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Rain water harvesting as additional water supply for multi-storey buildings in Arba Minch, Ethiopia

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ABSTRACT

During the last years, multi-story buildings (MSBs) have been introduced in Arba Minch and other Ethiopian cities as condominium houses. Constructed at the edge of the city boundaries, they have a standardized design including flush toilets. The water supply scheme in place can hardly cope with the water demand inside the new buildings. Shortage of water causes many problems in bathing, washing and flushing toilets. These unhygienic conditions are inducing toilet blockage, smells in the houses, infection which can lead to a negative effect on health. The more people are moving into these condominium houses, the more these problems arise. The objective of this paper is to study the feasibility of rainwater harvesting (RWH) as additional water supply for MSBs. Two MSBs were selected as a pilot plot in Bekele Mola site. In this case, flashing toilet by rainwater could save 33 m^3/month of potable water. That means we can reduce the use of potable water for non-potable-water needs by 42 L/household/d. This RWH system is recovering only 19.5% of water demand and 84% of flushing water demand with maximum 130 habitants at the pilot buildings. The supply is limited by the amount of rainfall and the size of the catchment area. In addition, the installation price is relatively high.

Keywords: Multi-story buildings (MSBs); Rainwater harvesting (RWH); Sustainability of water supply; Flush toilet; Arba Minch

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1. Introduction

Arba Minch (Forty Springs) is the largest town in Gamo Gofa Zone in southern Ethiopia, located in the Southern Nations Nationalities and Peoples' Region about 500 kilometres south of Addis Ababa at an elevation of 1,285 meters above sea level. During the last years, the Ethiopian government has started a new housing programme; the so called "condominium buildings" are also described as multi-story buildings (MSBs) [1]. However, the water supply scheme in place can hardly cope with the water demand under normal conditions in these MSBs. In the frame of CLARA project (http://clara.boku.ac.at/), measures to reduce water consumption at the MSBs and resources-oriented solutions are researched. The development and implementation of solutions for MSB and the installation of a pilot facility shall have highest priority to reduce health risks for the increasing part of the population.

Since ancient times, the collection and use of rainfall has been practised. In fact, the ancient Carthaginian-Roman civilization in Sardinia used rainwater cisterns to provide for public and household needs in the ninth century BC [2]. In recent times, rainwater harvesting (RWH) has been used as a low-cost technology for water supply in rural areas where other appropriate water sources are unattainable and where surface water and groundwater sources are either expensive to utilize or are inadequate for consumption [3]. It is recommended that if potable water is available; RWH should be used solely for non-potable needs like toilet flushing, laundry washing and landscape irrigation. Plumbing for potable and non-potable rainwater sources must be completely separate systems. Rainwater can supplement municipal water supplies to reduce demand on these supplies to serve non-potable demands in and around the home [4]. In this pilot project, the water harvested from rainfall is intended for non-potable domestic use such as toilet flushing and general cleaning.

The feasibility of RWH system depends on the availability of sufficient rainfall and adequate roof area, storage space and ultimately the cost of design and installation of the system. Arba Minch and its surrounding area receive mean annual rainfall above 833 mm, which is greater than 400/500 mm in which RWH option is plausible. The objective of this work is to study the feasibility of RWH as additional water source to decrease water scarcity in MSBs and to improve water borne sanitation.

2. Methods

Data were obtained through key informants or other respondent interviews and field observation. Other data were sourced from contemporary literature, official documents [5], as well as relevant web cites [6]. Many visits to the site were done, aiming to get an overview regarding social factors, water supply and sanitation of the people living in the condominium houses. In-depth door to door interviews, trying to get an idea of their water demand, were also done.

2.1. Cost analysis

For the options presented in this work, construction costs (materials and labors) are based on cost estimates provided by several local construction firms. The cost estimates is given as a bill of quantities based on design specifications rather than as a lump sum. Capital costs may be estimated fairly easily; estimating O&M costs on the other hand is more difficult. Overheads in form of salaries for the management, expenditure for the logistic requirements of operation and maintenance are extremely difficult to foresee, especially in the case of co-operatives. The total investment cost is including allowances for contingencies and overheads estimated at 10% and 15% of capital costs, respectively. Ten per centof the total investment cost is assumed as a rough estimate of annual O&M cost for respective options including investment, reinvestment and operation and maintenance. Land costs are not included; land in the Arba Minch is generally under governmental control and is allocated to applicants as necessary by the Lands and Planning Authority; applicants typically only pay administrative charges for the plots allocated to them. It is thus assumed that for the onsite systems land required is assumed to be a part of the user's property.

