Rainwater in Ethiopia as A New Energy Resources. New Approach to Sustainable Development in the Mountain Area

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Abstract. Rainwater harvesting can be not just the process of collecting, moving and the storing of rainwater for future use in the domestic area, offices or in the garden. Water collection can also be a process that can be used as one of the renewable energies sources. Ethiopia is the country where the rainwater in the mountain area is between 1270 to 1280 miller per year. Small-scale settlements integrated with irrigation technologies, especially micro irrigation, are still relatively new in Ethiopia - especially in connection with energy generation. The first part of the paper a water problem in Ethiopia is presented. Though the country’s highland has excessive rainfall, its poorest harvesting method and improper water management challenges development of the society in their activity toward poverty alleviation. In other way when there is heavy rainfall that the Ethiopian highland exhibits, there is the downstream rivers pollution and soil degradation with turbidity that challenges the aqua lives. It also hurts the existing limited number of hydro power reservoirs those generating the hydropower for major cities in the country. The second part presents result of the research program undertaken at Wollega University with co-operation with the West Pomeranian University of Technology in Szczecin by authors. The program goes on to attempt to solve the problem through application traditional and new technologies. This study highlights the use of rainwater and the formation of terrain to generate energy for human settlements in mountainous areas. In conclusions emphasizes, If the implementation of water and energy resources development projects will be really successful, significantly to ensure food security, vegetables and other cash crops will be produced to increase incomes and improve nutrition, and the burden of women in collecting water will be reduced. A virtuous cycle is then possible to increase food. That the research program will force architects, engineers and urban planners to revise and redefine contemporary design process and understanding of sustainable design.

1. Introduction
Most of the world water problems are all related to water. By proper rainwater management, we can reduce the risk of such problems and enhance the resilience. According to the UN and the Food and Agriculture Organization (FAO) report, one billion people do not have access to safe drinking water and some 840 million people still suffer from undernourishment [1]. Due to climate change and urbanization, water shortage problems are increasing throughout the world in both developing and developed countries. Ethiopia is very well known for its enormous water resources potential, especially rainwater in its the Ethiopian Highland. The presented study is an application of an
experimental approach in recently re-opened discussion on possibility and advisability of creating a systemic solution to resolve the problem of supplying the country and neighbouring areas with water. It envisions a new infrastructure to collecting rainwater in the Ethiopian dryland plateaus bordered by mountain. This rainwater harvesting system could be able also to reduce the climate change impact to this unique region.

2. Methods of rainwater harvesting in dry lands

Water needs are directly proportional to population growth. Agriculture still accounts for at least 70% of the world’s total water usage [2]. Rainwater harvesting (RWH) is a technology where surface runoff is effectively collected during yielding rain periods (figure 1, 2). The harvesting of rainwater involves the collection of water from surfaces on which rain falls, and subsequently storing this water for later use. Rainwater harvesting consists of 5 components: 1) rainfall, 2) catchment areas, also called watersheds, onto which the rainwater falls, 3) gutters, or conveying channels, to bring rainwater from a catchment area to storage reservoir, 4) storage reservoirs can be tanks, ponds, dams and in situ storage in sand and soil, 5) retrieval water is extracted from reservoirs either by gravity or by pumps and lifts. With its low-tech approach, flexibility of design, and near-universal applicability, rainwater harvesting remains popular, and is practiced in places as diverse as India, Brasil, Sierra Leone, Tunisia, Ethiopia and many other countries around the world.

![Figure 1 a-b-c](image1.png)

**Figure 1 a-b-c.** Traditional collection water from surfaces a) contour ridges, b) Contour-bench terraces, c) semi-circular and trapezoidal bunds, [3]

![Figure 2](image2.png)

**Figure 2.** Methods of rainwater harvesting in dry lands, [3]
Rainwater harvesting has a long tradition for thousands of years. Runoff water harvesting is best known and practiced in the semi-arid areas where annual rainfall is in the range between 400 and 600 mm. The runoff irrigation facilities in the Negev Desert were built during the Israeli Babataean and Roman-Byzantine periods back in the 1,300-2,900 years, and this practice provided a livelihood for a considerable population of more than 2000 years ago and continuing until about 700 AD [3].

