designed First flush off system and three layer Roughing filter. The payback period was found reasonably attractive - 5.6 years, thus the study recommended RRWH reinforced concrete system as a supplementary source of water at the mill with economic profit due to reduction of water utility bill. In addition environmental benefits can be obtained, such as control of storm water and decrease of vector borne diseases, e.g. malaria, which was not quantified. Specific recommendations were made in order to promote and scale up RWH in Kenya.

Keywords: Roof Rainwater Harvesting, industry.

1. Introduction

At the World Summit for Sustainable Development (WSSD) in 2002, water and sanitation were recognized as inextricably linked to the eradication of poverty and to the achievement of sustainable development. The United Nations recognize the role of water as a key to development as well. Water is at the heart of Millennium Development Goals (MDGs) numbers 1, 3 and 7, and is indirectly associated with the success of all the other Goals. The target 10 of the 7th UN Millennium Development Goal (insuring environmental sustainability) states that by the year 2015 nations must work progressively to halve the number of people without access to safe drinking water and acceptable sanitation (UN, 2009a). Furthermore, chapter 18 of Agenda 21 highlights the protection of the quality and supply of freshwater resources for the benefit of the Earths ecosystem as well as human population through the following statement: “The general objective is to make certain that adequate supplies of water of good quality are maintained for the entire population of this planet, while preserving the hydrological, biological and chemical functions of ecosystems, adapting human activities within the capacity limits of nature and combating vectors of water- related diseases” (UN, 2009b).

1.1. Kenya - a chronically water- scarce country

Kenya is situated in East Africa at the equator and is subsequently influenced by the Inter Tropical Convergence Zone (ITCZ) as well as the El Niño-Southern Oscillation (ENSO) phenomenon. The ITCZ is a fluctuating low pressure zone characterized by thunderstorms and heavy rainfall. ENSO refers to an unusual warming (El Niño) and cooling (La Niña) of the waters of the Pacific Ocean which occurs in association with changes in atmospheric pressure known as the Southern Oscillation. ENSO occurs with a periodicity of approximately 5 years and is associated with seasonal rainfall anomalies in the Tropics, in the form of droughts in some regions and floods in other regions. ITCZ and ENSO affect precipitation in a wide belt in the tropics. The passage of ITCZ results for Kenya in two annual rain periods; one short in October-December and a longer one in the period of March-June. Average annual rainfall is relatively high, but rains are poorly distributed both spatially and temporally leaving some areas of the country experiencing dry spells while other areas have occurrences of floods during the same season (Malesu et al., 2007).

Water flow in Kenya originates from the country’s five “water towers”: Mount Kenya, Aberdare

Range forests, Mount Elgon, Cherangani Hills and the Mau Forest complex. Since the 1980s, increasing immigration and changing land use practices have interrupted these fragile ecosystems. Extensive logging, disappearing mountain top glaciers and deteriorating forest conditions are some of the identified issues affecting sources of water supply (UNEP, 2009). Increasing rates of illegal abstractions have caused low flows in many of the rivers while the supply of piped water has deteriorated over the years with some areas receiving less than 12 hours of service per day (CFS, 2012).

Kenya is classified by the United Nations as a *chronically* water - scarce country (Republic of Kenya, 2010), and currently ranks 21st for the worst levels of access to potable water in the world (UN, 2008). A water - *stressed* nation has a per- capita freshwater supply of 1,000-1,700 cubic meters; a water - *scarce* country on the other hand, has less than 1,000 cubic meters per capita. Kenya's natural water endowment is 647 cubic meters per capita (Mogaka et al., 2006). In 2008, only 59% of all Kenyans had access to safe water (UNICEF, 2008). The 2006 drought in Kenya was declared a national disaster, as 3.5 million people faced starvation and food shortages (Moyer, 2006). Droughts continue to plague the region. Beyond the threat of drought - induced food scarcity, 10% of deaths in Kenya occur from water-borne or sanitation-related diseases (Pruss - Ustun, 2008).

