Review

Water harvesting technologies in semi-arid and arid areas

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Received 4 July 2019, Accepted 3 August 2019

Abstract: With the increases in world population, the demand for natural resource like water also increases. Groundwater and surface resources have been used are being utilized quicker than they could be replaced. Thus, water harvesting is an exercise that has been implemented by several countries as a feasible means of water management techniques. The aim of this paper is to review of literature on various types of water harvesting technologies available in different semi-arid and arid areas; to show features of water harvesting technology use and storage mechanisms; and to overview major pros and cons of water harvesting. It is concluded that since there are various water harvesting techniques with their unique characteristics, pros, and cons, it is always crucial to take the local context in to account where the water harvesting techniques are implemented.

Keywords: catchment, semi-arid and arid, technologies, water harvesting

To cite this article: Gebreyess, B.F. and Amare, A. 2019. Water harvesting technologies in semi-arid and arid areas. J. Degrade. Min. Land Manage. 7(1): 1921-1928, DOI: 10.15243/jdmlm.2019.071.1921.

Introduction

Human beings are endowed with an environment consisting of various natural resources which are crucial for life. Natural resources reinforce the basis of human activity (Kumar and Gopal, 2015). Environment consists of natural resources such as air, water and land and the interrelationships that happen among and between these resources and human beings and other living things such as microorganisms, animals and plants. Human beings are consuming massive quantities of natural resources in their day to day life without having much knowledge of their sustained ease of use in the future or the real value a diminishing natural resource (George, 2015).

Confronting the challenges of food needs of an increasing population of Africa, for instance, necessitates a model that goes beyond concentrating only on productivity. Rather it should also consider addressing poverty, appropriate natural resource administration and sustainable development (FAO, 2014). Most of these natural resources are limited that wise utilization of the resources is crucial and without which survival of human being is unthinkable. Water is among the limited resources that need efficient and effective utilization for sustainable economic and social development. It is pointed that because of a continuous increase in population from time to time, the demand for water usage for agricultural activities is also increasing. Moreover, due to the same reason, there are various areas where water resources are scarce to meet domestic needs such as for drinking and sanitation, and for agricultural purposes. (Dearing et al., 2014; Cosgrove and Loucks, 2015; Pradeep, 2016). These days, various parts of the world are negatively influenced by shortage of water scarcity (Mancosu et al., 2015). This problem is further aggravated by adverse influences of climate variation (e.g. drought) on the sources of water which causes water scarcity (Calow and Mason 2014; Schewe et al., 2014; Gerard et al, 2015).

According to the United Nations water development report of 2006, a combination of higher evaporation and lesser precipitation in various areas decreases water levels in groundwater, lakes and rivers (Huntington and
Without availability of water, food production brings to an end, cities could stop functioning well, economic activities could be hindered and forests could be turned to desert (Schewe et al. 2014; CBD, 2016). There is now considerable indication that natural infrastructure and ecosystem renewal works could be applied. In most cases, these works give profitable and long lasting resolutions to scarcity of water. These include such as taking care of water deliveries by maintaining forests; recycling impurities for improving quality of water by working on forest or wetlands used as buffer zones; restoring soil biodiversity and functions to supply better-quality water accessibility to crops and hence increase food security, at the same time as decreasing use of water and off-farm problems; substituting, or decreasing administrative expenditures of water management facilities by restoring landscapes; regenerating natural water storage in catchments using swamps but also via reinstatting soil healthiness and land cover by decreasing flood, erosion and drought dangers; reinforcing coastal ecosystems as buffers for guarding coastal societies from storms; and retaining water in the ground by addressing desertification through repairing land cover and soils (Young and Loomis, 2014; CBD, 2016; Liu et al., 2017).

To ensure the sustainability of the water sector, it is necessary to design water investments together with pertinent subdivisions, like agriculture, industry and energy in order to exploit progressive employment and economic results. By implementing an appropriate governing framework, private -public partnerships provide promises for ample desirable deal in the water sectors, comprising constructing and functioning setup for water supply and irrigation, treatment and distribution (Van Leeuwen, 2015; Lund, 2015; UNWWAP, 2016). Reliable natural resources are indispensable for sustainable development. However, infrastructure and technologies of water storage like huge dams could interrupt ecosystem stabilities. Some soft structure (e.g. flood plains, wetlands, and groundwater recharge), moderate walls, harvesting of rainwater, or properly sketched structure are more environmentally profound and economically gainful (Norris and Suomela, 2017; Markolf et al., 2018).