2.2. Conversion of costs into net present values

The financial decisions on option selection should not primarily be made on capital costs, but on net present value (NPV) or whole-of-life costs, which includes the annual costs for operation and maintenance. The capital costs argument should be less important than the reliability and long-term sustainability of the treatment plant, including its financial sustainability which is strongly influenced by annual operation and maintenance costs.

Once the costs had been compiled, the NPV of each alternative were determined using the following conversion factors:

$$\mathrm{PV} = \left[\frac{1}{(1+i)^n}\right] \quad (1)$$

where PV = present value, n = time period, i = discount rate.

The sum of these present values of capital and operating costs then gave the NPV for each option. Assumptions made include: unified component lifetime, evaluation time periods and discount rate.

3. Results

3.1. Pilot site description

The condominium area of Bekele Mola consists of 28 MSBs, with 343 households and 39 shops or other service facilities. Actually, less than half of the houses are currently inhabited. Fig. 1(a) shows a panoramic view with all MSBs of the Bekele Mola site.

The selected two buildings (Fig. 1(b)) are made of one block with a stair case as shown in Fig. 2, and that design applies mirrored for both buildings. The two condominium buildings selected are not unique and are spread in different parts of the town which will facilitate reproduction of option selected within Arba Minch Town and other towns in Ethiopia. One building contains 13 households; five houses in the ground level and eight houses in the first and the second levels (Fig. 2). According to Augustsen and Hausso [8], there are 3.1 people per habited household in the MSBs in Arba Minch. However, in our selected pilot only 2.5 people per habited household is living. Taking in account that the average number of people in Ethiopia per household is five [9], the two MSBs with 26 households are expected to host maximum 130 people.

3.2. Water demand and supply situations

After door to door assessment of the two MSBs selected as pilot with in total 26 households, the water demand is in the range of 25–70 L/c/d and the average consumption is 43 L/c/d (Table 1). The questionnaire

Fig. 1. (a) Bekele Mola condominium houses [7] and (b) two MSBs chosen as pilot plot.

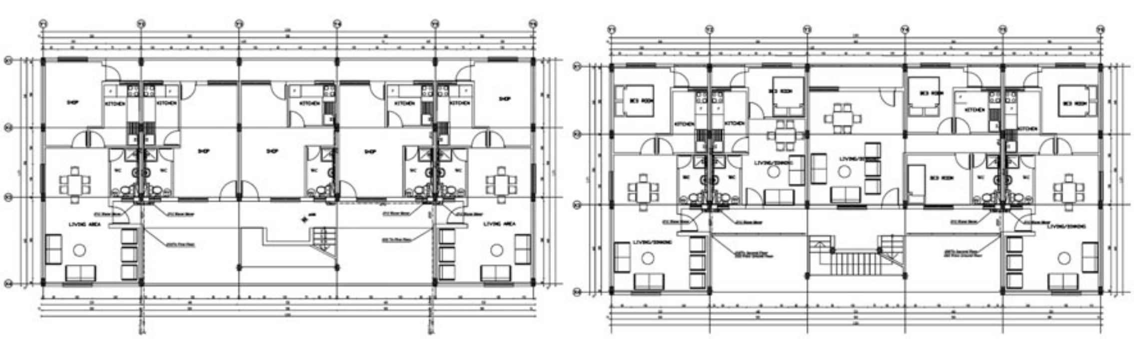

Fig. 2. Ground floor plan; first and second floor plan for MSB.

Table 1
Water consumption after door to door assessment in the selected pilot (MSBs) at Bekele Mola site

Household reference	Number of persons/per household	Water consumption/household/month (m^3/month)	Water consumption/capita/day (L/c/d)
R1	2	3	50
R2	2	2	33
R4	2	2	33
R6	3	4	44
R9	3	3	33
R10	2	3	50
L1	3	6	67
L3	3	3	33
L6	3	3	33
L8	4	3	25
L11	1	2	67

was done on Sunday, (14 October 2012). Eleven households were occupied giving an occupation of 42%; the rest was not occupied or rented for this period.

In the other hand, according to water supply and sewerage enterprise, actually they supply only 20 L/c/d of water 4 d a week. Even that water supply can be sufficient for people living in MSB since less than 50% off the total households in this site are currently occupied. In fact, the majority of habitants are storing water in containers inside the house for fulfilling all the demand during the water cut. The more people move into condominium houses, the more the problem of water scarcity in the MSBs will arise.