Water storage capacity remains dreadfully low in most of Kenya. In fact, the country's per capita water supply storage has declined from 11m^3 in 1969 to below 4m^3 in 2002 (Republic of Kenya, 2010). The importance of increasing investments to enlarge this storage is reflected by the clear correlation of economic development and per capita investment in water storage, management, and utilization (Ngigi, 2009). However, this should not assume that investments solely in large-scale storage projects are needed. Conceivably it should be realized that universal delivery of piped household water from a centralized source is not realistic in the near future. The high energy requirements alone prove barriers too large for quick implementation (UN Habitat, 2007). There is an increasing realization that these solutions must be found in more decentralized and smaller scales. Rainwater harvesting fits well to this need.

1.2. Rainwater harvesting

Like other living organisms man cannot survive without water. Rain Water Harvesting is being practiced from the birth of human civilization. During the twentieth century the use of rainwater harvesting techniques declined around the world, partly due to the provision of large, centralised water supply schemes such as dam building projects, groundwater development and piped distribution systems among others. Currently RWH enjoying a revival in popularity due to the inherent quality of rainwater and interest in reducing consumption of treated water. Rainwater is valued for its purity and softness. It has a nearly neutral pH, and is free from disinfection by-products, salts, minerals, and other natural and man-made contaminants. It makes use of a natural resource and reduces flooding, storm water runoff, erosion, and contamination of surface water with pesticides, sediment, metals, and fertilizers. Rainwater collected immediately after precipitation is the purest of all natural waters. It may contain traces of gases dissolved out of the atmosphere and possibly a small amount of finely divided solid matter derived from the air. In towns rain may collect dissolved or suspended impurities such as soot, traces of sulphur dioxide or sulphuric acid and other by-products of industrialization (Vesilind, 1991).

Rainwater harvesting (RWH) can be defined as the collection, conveyance, and storage of rainwater for an intended use. Roof Rain Water Harvesting (RRWH) is the practice of capturing the rainfall from roofs, diverting it through gutters and drains, and storing the water in tanks of various sizes for later use (Malesu et al., 2006).

Rainwater may be collected from any kind of roof. Tiled or iron sheets are easier to use and produce the cleanest water. The only common roof not suitable for roof catchment is that of lead flashings or those painted with lead based paints. Roofs made of asbestos can be used if fibres chips have not been detached from damaged areas (IRCS, 2013).

Rain water is safe for non-portable purposes, such as in wet processing operations at a textile mill. The main criteria for such water are: Freedom from suspended solids that can give staining in processing, No great excess of acid or alkali, i.e. a pH range of ±2 on either side of the neutral point, and Freedom from substances affecting the textile processes, such as Iron, Manganese, Calcium, or Magnesium salts and Lead (Little, 1975).

With the introduction of Kenya's Water Act of 2002 and afterwards draft of the National Water Policy 2012, the national government provided more freedom and autonomy to allow other government and non-government bodies to supply water by providing a more conducive environment to facilitate a decentralization of water supply. As a result, new water sector institutions have been created, and new ideas for water supply have come about. One of the ideas gaining attention with this new system has been RWH, which may previously have been treated as an afterthought or lacked applicable knowledge.

Many reports and articles have been written on the promising benefits of rainwater harvesting for rural communities of Kenya (Gould, 1999; Relma, 2002; Akumu, 2006; Martinson, 2007 and Enfors, 2009 among others) however very little studies, if at all, have been conducted on potentials of Roof Rain Water

Harvesting (RRWH) at an industrial setup. To bridge this gap this study examined the RRWH prospective at textile mill together with assessment of existing at the time of the study legal framework on RWH.

2. Materials and Methods

To document precipitation variation climatic data was gathered and compiled (retrospective rainfall data for 10 years) at the Kenya Metrological Department. The rainfall data was tested on consistency and homogeneity. Standard methods of Descriptive statistics were used for univariate and bivariate analysis of the retrieved information. The rainfall probability was found graphically according to RELMA, 1998. The following formula is applicable: $P = m / (n+1)$

Where: *P*- rainfall probability, *m* - rank of rainfall value, *n* - total number of subject years.