![Figure 3 a-b-c. Traditional rainwater harvesting based on local materials](image)
a) small farm reservoirs, b) cisterns, c) wadi-bed cultivation, [3]

In order to support such technologies RWH systems should be based on local skills, materials and equipment (figure 3). One millimetre of harvested rainwater is equivalent to one litre water per square metre. After collecting and storing the rainwater is a source in households for drinking, cooking, sanitation, etc., as well as for productive use in agriculture, [4]. Even in regions that are water-rich, rainwater can provide benefits such as reducing water supply costs, reducing water extraction and ensuring water security in emergencies. Rainwater harvesting systems can reduce dependence on the mains water supply, relieving pressure on often overused water resources.

2.1. Rainwater harvesting in Ethiopia

Ethiopia is one of the largest countries in Africa (a land area of 1.13 million km²). With a population of over 107 million people, it is the most populous country in sub-Saharan Africa, and the third on the continent (figure 4). The country is known as the Water-tower of North-Eastern Africa for its source of 12 big River Basins including the Blue Nile. Annual rainfall in the country ranges between 2700 mms in the south-western highlands and less than 200 mms in some parts of the northern and south-eastern lowlands with a further decrease to 100 mm in the north-eastern lowlands [5]. Ethiopia has five major agro-climatic zones, which are broadly defined on the basis of altitude ranges, viz. Bereha, Kolla, Weyna-dega, Dega and Wurch. Climatically Ethiopia is in equator and the majority of its highland are getting maximum rainfall from June to mid-August where the western part gets rain from May to mid-September. The greater riftvalley area has minimum rainfall in comparative to highlands. There are deserts like Afar area, Ethiopian Somali land, Borena and part of Harar.

![Figure 4. Ethiopian highland map and areas bordered by mountains](image)

The history of water harvesting in Ethiopia dated back as early as the pre Axumit period (560 BC). It was a time when rainwater was harvested and stored in ponds for agricultural and water supply purposes. Anthropologists [6] have documented evidences of the remains of ponds that were once
used for irrigation during this period. A roof water harvesting set up is still visible in the remains of one of the oldest palaces in Axum; the palace of the legendary Queen of Sheba. Other evidences include the remains for one of the old castles in Gondar, constructed in the 15-16th century, which used to have a water harvesting set up and a pool that was used for religious rituals by the kings. In south of the country, the Konso people have had a long and well establis hed tradition of building level terraces to harvest rain water to produce sorghum successfully under extremely harsh environment; low, erratic and unreliable rainfall conditions. It is indeed one of the wonders of this country, and it has been practiced for millennium; a symbol of struggle for survival by the Konso people against the adversaries of nature [7]. Currently, the rain-water-harvesting techniques most commonly practiced in Ethiopia are run-off irrigation (run-off Farming), flood spreading (spate irrigation), in-situ water harvesting (ridges, micro basins, etc.) and roof water harvesting. These techniques, though dates back in the antiquity, their importance has not been recognized until very recently, it was following the devastating drought and famine of the 1980s [8] (figure 5).

Figure 5. Typical methods of rainwater harvesting in Ethiopia (Southern Tigray) Photos: Kifle Woldearegay

The promotion and application of rainwater-harvesting techniques as alternative interventions to address water scarcity in Ethiopia was started through government-initiated soil and water conservation programmes. It was started as a response to the 1971–1974 drought with the introduction of food-for-work (FFW) programmes, which were intended to generate employment opportunities to the people affected by the drought. The earlier rainwater harvesting activities included, among others, construction of ponds, micro-dams, bunds, and terraces in most drought-affected areas in Tigray, Wello and Hararghe regions (Kebede 1995). Non-governmental organisations (NGOs) involved in Integrated Rural Development Projects (IRDPs) and the water sector in many parts of the country also undertake rainwater-harvesting interventions. These interventions include conservation of rainwater by making use of physical structures and rainwater harvesting for domestic and irrigation purposes through pond and micro-dam construction and roof catchment schemes [9] (figure 6).

Figure 6. Percolation ponds to collect water from road, Zata area, Southern Tigray, Design and construction by MERET, Tigray Bureau of Water Resources, 2013. Photos: Kifle Woldearegay
The country is currently economically unable to optimally utilize its large rivers for different development purposes in line with national/regional/local interest. The only water resource available is rainfall as a local source and this is why rain water harvesting is extremely necessary. Even though the country has huge water resources; 12 river basins with an annual runoff volume of 122 billion of water with an estimated 2.6 billion cubic meter of ground water potential, the effort made so far to exploit these resources is extremely low, [9]. In contrary there is a water shortage and food insecurity because of the people poor water management and lack of smart water utilization. It is an ideal place to conduct research in the area of water potential analysis and management. Majority of the country is highland and exhibits great ground water flows from those high lands and mountainous areas to lowlands.