The flow of wastewater can be estimated by using the following equation:

$$Q_{WW} = kQ \quad (2)$$

where Q_{WW} = wastewater flow (m^3/d), Q = water consumption (m^3/d), k = return factor.

The value of k (the fraction of the water consumed that becomes wastewater) is normally 0.8–0.9, lower in richer countries where more water is used outdoor [10]. Choosing $k = 0.9$ should be reasonable since this is not a rich area, and it is better to slightly over dimension the capacity than to underdimension it. The percentage of greywater is assumed to be 70% of the wastewater, meaning 30% is blackwater [6]. That means 38.7 L/c/d of wastewater is produced, where 27.1 and 11.6 L/c/d are greywater and blackwater, respectively. We assume that the water demand for toilet flushing is about 10 and 1.6 L/c/d is used for anal and urine cleaning. The total flashing water demands for the building per day and per year are given as 1.3 and 474.5 m^3, respectively.

3.3. Rain water harvesting potential

According to the National Meteorological Agency of Southern Zone [11], the town receives mean annual rainfall of 833 mm at least for the 35 years period from 1973 to 2008 and characterized by bi-modal distribution, with two rainy and two drier seasons occurring intermittently as shown in Fig. 3. Rainfall data with higher resolution could not be provided. An estimate of the approximate mean annual run-off from a given catchment can be obtained using the following equation:

$$S = R \times A \times Cr \quad (3)$$

where S = mean annual rainwater supply (m^3), R = mean annual rainfall (m), A = catchment area (m^2), Cr = run-off coefficient.

Using a run-off coefficient of 0.9 and a total roof catchment area of the two MSBs equal to 533 m^2, the average amount of water that can be harvested from roof top is around 400 m^3 per year. The harvested

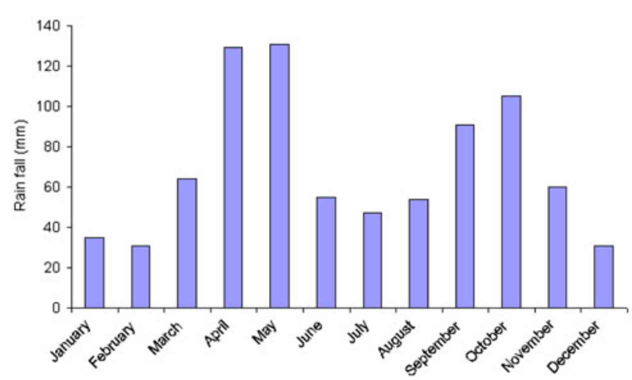

Fig. 3. Mean monthly rain fall in Arba Minch (1973–2008) [11].

water from the roof is intended to be used as auxiliary to the municipal water supply to satisfy the requirements of toilet flushing.

According to the calculated harvested rainwater quantity per year, about 33 m^3/month of potable water could be saved. Using a storage tank for rainwater, habitant can use the collected water for flashing toilet and plant irrigation without any additional treatment. So, we can reduce the use of potable water from non-potable water by 8.4 L/c/d. The RWH system is recovering only 19.5% of water demand and 84% of flushing water demand. The supply is limited by the amount of rainfall and the catchment area size.

3.4. Estimation of RWH storage requirement

A sufficient storage will be required to bridge the periods of scarcity and should be carefully calculated to avoid unnecessary expenses. It was estimated by supply side approach (graphical methods). This method allows estimating the most appropriate storage tank capacity for maximizing the supply. It represents roof run-off and daily consumption graphically. The spreadsheet calculation for sizing the storage tank is shown in Fig. 4. It takes into account the cumulative inflow and outflow from the tank, and the capacity of the tank is calculated as the greatest excess of water over and above consumption (greatest difference between the two lines). All this water will have to be stored to cover the shortfall during the dry period. This occurs in October and March giving a storage requirement of 60 m^3.