Mill's rainwater was tested in order to assess its suitability for textile purposes. Rain gauges were installed at mill's premises and duplicate samples were collected at twenty different precipitation incidents during the rainy season. The tests parameters were limited to pH, TSS, Iron, Manganese, Lead and hardness. Rainwater samples were obtained with the help of a standard plastic rain gauge. The samples were then poured into 0.5 liter glass bottles that had been soaked in nitric and sulphuric acid solution 1:1 volume ratios, washed, rinsed and then dried prior to field work. Samples destined for the determination of metals were not filtered, but only acidified to pH 2 with concentrated nitric acid according to APHA, 1997. Determination of Lead, Iron and Manganese in rainwater samples was as follows: Acid preserved rainwater samples were digested as pre-requirement for Atomic Absorption Spectrophotometer (AAS) analysis so as to avoid interference from complexing organic matter (Eaton *et al.*, 2005). Samples were digested (nitric acid-sulphuric acid) and concentrated on a hot plate from 100 mL to the lowest possible volume for about 3 hours. Then after cooling samples were topped up with the ionized water to give volume of 10 ml. Then they were placed in 125ml polythene sample bottles and stored in a refrigerator at 4^{o}C until when AAS was due. At least three calibration standards were prepared for each metal.

Water demand in the mill was assessed, rainwater catchment area was calculated, and determination of yield and the volume of rainwater collection tank were chosen by Rapid Depletion Method, alongside with tank type, dimensions, materials, sitting and in the end payback period of the proposed system were estimated.

Plotting positions refers to the probability assigned to each piece of data to be plotted. Empirical methods were used for the determination of plotting positions for rainfall data. The Weibull formula was applied on account of the following: it is compromise with more statistical justification; probability values are distributed uniformly; plotting system is simple; it will not lead to expensive structure.

Tank design principles (Nissen-Petersen, 2007; Walton, 1995) were conformed to the codes of practice for Reinforced concrete, Liquid Retaining Structures and Foundations BS8110, BS8007 and BS8004 respectively. The loading regime included the traffic loads, earth pressures, water pressures and material self-weight. The tank was designed for serviceability condition against leakage and checked for ultimate limit state of strength. The factor 1.1 against floatation was used. Based on Manning's formula and other considerations a pipe size of 250mm was chosen on slope of 2%. Conditions of tank exposure is class A (alternating wetting and drying) with maximum crack width of 0.1mm. The code of practice for Roof Drainage BS6367; 1983 was used. Vertical rainwater pipes would have same bore diameter as gutter outlets, while horizontal rainwater pipes would have a small fall to prevent pounding.

The assessment of legal framework on RWH was done primarily by desk study based on reputable sources of published information.

3. Results

All mill's water in portable form was received from the Municipal Water Supply system and had been considered to be generally of a reasonably high standard. Preliminary studies identified that in the past the mill experienced several incidents of water shortages due to water rationing, and water disconnection due to non-payment. Water disconnection is a very drastic measure for a textile wet processing and means complete freeze of operation and consequently financial losses to a mill.

Descriptive statistics for univariate and bivariate analysis showed significant variation between and within the rainfall data samples. The significant difference within the samples can be attributed to the seasonal variations in precipitation, while the difference between the samples reflected effects from both El Niño and La Niña phenomena. The average rainfall was found at 91mm. Rainfall probability of 66% was optimized graphically as shown in Figure 1.