One of the major challenges in rural Ethiopia is the ever-growing magnitude of soil erosion. Ethiopia is among the three most countries of the world affected by massive soil erosion. Annually, Ethiopia losses up to 200 tons of soils from every hectare of agricultural lands. Erosion in the form of sheet erosion is massively taking place on croplands [10].

In the last years, two opposite school of thoughts have developed: the first one suggests that intense rainwater management can have negative effects on downstream agri-ecosystems, due to the reduction in water availability for downstream areas, while the second one affirms that the intensification of these interventions may lead to a global increase in the catchment ecosystem services, in particular by reducing peak flows and erosion, increasing base flow and groundwater recharge [11]. However, the most recent studies on the effect of rainwater management intensification are based on a modelling approach [8],[12], while practical field analysis are lacking [10].

These issues were addressed by authors to be developed as part of a research program (Climate Change Adapted Architecture and Building Structures) which is currently running at the West Pomeranian University of Technology in Szczecin (Szczecin WPUT). The research program is focused on the climate change oriented design as an adjustment of conditions compatible with changeable climate characteristics and ecology. New strategies are developed to anticipate exterior environmental variations as well as interior interaction with inhabitants to response to all weather phenomena during the global climate change era.

3. Research
This research covers issues of water management in Ethiopia during the climate change era. The studies concern on dryland plateaus bordered by mountains around 3000 – 3500 m a.s.l., scattered precipitations of the summer rainy seasons represent the main source of water for the rural population and the environment (for example Southern Tigray, the north region of Ethiopia). The southern, central, eastern and southern highlands of the country have a bi-modal rainfall pattern while the south-western and eastern areas are characterised by a mono-modal rainfall [12].

In the first part of our research project, different approaches to water management in Ethiopia were considered, with a focus on rainwater harvesting strategies and techniques rooted within local tradition of agriculture. The main negative and positive factors affecting agri-ecosystems and the catchment ecosystem services were defined. The impact negative effects of climate change along with their correlation with practiced rainwater management (lack and excess rainwater) were discussed. The second part of the research goes on to attempt to solve this problem through architectural design, using the latest technology and traditional techniques such as a hydrostatic pressure produced by elevation of water. The intention of this design was to not only to minimise but to eliminate any negative environmental impact completely along with their correlation with traditional method of rainwater catchment in the mountains. This was possible by using intelligent and sensitive design conceptualization. The proposed systemic solutions such as hillside suspended rainwater reservoir tank systems and vertical hillside farming would be responsible for the minimise the ever-growing magnitude of soil erosion the dryland plateaus bordered by mountains. With the use of parametric design tools, and multidisciplinary knowledge design ideas are programmed and represented visually in the form of diagrams, drawings, digital abstract or physical models and computer-generated images.
This type of concept representation can be not appropriate for a precise, and unique material reality and further states that even the most convincing techniques of representation do not correspond fully to the experience of the built reality. Therefore, a representation is usually a description of way of thinking and material systems.

4. Results - envisioning hillside rainwater reservoir tank systems and vertical hillside farming

The natural resource bases of Ethiopia seem to have a potential for supporting a far greater number of the population. Ethiopia’s geographic location and its natural endowment of favourable climate have provided it with a relatively higher rainfall in the region. Rainfed agriculture is the dominant form of land use in Ethiopia. The economy of the country is highly sensitive to climate, and extreme variability on intensity of rainfall and frequency of dry spells are the main causes of drought [8]. In this context, rainwater management and rainwater harvesting represent fundamental tools for land and water development, because they allow the management, the storage and the use of scattered and intense precipitation for productive purposes, allowing to overcome dry spells and to enhance local ecosystems rather than generating violent runoff flows, erosion and sediment loads in downstream areas [11].

4.1. Hillside rainwater tank capsule systems

Geologically the country is dominated with volcanic rocks from northern, Eastern and from southern to partly western. The western has metamorphic rock coverages and sedimentations are there as well following the Abay River (Blue Nile) gorges. The Eastern parts like Harar area has sedimentary rock coverage in addition to volcanic rocks. For many traditional communities in rural areas where natural sources of water are lacking, collection of rainwater from pits on rock outcrops and excavated ponds are common practices [13]. It makes opportunity to use these hillsides to construct a simple gravitational system of rainwater harvesting. The aim of the technical solutions is to provide water protection to the development of the crop in the dryland plateaus bordered by mountains.