Water harvesting offers water not only for drinking purpose but also both for rain-fed farming systems and animals of the dry lands mainly in the developing world by using underutilized water potentials. Water harvesting contributes for reducing hunger and alleviating poverty, and improving the resilience of the environment. Water harvesting is a technique of water management that is supposed to contribute, significantly, to ensuring sustainability of water in various nations. Water harvesting could be explained as all actions to accumulate obtainable water resources, provisionally storing leftover water for consumption when needed, especially in drought seasons or when no continuing water resources are existing (Kalkidan and Tewodros, 2017; Lani et al., 2018). The initial point is to collect natural water resources from fog, rainwater, runoff water, groundwater or even waste water, which if not would have been runaway (Patel and Shah, 2015; Srivastava et al., 2015; Madkour et al., 2018; Qadir et al., 2018). Water harvesting is also defined as “The collection and management of floodwater or rainwater runoff to increase water availability for domestic and agricultural use as well as ecosystem sustenance” (Studer and Liniger, 2013).

To alleviate water scarcity problem and better utilization of water resource, new techniques are essential to be developed and the existing techniques should be reconsidered. Hence, these paper reviews the different types of water harvesting techniques used in semi-arid and arid areas.

There are many different techniques of harvesting of water which have been developed through time. Water harvesting technology with the identical techniques could be named differently in different districts and some others might be named similarly though they are totally unalike in reality. Accordingly, there are various descriptions and categorizations of techniques of water harvesting and the name of a technique practiced at the local and worldwide levels has not been clearly standardized. There are two commonly used criteria to categorize water harvesting system. These are the water storage method applied, and catchment type and size of it. The water harvesting classification based on type of catchment is distinguished in to four groups (Studer and Liniger, 2013). These are flood water harvesting, macro-catchment systems, micro-catchment systems, and harvesting of water from courtyard or rooftop. This classification looks at the catchment size and considers methods of storage and purpose of harvesting of water (Oweis et al., 2012; Tuinhof et al., 2012; Yemenu et al., 2014). Water harvesting technologies could be categorised in various ways based on the criteria that water harvesting is taking in to consideration: these include hydro-climatic hazards, agro-climatic zone, spatial scale of runoff collection, size, catchment type, storage systems and strategies, or water use (Oweis et al., 2012;
Tuinhof et al., 2012). Studer and Liniger (2013) summarized the four groups of water harvesting together depending on the type of catchment as follows.

**Water Harvesting Groups Classified Based on Catchment Type**

**Floodwater harvesting**

Floodwater harvesting can be described as pooling and storing of transitory canal pour for groundwater restoration, and for watering of plants. The distich between the catchment area and its destination may be quite long. Floodwater harvesting catchment type gives choice for the ideal use of flooding water. It is especially good where there is higher evaporation than rainfall. Harvesting of floodwater could be additionally categorized into floodwater diversion which is diverting the floodwater from the streambed and floodwater harvesting within streambed. In the case of the former one, it is also known as spate irrigation, water either overflows the stream (canal tank) onto nearby farm sites or pushed to get out from its original runway and diverted to the surrounding sites. In the case of the later method of floodwater harvesting, water is forced to flow on the streambed to infiltrate in to the soil to make the soil wet. Then water stored soil is used for farming (Critchley and Gowing, 2012; Oweis et al., 2012; Studer and Liniger, 2013).

**Macro-catchment water harvesting**

Water harvesting by macro catchment method is collection of overspill water from the slant of a highland or hill. It is collection of overflow water from surfaces of highlands or hills, diverting it onto required location of implementation using obstructions and storing mechanisms. The collected and stored water could be used for irrigation, animal production and household consumption based on the amount and safety of the available water (Critchley and Gowing, 2012; Oweis et al., 2012).

**Micro-catchment water harvesting**

Water harvesting by micro catchment is a way of collection of exterior overflow and occasionally small canal flow of water from short interval slight catchments. The overflow is accumulated in a nearby the used fields and kept in root region for consumption by the plants directly. Water is accumulated with in a limited boundary where plants are produced that the catchment and irrigation areas are found in the same zone. For this reason, there should be application of number of similar duplicated arrangements. This method is frequently used together with some agronomic practices such as plant growing, managing soil fertility and management of pest (Critchley and Gowing, 2012).

**Courtyard and rooftop water harvesting**

These types of water harvesting are used to maintain water access for household hygiene use or irrigation purpose. These are mainly used by developed and economic evolving nations such as the South-Pacific, India, China, the Caribbean, and Australia. Rainwater can be harvested from rooftops of houses or buildings of various services. The amount of the collected rainwater depends up on the size of the rooftops of houses and buildings and the amount of the rainfall in the season. Since the rainwater is trapped from the rooftops, there is not much wastage of water; from 80-85 percent of rainfall can be captured and deposited. Where there is no or lack of tap water, the captured water by rooftop mechanism is used for household drinking purpose. These mechanisms are applied in most semi-arid and arid regions. In the case of courtyard water harvesting, rainwater is captured from condensed, concreted ground or plastic covered ground. The amount of rainfall, slop of the surface, and size of the ground where water is stored determine the amount of volume of collected water (Oweis et al., 2012; Studer and Liniger, 2013).