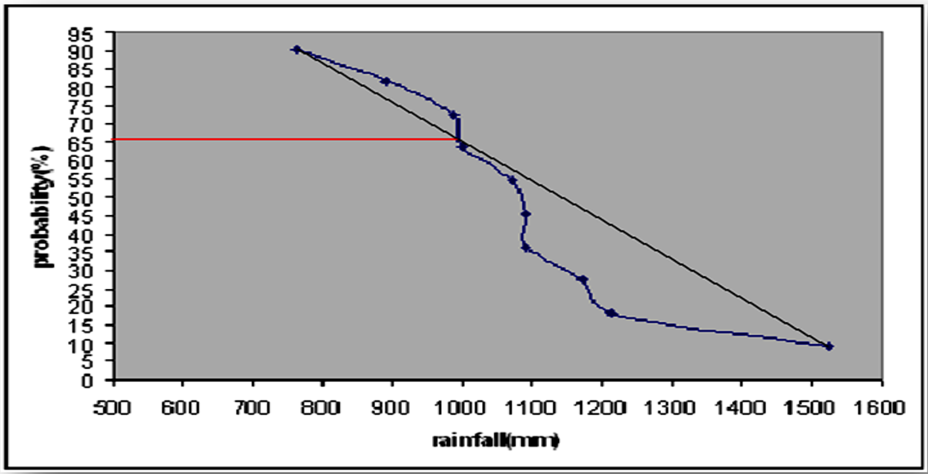

Figure 1: Graphical identification of Rainfall data probability.

The Hydrological Vertical Electrical Survey resulted in borehole log: Water struck level = 8-10 m, Water rest level = 7.0 m, and Main aquifer = 30 m. Topographical survey assessment showed that the site was relatively flat and the geology failed under the volcanic middle and upper tertiary geological age. Regarding mill's catchment's area and surface it was found that the total land area covered by the factory and including the unused land was about 100,410m^3. The factory was divided into 6 bays, each consisting of a number of buildings housed under one roofing. Roofing at the mill was of corrugated asbestos cement (CAC) sheets, made from asbestos fibres and cement in the proportion of 1:7. These were produced according to BS 690: Part 3 Roof specifications.

For determination of Rainwater yield at the mill, three methods were considered, namely: Demand/Dry Spell (DDS) method, Rationed Consumption method (RCM) and Rapid Depletion method (RDM). The following volume (m^3) of rainwater collection tanks were estimated by each method respectively: DDS - 4500, RCM - 1163 and RDM - 550. Rain water quality testing and analysis was conducted and results are presented in Table 1.

Table 1: Summary of rainwater quality test results

Parameter	Units	Mean Value	Standard	Remarks
pH	No	6.54	[5-9]	Acceptable
TSS	Mg/L	14.7	≤5	**Unacceptable**
Hardness	Mg/L as $CaCO_3$	50.9	≤70	Acceptable
Iron	Mg/L	0.017	<0.3	Acceptable
Manganese	Mg/L	0.0	<0.05	Acceptable
Lead	Mg/L	0.0	<0.01	Acceptable

Due to high durability requirement reinforced concrete was chosen as the best material for the rainwater storage tank. Thus the required tank dimensions are: Height (H) = 7m, Underground Height = 5m, Diameter (D) = 10m, Wall thickness (e_s) = 200mm.

A new water bill was under discussion in 2012. If voted into law, the bill would transform the 8 Water Service Boards (Asset Holding Companies) into 47 Water Works Development Boards in each county of Kenya. This is in line with the decentralization prescribed in the 2010 Constitution of Kenya. Also, the National Water Conservation and Pipeline Corporation would become a National Water Storage Authority, the Water Services Regulatory Board would become a Water Services Regulatory Commission and the Water Services Trust Fund would become a Water Sector Trust Authority. The Bill is meant as an improved version of the Water Act of 2002, rather than another fundamental reform of the sector (Republic of Kenya, 2010; Republic of Kenya, 2012).

There is currently no formal Government policy on the operation of rainwater systems either in the home or within a commercial or industrial setting. In the Policy Objective and Policy Statements of the Republic of Kenya Draft of the National Water Policy 2012 it is stated that "the sector will require water-related disaster preparedness and rainwater harvesting and storage strategy".