Figure 7. Rafał Kapusta, Rainwater tank capsule systems on volcanic rocks in Ethiopia, West Pomeranian University of Technology in Szczecin, 2017
The reservoir tank capsules, connected with distribution system a water, can rely on hydrostatic pressure produced by elevation of water (due to gravity) to push the water into domestic and irrigation water distribution systems. Elevated tanks do not require the continuous operation of pumps, as it will not affect the distribution system since the pressure is maintained by gravity. Strategic location of the tank can equalize water pressures in the distribution system. However, precise water pressure can be difficult to manage in some elevated tanks. The use of elevated water storage tanks has existed since ancient times in various forms. Throughout history, wood, ceramic, and stone tanks have been used to construct water tanks.

4.2. Recultivation and vertical farming with use rainwater

Taking the large scale agriculture to the mountains, means shifting from horizontal cultivation model to a vertical one. By elevating the farming megastructure on hillside-runoff systems most of the affected by massive soil erosion will be available for recultivation of the cleaned-up agricultural lands. The recultivation should imply a package of measures aimed at the restoration of productivity and economic value of the lands disturbed in the course of nature management as well as improvement of environmental conditions. Recultivation period can last ten years and more. It includes technical and biological stages. Biological stage should involve fertility restoration performed after the technical stage; it will be including a package of agrotechnical and phytomelioration measures aimed at restoration of historically established system of flora, fauna, and microorganisms.

![Figure 8.](image)

**Figure 8.** Karaol G. Kowalski, Rock-wall vertical farm in the Ethiopian highland (concept design), West Pomeranian University of Technology in Szczecin, 2017.

The envisioned hillside structure offers vertical farming protected from the environment, but still uses natural sunlight as primary source of lighting and heating (figure 8). Artificial lighting can be assured as a support system for a water-based method of growing plants. It includes also using mineral nutrient solutions (cultivation without soil) or supported by an inert medium, e.g. perlite, gravel
(hydroponics technology) [14]. The aim of the technology is to provide protection and maintain optimal growing conditions throughout the development of the crop. Although, aquaponics technologies could be preferred – a closed water cycle system combining aquaculture with hydroponics in a symbiotic environment with participation of nitrifying bacteria. Water from an aquaculture system is fed to a hydroponic system where bacteria purify it by gradually breaking down the aquaculture’s by-products to the nitrates utilized by plants as nutrients [14]. In this case local rainwater should be used to growing plants. A basic principal of the design was to provide closed cycle of water and an alternative sustainable source of completion if needed. As a result, the main source of water needed for cultivation process should be delivered by rainwater from rock surfaces. A water supply sub-system could be delivered by water-from-air absorption system, which was designed as a structure envelope. It will be based on advanced hygroscopic materials such as a water absorbent foam mesh currently under development. Humid air flows through the foam mesh, where condensation process occurs. Although, the harvester is meant to be connected to the power grid, its primary source of electricity will be translucent photovoltaics system and the secondary power source will be wind turbines in its core shaft. The next generation PV will rely on the light spectrum which is also utilized in photosynthesis process, therefore only small amounts of the necessary spectrum will be available for plants’ growth process. However, translucent envelope will provide a visible spectrum, which is necessary for human vision. The main source of light for cultivation purpose will be delivered by artificial lighting, based on LED technology. After the recultivation period (the ten years) the hillside farms could be exchanged to rainwater reservoirs.

Figure 9. Rafal Kapusta, Karol G. Kowalski, Krystyna Januszkiewicz (mentor), Rock wall vertical farm and rainwater reservoirs systems in the Ethiopian highland (concept design), West Pomeranian University of Technology in Szczecin, 2017

Depending on the location and needs, the rock walls vertical farms and the reservoirs or rainwater tank capsules on volcanic rocks could be created a water-food bank system combined for both private and public roles (figure 9). Different human settlements in mountainous areas such as habitats and breeding or agriculture farms could create Wi-Fi networks with a local water management to inform about water and vegetables demand. It would become a living part of the dryland plateaus in Ethiopia.

5. Conclusions
Rainwater harvesting practices and their recognition as alternative options to supplement other water sources is not new in Ethiopia. Population growth in the country and shortage of resources and food security demanded to intensive forms of development, and rainwater harvesting for both domestic water supply and for agricultural purposes is increasingly becoming important. Given the good potential of Ethiopia’s agro climatic resources, the prevailing limitations in terms of rainfall
distribution and amount could be effectively addressed if rainwater harvesting is seriously taken. An integrated approach is essential to pursue a more effective water management.

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