Assessment of Rainwater Harvesting Technologies in The Upper Takatu-Upper Essequibo Region of Guyana.

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DOI: 10.29322/IJSRP.8.5.2018.p7755
http://dx.doi.org/10.29322/IJSRP.8.5.2018.p7755

Abstract- Water scarcity severely impairs food security and economic prosperity in many countries today. The scarcity of water is directly linked to climate change, and its impact is clearly visible given the temperature and rainfall variability, and occurrences of drought that have increased and intensified over the last two decades. Rainwater harvesting (RWH) is listed among the specific adaptation measures that the water sector can use to cope with water scarcity due to climate change. However, there is limited application of RWH, despite its high potential for alleviating the impacts of climate change. Region # 9 or the Upper Takatu-Upper Essequibo Region of Guyana experiences erratic rainfall and hence often fails to support rain-fed agriculture due to recurrent droughts and flooding resulting in persistent crop failure and subsequent food shortages in the district. As a result, the Government of Guyana intervened to address the water deficit issues in some communities in Region 9 by implementing some RWH schemes/projects. This paper thus seeks to review how RWH systems have been applied in other regions in the world. The present investigation also proposes an analysis of Guyana's rainwater situation in aspects such as the cost analysis and the capacity depending on specific areas of this study, more over it indicates the necessity of further exploration, for different parameters to determine the optimum water capacity of the implemented systems.

Index Terms assessment, rainwater harvesting, technology, agriculture, Guyana, climate change,

I. INTRODUCTION

Water availability is crucial for the global economy since it is a vital resource in many forms of industry including agriculture, electric power generation and industrial manufacturing[2] [3]–[5]. However, in recent times water is becoming scarcer globally and it is becoming more apparent that it will become even more so in the future [3], [4]. Expected future population changes will, in many countries as well as globally, increase the pressure on available water resources thereby impairing food security and economic prosperity in many countries globally. The scarcity of water is directly linked to climate change, and its impact is clearly visible given the temperature and rainfall variabilities, and occurrences of drought that have increased and intensified over the last two decades. It has been estimated that about 70% of water used worldwide is used for agriculture with developing countries presenting the highest percentage as a result of growing population. The reduced water availability is already impacting food commodity prices, as shown by last year's sharp increase in global rice prices triggered by a drought-induced collapse of rice production in Australia. This prevailing situation has thus made it imperative to come up with alternative water supply measures to help deal with the scarcity of this vital resource.

Rainwater harvesting (RWH) is listed among the specific adaptation measures that the water sector can use to cope with water scarcity due to climate change. However, there is limited application of RWH, despite its high potential for alleviating the impacts of climate change. RWH is a general term which describes the concentration, collection, storage, and use of rainwater runoff for both domestic and agricultural purposes [6] [7]. Besides its application to agriculture, RWH may be developed to provide water for human consumption, other domestic activities, environmental purposes, and a number of small-scale productive activities [6] [8]. Other than large reservoirs, small on-site rainwater harvesting systems (RHSs) have been successfully implemented as alternative water supply sources in some countries like Japan, India, Singapore, Zambia, South Africa and the United States [8]–[12].

There are three major forms of RWH, namely In situ RWH, External water harvesting and domestic RWH [13]. In situ RWH is collecting the rainfall on the surface where it falls and storing in the soil. External water harvesting is collecting runoff originating from rainfall over a surface elsewhere and stored offside, both are used for agricultural RWH. Domestic RWH (DRHW) is where water is collected from roofs and street and courtyard runoffs [13]. Examples of these techniques include tied ridges, infiltration pits and fanyajuus which are all aimed at achieving sustainable agriculture [14].

II. RAINWATER HARVESTING FOR DRINKING PURPOSES

In Zambia, a study was conducted to investigate the applicability of rainwater harvesting in urban areas [15]. The concept of rainwater harvesting has been in use before in Zambia but mainly in rural areas. There was need to investigate what style of rainwater harvesting was suitable, the quality of harvested water, affordability of the system by utilizing local materials and skill, and economic and socio-cultural aspects. Two areas were selected based on the degree of water scarcity. The results of a survey indicated that water was among the two main agendas by the Residential development committee [8]. Design of the systems was based on the mass curve analysis for storage and rational formula for the gutters. Samples from the roof water system showed that the water can be used for drinking [15]. Although one cannot draw conclusions on the water quality based on one sampling, the indication was that the water which would be harvested from the pilot stations could be used for drinking purposes [15].