4. Discussions

According to the Kenya Rainwater Association, RWH is generally feasible if the amount of annual rainfall at least 600mm (50mm per month). From the rainfall data analysis, this amount (600mm) is exceeded even for the driest year (762.9mm). On the other hand, the decadal monthly rainfall mean (10 years) was found at 91mm, which again higher than the 50 mm advised as feasible for RWH. From the graphical estimation rainfall probability of 66% equals to probability factor of 0.66 which considered as pragmatically reliable rainfall, and consequently RWH at the mill was found feasible and decadal mean precipitation value of 91mm was to be used as a design parameter.

Due to economic and structural considerations only four bays BAY 1, 2, 3, and 4 were to be considered as rainfall catchment's area. Each bay consisted of six buildings, each 16.46m x 87.78m giving the total catchment's area of 34, 676, 6 m^2. Under the roofing specification BS 690: Part 3 Roof, asbestos fibres were deeply embedded and firmly bounded in the cement to produce strong, durable roofing material. They do not produce any health risks during normal cutting, drilling, fixing and use (Walton, 1995). On the other hand, asbestos is a known carcinogen *only* if inhaled. It can also cause asbestosis, which is mainly of concern when mining. According to 16th IRCS Conference and International Symposium on Rainwater Utilization, 2013 roofs made of asbestos can be used if fibre chips are not being detached from damaged areas. The researchers observed the mill's roofing surface and found it to be in good condition (not damaged). Private correspondence with Dr. Aitio's of WHO confirmed, that at the time of the study "there are no data available to indicate that asbestos in drinking water would cause health problems."

Out of three methods under consideration, Rapid depletion method (RDM) tank was chosen due to following considerations: DDS method did not take into account the pattern of the rainfall and assumed that the rainfall is sufficient to supply the demand. This method is mainly suitable for rural community projects, where both water consumption and catchment's area is relatively small. RCM method was based on the assumption that the consumption of the water to be utilized uniformly throughout the year using the rainwater collected from catchment's area. Water demand at a textile mill fluctuates depending on orders and consequent volume of production. In addition, both DDS and RCM methods projected unrealistically large rainwater collection tanks requiring large capital investment and therefore both were found uneconomical and unsuitable for the mill. Figure 2 shows cumulative rainfall and cumulative demand according to RDM.

From the rainwater tests data it can be concluded that all parameters were within the set standards with exception of TSS which value exceeded the standard by 294%. Solid particles can stain fabrics and textile garments. Such stains are very difficult to remove owing to their insolubility and resistance to wetting. To avoid such troubles, the rainwater has to be freed from excess solids. First run off from a roof after a long period of drought is usually contaminated from dust, dead leaves, bird droppings etc. which accumulated on the roof and gutters during long dry season. Therefore the first roof run off should be diverted from the tank to reduce solids accumulation.

The following trouble-free system was designed: two strong plates to control the flow of water either into the storage tank or to the side drains (for the foul flush). Considering frequency of operation this can be done manually. Figure 3 shows the positioning of plates. In addition, to minimize the rain water contamination it was proposed that a standpipe type roof washer system be manufactured locally and incorporated into already existing at the mill gutter system.