**Major Technologies under Each Group of Water Harvesting**

An organized indication and small explanation of pertinent and similar technologies under each water harvesting group, using case studies from different regions, is given by Studer and Liniger (2013), based on the of management approaches, and tools and methods of technologies available in different parts of the world.

**Techniques under floodwater harvesting**

Some major technologies classified under floodwater harvesting are shortly pronounced as follows.

**Spate irrigation:** It is sidetracking periodic floods of short interval from short-lived streams to water cascades of flattened and embanked grounds in the surrounding areas by applying old-fashioned water diversion and dissemination technique. This technique is applied in the case of Eritrea.

**Floodwater and runoff farming:** This technique is accumulation of water which is practiced in Ethiopia. It aims to collect flood water and overflow from short-lived streams, roadsides and hillsides via impermanent rock and soil ridges for
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ranging crops, vegetables, and fruit trees. This technique is applied for immediate use of the water for farming site that farmers prepare temporary soil and rock ridges early to manage the upcoming runoff and floodwater.

**Harvesting of water from concentrated runoff for irrigation purposes:** This water collecting technique is practiced in the case of Spain. It is done by building bunds using slight stone to change the direction of the flood water on the way to almand plantations and/or cereals production sites from recurrent watercourses.

**Development of degraded dry river valley by water-spreading weirs:** It is a type of water harvesting technique which is practiced in Chad to distribute floodwater to nearby farming site by designing structures that can cover the whole part of basin. The purpose of the weirs is to disseminate the overflow water that come from valley floor and to enable the soil infiltrate ample water. This technique is not used for storing water for long time rather to distribute the overflow mainly to farming sites.

**Tabia:** Tabia sand ditch is a technique of water harvesting made in the gentle slope and bottom hill areas. It is usually prepared either in the bottom of foothills, inside or nearby to across the riverbeds at the foot portion of the watershed, in a place where a slope is not going beyond 3 percent and top soil is reasonably deep. This water harvesting technique is practiced in Tunisia mainly for producing tree products such as olive, almond, and palm, and annuals like barley.

**Jessour:** Jessour water harvesting technique is also applied in Tunisia which is an ancient overflow water harvesting technique mainly practiced in the semi-arid and arid highlands with slant plots. In this case a dyke which is made of earth is used as a block to prevent back sediments and overflow water, and then plants are grown on this part. It is used for the production of a various types of plants such as palms, almonds, and olives as well as cereals and legumes.

**Techniques under macro-catchment water harvesting**

According to Studer and Liniger (2013), the macro-catchment water harvesting group has been classified into small earth dams, sunken streambed structure, recharge well and sand dams. They are described as follows.

**Small Earth Dams:** It is preparing designs and constructing thin units of gorge by using small earth barriers or dams to store runoff created from upriver catchment areas. The barriers or dams are principally used for household use, watering plants or for providing animals to drink. Zambia is among good example of the cases where this technique is applied.

**Sunken streambed structure:** is maximizing water volume from thin fountains for additional irrigation by diggings in streambed to deliver provisional storage of overspill. This technique is implemented in India.

**Recharge well:** This type of technique of water harvesting is practiced in Tunisia. It is a drip irrigation technique intended for lowest use of labour and water for the best irrigation of crops and vegetables in semi-arid and arid areas. Injection or recharge shafts are essential to properly flow water towards deep aquifer of land. Injection shafts are appropriate basically in zones where there is thick impermeable or slowly penetrable layer between the surface of topsoil and the aquifer.

**Sand dams:** It is a stepping-stone brick wall across a periodic sandy river bottom that captures soil and rainwater rolling down to the drainage area. It is a simple, cheap and easy to maintain, reproducible water harvesting technique. It could supply clean domestic water for households’ consumption and it could also be used for irrigation purpose in dry and semi-dry areas. It is applied in Kenya.

**Types of micro-catchment water harvesting techniques**

Types of water harvesting techniques under micro-catchment are categorised into four classes. These are Furrow-enhanced runoff harvesting for olives, planting pits and stone lines, Fanya juu terraces and Vallerani system.

**Furrow-enhanced runoff harvesting for olives:** it is commonly practiced in Syria. Runoff harvesting through yearly built V-shaped micro catchments and it is improved by down slope ploughing of the land. The bunds should essentially be reconstructed annually. If the constructions are destroyed after a heavyweight rainstorm, they need to be restored. Application of this technique is not difficult and inexpensive to conserve, and people have sufficient indigenous cleverness for developing and maintaining this method. It is used for tree plants and sometimes for annuals simultaneously.