On the basis of hydrological and technical as well as social and cultural conditions, appropriate solutions for RWH were developed and evaluated in central northern Namibia [12]. Two small-scale RWH systems are examined: roof catchments using corrugated iron roofs as rain collection areas and ground catchments using treated ground surfaces. The feasibility of the RWH systems was assessed in relation to local socio-economic conditions. The calculations reveal that it is economically feasible to apply decentral techniques of RWH in terms of the roof catchment systems. Moreover, the proposed technologies provide comparable benefits to the public water supply. The ground catchment system, however, needs moderate subsidies to obtain the same benchmark.

Rainfall harvesting from rural/urban catchments has not received large attention in Jordan [16]. In the absence of run-off sewer systems in most Jordanian rural and urban areas, rainfall harvesting from roads, parking lots and rooftops can increase water supply for various domestic uses and help combat the chronic water shortages in the country. The Main aim of this paper is to measure the potential effects of using rainwater in residential areas of 12 Jordanian areas and
to provide recommendations to improve and enhance the process of rainwater harvesting. Results show that a maximum of 15.5 Mm3/y of rainwater can be collected from roofs of residential buildings provided that all surfaces are used and all rain falling on the surfaces is collected. The potential for potable water savings was estimated for the 12 governorates, and it ranged from 0.27% to 19.7%. Analysis of samples of harvested rainwater from residential roofs indicated that the measured inorganic compounds generally matched the WHO standards for drinking water. On the other hand, fecal coliform, which is an important bacteriological parameter, exceeded the limits for drinking water [17].

Recent severe droughts, concerns over the environmental impact of storm water runoff and increased water demands have generated interest in rainwater harvesting systems in humid, well developed regions, such as the southeastern United States. To study the use of rainwater harvesting in the region studies were conducted at three rainwater cisterns in North Carolina. Computer model simulations were conducted for 208l rain barrels and larger cisterns. Results of the monitoring study showed that the rainwater harvesting systems were underutilized, which was suspected to result from poor estimation of water usage and public perception of the harvested rainwater. The computer model simulated system performance by evaluating a water balance using historical rainfall data and anticipated usage. Simulation results showed that a rain barrel was frequently depleted when used to meet household irrigation demands and overflowed during most rainfall events. Simulations also illustrated the improved performance of large systems while providing an indication of diminishing returns for increased cistern capacity

III. RAINWATER HARVESTING FOR AGRICULTURAL PURPOSES

In India, a study was undertaken to propose an economic analysis of water harvesting structures for the Soan catchment [18]. The Soan river catchment in the northwest Himalayas is fed only by rainwater[11]. Hence, a strategy of rain fed agriculture had to be developed through water conservation and storage techniques. The purpose of the investigation was thus to see if they could control erosion and conserve water to meet the requirements of supplemental and pre-sowing irrigation for major cereal crops in the area and to maximize agricultural productivity. Benefit/cost ratios ranging from 0.41 to 1.33 were obtained for water harvesting structures of different sizes with estimated life of 25 and 40 years respectively, by taking into account different crop return from maize and wheat [11].

A study was carried out at three sites in Communal Lands of Zimbabwe with the objective to evaluate and recommend rainwater harvesting techniques that ensure effective capture and utilization of rainfall for sustainable crop production [19]. This was achieved through monitoring residual moisture, after every rainfall shower, and determination of maize yields of maize from the different tillage treatments. Tied ridges were ranked in retaining moisture compared to all the other treatments in the season under consideration. The farmers who practiced tied ridges realized yields of about 3 t/ha compared to conventional tillage treatments whose yields were about 1.5 t/ha. Yields were statistically significantly different for the different treatments, with the final recommendation being for the farmers to adopt the tied ridges system in areas that receive marginal rainfall and experience mid-season droughts [19].

Another study examined the contribution of RWH technologies to sustainable agriculture and rural livelihoods in Zimbabwe [14]. The methods employed included a questionnaire survey; key informant interviews and field observations. The main benefits of RWH technologies found in the study were an increase in agricultural productivity, and improving environmental management through water conservation, reduction of soil erosion and resuscitation of wetlands in the study area. However, the major constraints facing technology adopters were water distribution problems, labour shortage, and water logging during periods of high rainfall [14].

Since 2006, around 600 rainwater harvesting systems have been constructed for agricultural irrigation in Beijing. A study was done to analyze economic and financial performance of the constructed rainwater harvesting systems in rural areas of Beijing through the method of cost benefit analysis [20]. The results showed that the rainwater harvesting systems are economically feasible. However, the financial feasibility of rainwater harvesting systems depends on the charge for groundwater and on the size of the rainwater harvesting systems [20].