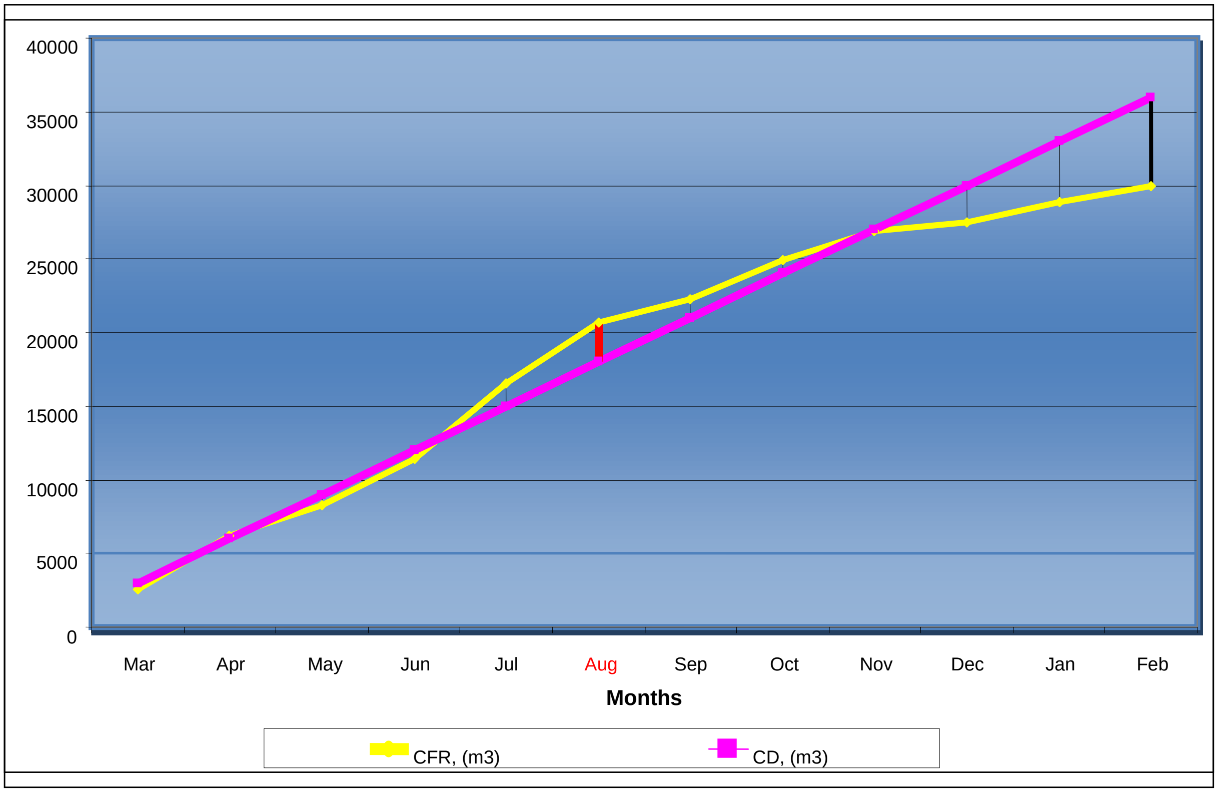

Figure 2: Cumulative rainfall (CFR) and cumulative demand (CD) according to Rapid Depletion Method.

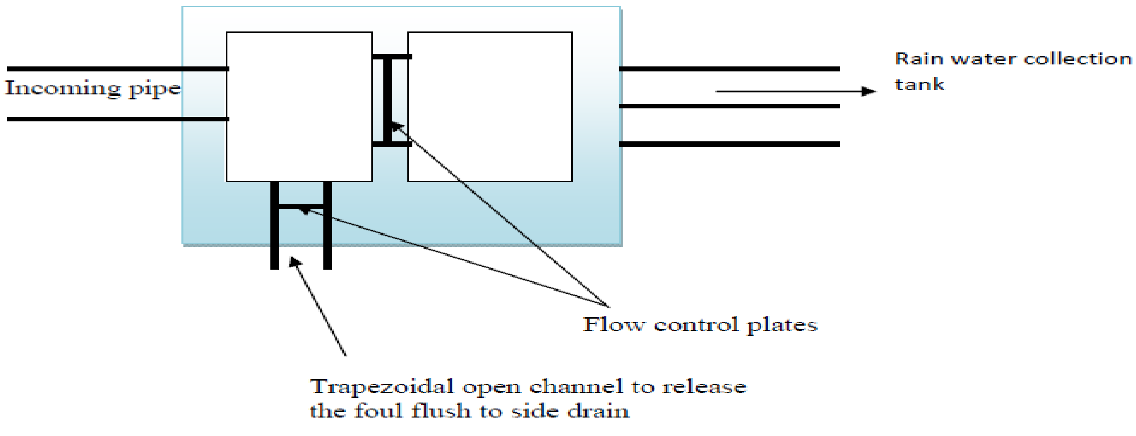

Figure 3: Designed system for first flush diversion.