**Planting pits and stone lines:** This technique is applied in Nigeria. It is used for restoration of eroded soil through compost planting pits in mixture with outline stone outlines. The general purpose of this technique is to collect and store rainwater and overflow, and thus increase water
Rainwater is harvested from rooftop for different purposes by using a concrete tank. For instance, in the rainwater harvested from the rooftop can be used for the purpose of household consumption (e.g. for drinking and hygiene) and irrigating kitchen cultivation fields in warm and dry summertime. Thus, the water helps to improve the living condition of the households using this technique.

Features of Water Harvesting Technology Use, Storage and Watering Mechanisms

There are various features which need to be considered to use a water harvesting technology because they have implication on sustainable utilization of the technology. These features would be the type of the technologies, the context where technology would be used, by whom it would be used, how it would be introduced and implemented (Cosgrove and Loucks, 2015; Fernandes et al., 2015; Smith et al., 2016; Lopez and Huhn, 2017). The authors also indicated that technologies should be easy to build, consistent to practice, and simple to maintain. Moreover, their construction expenses should not be high and they should consider gender specific needs, and proper use of environmental services.

Water which is harvested by different techniques could be used in various fashions by implementation of different storage choices. Each storage choice could have its own special feature based on the mechanical practicability, social and economic desirability, and legal conditions. For instance, in India and China, there are fruitful ways of water storage to advance the administration of vessel watering by offering water to farmers as and when they want it. In Nigeria, there are cases of storage in tanks alongside waterway schemes. There is a long time habit of night-time storage vessel watering in Sudan whereas in the case of Ghana, the storage is done in combined form. Some storage of water in tanks and vessel watering mechanisms have enabled farmers get more consistent water and have allowed farmers to cultivate diversified crops (Doczi et al., 2014; Peloso and Morinville, 2014; Douhri et al., 2015; Yu et al., 2015; Khan et al., 2017; Salih et al., 2017; Hans, 2018). However, other storage and watering mechanisms have been unable to provide substantial benefits to the farmers. The advanced usage of consistent water harvesting technologies, storage and
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Watering mechanisms is vital and it could lead to wider aspects of agricultural advancement in developing countries especially in dry areas. Thus, first of all it is very crucial for those who participate in water management of agriculture to make appropriate selection of available type of water harvesting technologies based on their various features. Moreover, it is important to consider the significance of the context in which implementation of the technologies, storage and watering mechanisms are made as mentioned above.

Pros and Cons of Water Harvesting

Principal number of studies (Critchley and Gowing, 2012; Oweis et al., 2012; Scheierling et al., 2013; Rahman et al., 2014; Smith et al., 2016; Ghazaleh et al., 2017; Fuentes-Galvan et al., 2018) indicated that there are list of pros and cons of water harvesting when it is used as a means to meet water needs of living things. Some of the major benefits obtained in one or another way from water harvesting are described as follows, on one side. These can be creating an access to fresh and healthy water for households; providing water for livestock; increasing availability of water and productivity of crops in dry land areas which leads to maximize food production and security; creating opportunity for cultivating cash crops by giving a chance to full irrigation; overcoming extreme situations such as soil degradation and flooding which could occur by rainfall inconsistency; and minimizing the work load of women’s and children by making water access able to them in nearby. However, on the other hand, the aforementioned studies and other studies such as Islam et al. (2014) and Liuzzo et al. (2016) indicated that there are various constraints faced when using water harvesting. The major constraints of water harvesting could be possibility of an inability to secure enough amount of water required for intended purpose since supply of water could be restricted by storage volume; taking up space, specially fertile land for water harvesting pond and canal construction; source for waterborne illnesses and good means of mosquitos’ production; demanding big launching and repairing capital and labour; and cause of conflict between upstream and downstream group of users due to ownership issues for common construction of water harvesting infrastructures.

Conclusion and Recommendation

There are various natural endowments which human beings are depending on to their survival. Water is one of the crucial natural endowments for survival of human beings in particular and for living things in general. It has been experienced that there is an increasing need of the cautious use of the limited fresh water resources, and sustaining and recharging the groundwater in different parts of the world from time to time. It is due to the fact that if appropriate measures cannot be taken up immediately, there will be occurrence of crisis and then it will be detrimental to the very survival of mankind. For these reasons, different measures have been taken to manage water resources in many semi-arid and arid parts of the world. Implementation of varied water harvesting techniques, storage and water recharging mechanisms are among the measures taken by actors working in water sector. There are several benefits and constraints which come from using different types of water harvesting technologies that it is important to familiarize the technologies to the contexts where they are suitable in terms of place, persons, and purpose. In other words, it is crucial to use water resources efficiently by applying varies water management techniques that could be promoting economic growth, reducing poverty, considering environmental sustainability, and considering socio-cultural issues that could come from the application of water management techniques. Thus, individuals, governmental or non-governmental bodies which are working in water harvesting issues should consider the situation from different dimensions before deciding to implement a specific type of technique.

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