A field study was conducted to determine the effect of a combination of ridge and furrow method of in-situ rainwater harvesting with gravel mulch on corn production, soil moisture storage, and water-use efficiency in the dry semi-arid region of China [21]. Results showed that plastic-covered ridges had an average runoff efficiency (runoff/rainfall) of 87% as compared to 7% for bare ridges and could generate runoff at a threshold value of 0·8±0·2 mm rainfall. The plastic-covered ridge and gravel-mulched furrow method of rainwater harvesting was effective in conserving moisture and increasing yield and water-use efficiency. The grain yield under this system was 1·9 times that of the conventional flat soil cultivation, and the water-use efficiency was 1·8 times that of the control, which is attributed to the better utilization of light rains, improvement of infiltration in the root zone, and suppression of evaporation losses [21].

IV. THE CASE OF GUYANA

Region # 9 or the Upper Takatu-Upper Essequibo Region of Guyana is made up of the Kanuku and Kamoa highlands, and the vast Rupununi savannahs. Located in the south, it is the largest region in Guyana at 57,790 square kilometers and is classified as one of the 4 hinterland regions of Guyana. The Upper Takatu-Upper Essequibo region experiences approximately 1500mm to 2000mm of rainfall per annum. However, this rainfall is erratic and unreliable hence often fails to support rain-fed agriculture due to recurrent droughts and flooding resulting in persistent crop failure sand subsequent food shortages in the district. Despite this, rain-fed farming continues to be the principal livelihood activity for most farmers who practice subsistence agriculture. The El Niño episodes of 1997/98 and 2015/16 resulted in water shortages throughout the country. The situation was most severe in the Region # 9, which is generally speaking the driest part of the country. This resulted in the residents of the Region suffering losses in crops and livestock and experiencing severe hardship due to impacts on their livelihoods and welfare.

The information required for evaluating the sustainability and applicability of individual water harvesting techniques is lacking in many settings. Some information is available in peer- reviewed literature and in the reports of government agencies, institutes, and NGOs that implement water harvesting projects [24]. Despite a plethora of studies modeling the feasibility of the utilization of rainwater harvesting (RWH) systems in particular contexts, there remains a significant gap in knowledge in relation to detailed empirical assessments of performance [25]. In light of this shortage of information, we then decided to assess some of the rainwater harvesting systems that have been setup and Region # 9 (see Table 1) and evaluate the cost analysis based on the design and the water capacity in the communities they were setup in.

Farming activities and water sources.

In the communities visited, each house hold had at least one hand dug well that is used for domestic and for irrigation purposes. However, during the months of February to April some of these wells become dry. Some persons are left with no other choice but to source water from their neighbours drilled well or invest in drilling their own deep well.

At Nappi and Annai, subsistence crop farming is mainly practiced for the cultivation of cassava (bitter) manihot utilissima for the production of farine, cassava bread, casareep and other dietary needs. Crop farms are located in close proximity to the mountain foot and forest where rainfall is more frequent. These farm locations can be miles away from the community in some cases at least 8 miles away. Crop production is dependent on rain fed irrigation.

Some of the Annai farms are located in the village of Wowetta in close proximity to the forests and the Kanuka mountain range as a good vantage point to receive rainfall during the dry months. They are also springs located in the mountains that provide water for the farms. However, during the wet season (May to September) these farm locations are affected by flooding that contributes to crop loss. Hand dug wells and existing creeks provide water for a cluster of 8 to10 farmers to wash and process cassava on their farm locations.

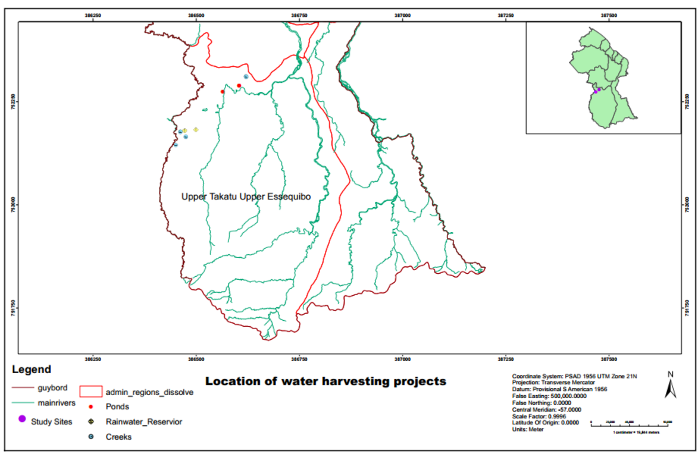
At Aranaputa, Central Lethem and Central Rupununi commercial mixed farming is practiced for the production of vegetables, fruits, grains, legumes, pasture grass, eggs, chicken, duck, pork, mutton, beef and fish. Crop and livestock production are dependent on various sources of water that includes combination of rainfall, hand dug and drilled wells, water catchments, rainwater reservoirs, creeks and rivers. Wells are usually generated by solar, wind and fuel pumps. Each commercial farm location possesses at least two wells (one hand dug and one drilled). The drilled wells serve as a reliable source of water during extreme dry months when the hand dug well fails. At some farm locations where a creek or river is located water is pumped to supply the crops and livestock during the wet season and early dry season (September to February) while the drilled wells are used for the late dry season (February to April).