Though it is not currently mandatory for institutional buildings to have rainwater-harvesting facilities, many institutional government buildings especially in the rural areas of Kenya, as such as hospitals and schools have already installed rainwater-harvesting facilities. Kenya's water policy takes into account all the relevant issues including water conservation and preservation of its quality. In this regard, mainstreaming and up scaling of rainwater harvesting is very prominent. To promote RWH development the several cumulative approached can be adopted:

a) *Systematic Approach*, where rainwater utilisation, together with water conservation and wastewater reclamation, should be incorporated into municipal rules and regulations. Some standardisation of materials, at least at regional level, may be desirable from a maintenance and replacement point of view. It may be also appropriate to standardise the design of the rainwater utilisation system, at least at the regional level.

b) *Implementation Policy*, where various implementation policies should be established to make rainwater utilisation and other measures a part of the social system. Leadership is very important and local governments at county levels must take the initiative to promote the concept of water resource independence and restoration of the natural hydrological cycle. Consideration should be given to subsidising facilities for rainwater utilisation.

c) *Technology Development and training*, by encouraging technology and human resources development to support rainwater utilisation is very essential. It is also important to promote the development of efficient and affordable devices to conserve water, facilities to use rainwater and devices to enhance the underground seepage of rainwater. Together with this, there is a need to train specialists with a thorough grasp of these technologies and devices.

d) *Networking,* to promote rainwater harvesting and utilisation as an environmentally sound approach for sustainable urban water management, a network should be established involving government administrators, citizens, architects, plumbers and representatives of equipment manufacturers. It is essential to encourage regional exchanges amongst public servants, citizens and industry representatives involved in rainwater storage, seepage and use, as well as the conservation and reclamation of water.

5. Recommendations

Taking into account the fact that the rainwater was proposed to be used only for processing and not for human consumption the mill's roofing surface-CAC was considered as suitable for RWH.

It is recommended to choose RDM rainwater collection tank of design capacity $550m^3$, due to its minimal volume in comparison with DDS and RCM tanks and the fact that in contrast to DDS and RCM rainfall pattern and factory fluctuating water demand was taken into consideration. This made the method closer to real conditions of the mill. Roof drainage system that to be used consist of 3 major parts; the gutter to collect flow from roof, outlet unit into which flow from gutter discharges, and pipe work that conveyed the flow to rainwater collection tank. Water to be pumped to the main tank from where it is transmitted by already existing distribution network to the mill's wet processing departments.

Three layers Roughing filter was recommended to purify the rainwater in order to reduce TSS. Up-flow filters are suitable as they provide for course to fine filtration process and are not liable to clog rapidly. Following best practices the study recommends the use of filters with porosities in the range of 0.2-1.0mm with no further filtration required for non-potable uses. Self-cleansing filters are preferred as they require less maintenance and reduce the cost of consumables (Greenbuilder, 2007).

The study recommended RRWH reinforced concrete system as a supplementary source of water at the mill, with potential economic profit due to substantial reduction of water utility bill, and in addition environmental benefits such as control of storm water and decrease of vector borne diseases, e.g. malaria, which were not quantified.

To make rainwater harvesting sustainable, there is need to include the RWH initiative in the National Integrated Water Resources Management strategy.

Besides, the study recommends taking serious consideration of Environmental Impact Assessment before conducting any major rainwater storage project in an industrial setup.

6. Conclusion

It is important to realize that rainwater harvesting is not a "universal remedy"; nevertheless it can be efficient as a complementary and viable alternative to large-scale water withdrawals, reducing negative impacts on ecosystems. Establishing an enabling policies and cost-sharing strategies, (including subsides) with technical know-how and capacity building is of paramount significance in promotion and scaling up of RWH in Kenya.

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