For this particular pilot project, it is proposed to construct a concrete underground tank with capacity of 60 m^3. In the case, where the rainwater supply will be automatic to the flush toilets, we will install on the top of the roof of each MSB one tank with 2 m^3 volume with galvanized pipes connecting each house-

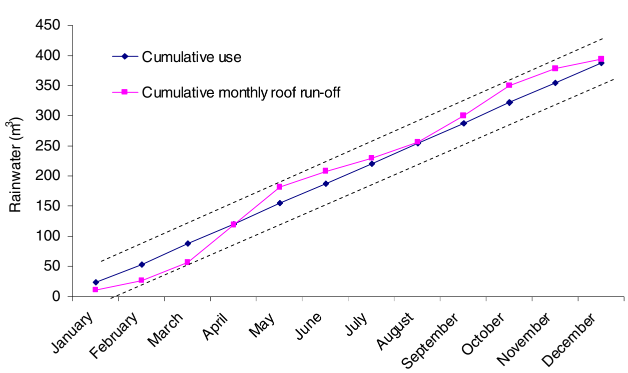

Fig. 4. Cumulative monthly roof run-off and cumulative water use.

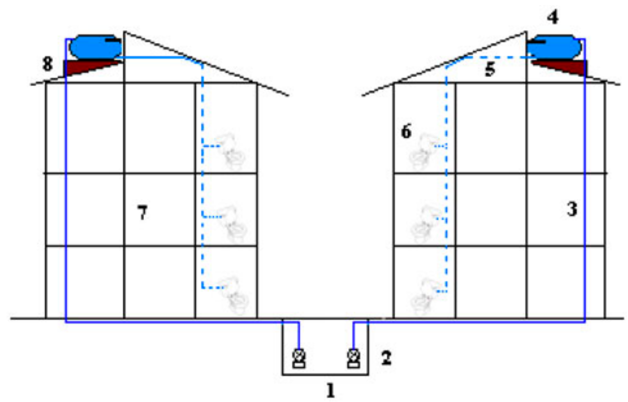

Fig. 5. (1) Underground storage tank 60 m^3, (2) submersible pumps, (3) pipe connections, (4) elevated storage tank 2 m^3, (5) pipe connection, (6) flash toilet reservoir, (7) multi-storey buildings and (8) support for elevated tank.

holds. The underground tank is equipped with two submersible pumps and each one is connected to the 2 m^3 tank (Fig. 5).

3.5. Cost estimation of RWH system installation in Arba Minch

The cost estimates are based on a bill of quantities derived from widely acknowledged design specifications (cite) and information on local unit cost (2012). The cost estimation in Ethiopian Birr (ETB) takes into account the excavation and earth work, the masonry, the rainwater supply pipes, the valves and accessories installation, the rainwater collecting system, tankers and pumps (Table 2). The underground tank is a concrete tank with access manhole, entrance, overflow pipe and air vent. Such a tank can be constructed locally. The two elevated tanks with 2 m^3 volume can be made of plastics or fibre glass and can be easily found on the local market. Two submersible automatic pumps are required to suppress water to the elevated tank on the roof of the building. The gutter and the down pipes are already installed.

The cost analysis was studied for two options:

- Option A: the collected rainwater is distributed automatically from the underground tank to the flushing toilet reservoir, using two pumps, two elevated reservoirs and all necessary pipe connection for each toilet.
- Option B: the collected rainwater is removed from the underground tank manually using a rope and a bucket. This water can be filled in 20 litre containers in order to be reused inside the house for flushing toilet using hand.

Table 2
The bill of quantity of RWH system installation for the selected pilot for option A and B

Item no.	Description	Unit	Quantity	Rate	Amount and option (ETB)[a]	
					A	B
1	*Sanitary installation and PVC pipe installation work*					
	Diameter 110 mm	m	90	90	8,100	8,100
	Diameter 200 mm	m	30	200	6,000	6,000
	Supply & lay internal galvanized pipes with all the necessary fittings as shown in Fig. 5					
	Diameter 1/2 mm	m	59	190	11,210	
	Diameter 3/4 mm	m	150	90	13,500	
2	*Chiselling & repairing work*					
	Seal the chiselled slab and wall surface for sanitary work with cement mortar or concrete & apply three coats of plastering	m	160	55	8,800	
	Seal chiselled wall surface for sanitary work with cement mortar & apply three coats of plastering	m	25	35	875	
3	*Terrazzo tile work*					
	200 x 200 x 20 mm thick terrazzo tile floor finish stuck to floor with 30 mm cement mortar	m^2	5	220	1,100	
4	Fibre glass tank of 2 m^3	No	2	3,750	7,500	
5	Support on the roof of the MSB for the tank of 2 m^3	No	2	3,000	6,000	
6	Submersible pump for water elevation to the roof top	No	2	15,000	30,000	
7	Tanker	No	1	60,000	60,000	60,000
	Total summary				153,085	74,100

[a]ETB = 0.042 Euro.