Pasture and Orchard cultivation are irrigated by rainfall while Plant Nurseries, vegetable crops cultivated in Shaded culture and open fields are irrigated by hand dug and drilled wells and creeks. Rice cultivation is irrigated by river.

Rainwater harvesting projects

These projects were implemented to counter the effects of climate change, the Government of Guyana has invested heavily in smart Agriculture which is an approach that seeks to address both food security and climate change. Some of the objectives the Government seeks to achieve is increase in farm income, investment in climate resilient food crops and reduction of greenhouse gas emissions from agriculture. One of the ways is through sustainable management of natural resources and expansion of Environmental services i.e. Stewardship of natural patrimony. The Inter-American Institute for Co-operation on Agriculture (IICA) have made funds available to work in collaboration with the National Drainage and Irrigation Authority (NDIA) of the Ministry of Agriculture to develop a number of water catchment ponds in communities of Toka, Rupertee, Annai, Wowetta, Aranaputa, and Massara. The water catchment ponds provided water for livestock and crop production.

Fig 1. Map of Upper Takatu-Upper Essequibo showing the locations of rainwater harvesting projects.



The projects that were assessed mainly consisted of construction of reservoir dams and expansion of natural existing ponds created by the topography of the lands, which are fed by springs and creeks that included Nappi Reservoir, Annai Itch Pond, Massara Pond and the Aranaputa Cattle Pasture Pond. This water harvesting projects have inexpensive earthen lining to aid in sealing the cap.

Table 1: shows a general description of a list of water projects located in the Upper Takatu-Upper Essequibo.

Name of Project	Owner	Year Completed	/Pond Size (ft x ft)	Total Depth (ft)	Capacity (ft3)	Cost (US Dollar)
Nappi Reservoir	Public	2017	1476 x 18	272	4500000	1.250,000
Annai Itch Pond	Public	2017	380 (dia)	6	20000	31000
Aranaputa Cattle Pasture Pond/ Reservoir	Public	2017	200 x 100	12	8557	22000
Massara Pond	Public	2017	55 x 40	8	4228	18000

Sourced:[22]

Nappi Reservoir

This reservoir was completed in August 2017 and is situated in the village of Nappi. Nappi Village is located on top of a hill three miles away from the base of the Kanuka Mountains With a population size of 719 persons, farming and eco-tourism is done to support the livelihood of the village. Cassava farms occupy an average of forty acres while 280 heads of cattle are owned by individual farmers and or household. The Reservoir water will benefit approximately 3,000 residents for drinking purposes, agriculture, aquaculture, and assist nearby communities[22] The Nappi Reservoir dam was completed in 2017 with a dimension of 450 x 5.5 meters and has the capacity to hold 4.5 million cubic meters of water .It's equipped with a culvert and a spill weir 35 meters in width.

Annai Itch Pond

This pond was completed in September 2017 and is situated in the central village of Annai. Annai Village is located on top of a hill three miles away from the base of the Kanuka Mountains (Guyana Government Ministry of Agriculture, 2016). Annai Itch Pond was developed in the vicinity of an active spring which is the main water supply. This was a joint collaboration with the National Drainage and Irrigation Association (NDIA) of the Ministry of Agriculture and International Institute on Cooperation for Agriculture (IICA). With a population size of 543 persons, farming is the main activity done to support the livelihood of the village. Farms of Cassava (bitter) manihot utlissima occupy an average of seventy-five acres while Bananas, Peanuts and Citrus combined occupy a total of fourteen acres. Approximately 300 heads of cattle are owned by individual farmers and or household. The Reservoir water will be available for agricultural purposes. Presently there is no farming activity being conducted around the pond. Livestock and wild animals source their drinking water from the pond. However the village plans to cultivate cassava with the use of a drip irrigation system.[23]. The pond size estimates to an average 380 ft in diameter with an average depth of 6ft. The total storage capacity amounts to 26,180ft^3 [22]It was recommended that this pond can supply water for 10 acres of land for cultivation[1]