A time period of 30 years is assumed for each of the options. Based on this time period, a discount rate of 10% and assuming no variations occur in annual costs, the NPV was derived by determining for each options the NPV of capital costs (initial investments) and NPV of O&M (annual operating costs, replacement), the sum of these gave the NPV for each option [12].

Tables 2–4 summarize the costs, water recovery and the ranking for the two options investigated.

The recovered water (in %) is reflecting the effectiveness of the options in fulfilling the demand of water for flushing toilet. The RWH solution can recover 84% and this value is the same for the two options. The recovered water quantity of the two options during the span life of the system is also the same (Table 4). However, the total capital investment for the two options installation is about 191,356 and 92,625 Euro for option A and B, respectively. The increase in cost for option A arises from the cost of the automatic distribution system of water to the flushing water reservoir (Table 3).

After NPV calculation, the specific cost of the recovered water is the total NPV cost divided by number of cubic metre saved per 30 years. It is useful for comparing between different possible solutions for water supply and recovery for the same case study.

Table 3
Costs for the entire design of options A and B

	Amount (ETB)[a]	
	A	B
Subtotal (for rainwater harvesting system installation for two MSBs with 26 households and 130 inhabitants maximum	153,085	74,100
Allowances for additional work	15,308	7,410
Overheads	22,963	11,115
Total capital investment	191,356	92,625
Annual operation & maintenance (10% of INV)	19,135	9,262

[a]ETB = 0.042 Euro.

In fact, the cubic metre price of the recovered water from each solution is different. The lower price is for the option B using less automaticity (Table 4).

The installation NPV cost per households is approximately 630 and 305 Euro. These amounts are relatively high compared to the medium standards of leaving in Arba Minch. In fact, more than 62% of the town inhabitants' monthly income is less than 70 Euro [9].

Table 4
Summary of costs for the selected pilot with maximum 130 habitants

		Water recovery (%)	Saved water for life span 30 years (m^3)	NPV cost (ETB)[a]	NPV cost (Euro)	NPV cost per household (Euro)	Specific cost (Euro/m^3)	Ranking
Options	A	84	12,000	389,779	16,371	630	1.36	2
	B	84	12,000	188,673	7,924	305	0.66	1

[a]ETB = 0.042 Euro.

This economic analysis ranks according to the least costs. It is clear that the option B is more affordable, but cannot resolve the problematic situation on site sufficiently. It is clear that none of the other is economically feasible without important subsidies.

3.6. Advantages and disadvantages

When considering the possibility of using rainwater catchment systems for domestic supply, it is important to consider both the advantages and disadvantages and to compare these with other available options. RWH is a popular household option as the water source is close by, convenient and requires a minimum of energy to collect. An advantage for household systems is that users themselves maintain and control their systems without the need to rely on other members of the community. The main disadvantage of RWH is that one can never be sure how much rain will fall. Other disadvantages, like the relatively high investment costs and the importance of maintenance, can largely be overcome through proper design, ownership and by using as much locally available material as possible to ensure sustainability (and cost recovery). The involvement of the local private sector and local authorities can facilitate up scaling of RWH. The barriers that exist to deter the implementation of RWH into new UK housing are (1) institutional and regulatory gaps, (2) economic and financial constraints, (3) absence of incentives, (4) lack of information and technical knowledge and (5) house-builder attitudes [13]. In the case of pilot area of Bekele Molla, the main barriers are especially the economic and financial constraints and the lack of capacity to operate and maintain.

4. Conclusions

The implementation of flushing toilets with rainwater involved could save 33 m^3/month of consumed potable water inside the MSBs. We can reduce the use of potable water for non-potable water needs by 42 L/household/d. However, the RWH system is recovering only 19.5% of total water demand and 84% of flashing water demand. The supply is limited by the amount of rainfall and the size of the catchment area.

The minimum installation cost per households is approximately 305 Euro. In fact, the automatic distribution of the harvested rainwater to the flushing toilet reservoir increases the complexity and the costs. The investment and operating cost of the option A and B compared to the medium standards living in Ethiopia was found relatively high. It is advised to reduce more the installation cost of this option and study more solutions for water scarcity in MSBs.

Rainwater harvesting alone does not have the capacity to solve the water supply problems at MSBs in Arba Minch. In general, for the construction of MSBs, the water supply situation should be considered as a main parameter. On the one hand, the public water supply development should be given highest priority to cover demands. If alternative solutions are needed they have to be included at the planning phase of MSBs.

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