Massara Pond

This pond was completed in April 2017 and is situated in the village of Massara which is located in the south east of the Georgetown Lethem roadway and the Rupununi River. This was a joint collaboration with the National Drainage and Irrigation Association (NDIA) of the Ministry of Agriculture and International Institute on Cooperation for Agriculture (IICA). With a population size of 424 persons, farming and cattle rearing is the main activity done to support the livelihood of the village farms of cassava (bitter) manihot utlissima farms occupy an average of sixty acres. Approximately 150 heads of cattle are owned by individual farmers and or household.

Currently there is no farming activity being conducted around the pond, however the village plans to cultivate the cassava crop. Livestock and wild animals source their drinking from the pond during the season from October to April. The pond size estimates to an average dimension of 55ft X 40ft with an average depth of 8ft. The total storage capacity amounts to 4,228ft^3. [22]This expansion will supply water for the cattle and the farm lands [23].

Aranaputa Cattle Pasture Pond

This pond was completed in December, 2017 and is situated at the base of a mountain with a gentle sloping plain where the pasture will be established. An existing spring about 100ft up the slope of the mountain that presently supplies water [23]The Guyana Livestock Development Authority identified the location for the pond while the development was realized as a joint collaboration with the National Drainage and Irrigation Association (NDIA) of the Ministry of Agriculture and International Institute on Cooperation for Agriculture (IICA). With a population size of 604 persons, farming and cattle rearing is the main activity done to support the livelihood of the village. Farms of cassava (bitter) manihot utilissima farms occupy an average of eighty acres. Approximately 875 heads of cattle are owned by individual farmers and or household.

This pond was developed to supply water to pasture lands and for local livestock. The Aranaputa Cattle Pasture Pond was developed where it is fed by an active spring located in the mountains. The pond size estimates to an average dimension of 200 ft X 100 ft with an average depth of 12ft. The total storage capacity amounts to 11,193ft^3[22]. This expansion will supply water for the cattle [1]

The information required for evaluating the sustainability and applicability of individual water harvesting techniques is lacking in many settings. Some information is available in peer-reviewed literature and in the reports of the government agencies, institutes, and NGOs that implement water harvesting projects [24]. Despite a plethora of studies modeling the feasibility of the utilization of rainwater harvesting (RWH) systems in particular contexts, there remains a significant gap in knowledge in relation to detailed empirical assessments of performance [25].

V. CONCLUSION AND RECOMMENDATIONS

Water harvesting is a suitable strategy for adapting to water shortages caused by climate change and applicable as an alternative approach to source water in cities across the world [5], [13], [26], [27]. In contrast to water-abundant developed countries, where rain water harvesting is prevalently considered as a backup supply source, very often systems for rainwater harvesting are a primary source of fresh water in several developing and drought-prone developed countries. Constraints such as local regulations and costs of implementation and maintenance play a key role in the system penetration rates and used technology in the various continents.

Historically, challenges to the social acceptance of rain water harvesting technologies have focused on water quality, risk perception, health risk, as well as financial viability [6], [12], [15], [17]. Despite some households being resistant to using rainwater indoors, it is now acknowledged that rain water harvesting is an acceptable source of non-potable water compared to other types of water reuse for non- potable purposes.

There have been many studies that assessed the financial viability of rain water harvesting systems [13], [17], [18], [28], [29]. Many of these studies make use of simple tools to match costs and benefits of system implementation. Various results have been obtained on the different level of viability of rain water harvesting systems with regard to the system size [6], [17], [25], [28]. Consequently, future research is expected to provide the streamlining of financial analysis of rain water harvesting systems including multiple beneficial aspects under complex engineering, hydrological, economic and social settings.
New approaches to focus on how to best represent rain water harvesting at larger scales need to be tested in different countries with different climatic conditions. Furthermore, more field data on rain water harvesting systems is required. There is a particular need to dedicate additional efforts to the monitoring of available pilot installations in order to improve quantification and types of rainwater uses [28].
The adoption of rain water harvesting technologies in sustainable agriculture has shown that there is an increase in agricultural production, improvement of people's standard of living and reduces environmental degradation. However, governments, agencies and donors wishing to advance agricultural development must consider local circumstances and indicators of social and economic conditions when evaluating rain water harvesting technologies.

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