IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 14, Issue 3 Ser. II (March. 2020), PP 12-19
www.iosrjournals.org

Effects of Intensified Erratic Rainfalls on the Capacity of On-Farm Water Harvesting Systems in Checking Surface Run-Off in Matungulu Sub-County, Machakos County, Kenya

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Abstract: *Rainwater harvesting has been embraced as one of the adaptation strategies for people living with high rainfall and temperature variability. Performance of the water harvesting systems depends on the farming systems, soil characteristics and hydrological factors. Thisstudysought to establishto what extend intensified erratic rainfalls affects the capacity of on-farm water harvesting systems in checking surface run-off in Matungulu Sub-County, Machakos County, Kenya. A descriptive survey design was adopted in which some 105 randomly selected respondents were drawn from 5 sub- locations of Matungulu Sub-County. The 105 were selected from 2 sub-Sub-Countys based on livelihood of the 2086 target households that is cash crop farms and grain crop farms. 21 households for each livelihood strategy from each of the five sub-locations taking the odd-numbered items were used. A structured questionnaire was administered to obtain data on farmers' use of water harvesting systems and their performance in light of climate variability. The data was statistically analyzed and results displayed in tables, graphs and charts. The study established that theFanya-juu system is the most practiced harvesting system in the area at (n=67, 63.81 %,) followed by Negarimsat (n=38, 36.19%).Results further show water stress factors effects on surface run-off control capacity of fanya-juu(r=0.1718, p=0.0874) is positively correlated though not supported by statistical test of significance and positive and statistically significance for negarims(r=0.4901, p=0.0002), contour buds(r=0.5042, p=0.0001) and contour ridges (r=0.5828, p=0.0001). By implication, the findings show that climate variability effects on performance of on-farm water harvesting systems in food production is positive and significant forfanya-juu(r=0.2284, p=0.0191) but insignificant for the other systems withnegarims at (p=0.5930), contour buds (p=0.8341) and contour ridges (p=0.8346). Based on the climatevariability effects on the on-farm water harvesting systems selected, the Fanya-Juu system is the most appropriate for use in the area. The study recommends that farmers in the area should be encouraged through awareness creation to harvest water using the fanya-juu system. Farmers also need to be sensitized and trained on monitoring and evaluation of the effects of climatic variability on the harvesting systems. Areas suggested for further research include replicating the study using a representative sample of farmers in other ASALs areas.*

Keywords: *Erratic Rainfall, Capacity, On-Farm Water Harvesting Systems, Surface Run-Off*

Date of Submission: 12-03-2020 Date of Acceptance: 27-03-2020

I. Introduction

1.1Background of the study

Water harvesting (WH), has supported subsistence farming in the arid and semi-arid regions of the world for a long time and proved to be one of the most promising methods of making water available for crop growth in arid and semi-arid areas [3, 14]

. Most water harvesting practices in the arid and semi-arid areas collect run-off water produced by rainfall from a catchment area and store it in tanks or soil profile for irrigation use [1, 5]. Management and performance related to water harvesting and use has been highlighted as one of the most important adaptation requirements to ensure the development of effective adaptation strategies that are cost-effective, participatory and sustainable [13].A case study in the loess plateau of China, a semi-arid region with rain patterns much like Kenya, examined methods of constructing compacted micro-catchments in order to increase food production [6]. The study proposed using a mixture of locally available soils, compacted by simple rollers, in order to increase run off which would then be collected into other areas using common methods of water diversion. Although the study proved successful, soil erosion proved to be a problem during flash floods, making this solution undesirable for locations like arid regions of Kenya with existing erosional problems.

[2]did a review on rainwater harvesting and management in rain-fed agricultural systems in Sub-Saharan Africa. Their study indicates that micro-catchment and on-farm rainwater harvesting techniques are more common than rainwater irrigation techniques from macro-catchment systems. The study concludes that, rainwater harvesting techniques improves the soil water content of the rooting zone, reduces risk of crop failure during dry spells and also improves water and crop productivity.[16] on his study on the potential of rainwater harvesting to reduce pressures associated with poor rainfall patterns and water shortage, showed that there are significant opportunities available to upgrade rain-fed agriculture in water scarce savannah agro-systems. This upgrading requires a focus on rainwater management targeting drought and dry spell mitigation he concludes. [11] indicates that even though rainwater harvesting practices can yield positive results through effective increase of soil moisture for crops in water scarce areas, each system still has limited scope due to hydrological and socio-economic limitations.

1.2Statement of the problem

In Kenya some climate scenarios predict an increase in rainfall in the highland areas and decreases in others, but greater variability in cycles is expected everywhere[12]. As a result, we could see more frequent occurrences of extreme weather events such as flooding and drought.The challenge facing the ASALs ecosystem now is how to enhance communities' resilience whose livelihoods depend entirely on climate-sensitive resources[7]. Generally, developing countries are investing on several adaptation activities to address impacts of climate change in the agricultural sector. Water harvesting techniques are already being used in many areas to adapt to the drier, degraded conditions brought on in part by changes in climate.In Arid and semi-arid regions of Kenya, major stakeholders are increasingly looking into rain water harvesting as a decentralized solution to water needs. Despite this heightening interest, water harvesting and storage capacity remains dreadfully low in most parts of Kenya and is declining[4].Exacerbating water stress further in Kenya is the negative impacts of climate change to the adaptation measures already underway.

1.3Objective of the study

To determine to what extend intensified erratic rainfalls affects the capacity of on-farm water harvesting systems in checking surface run-off in Matungulu Sub-County, Machakos County, Kenya.

1.4 Significance of the study

The study provides insight to planners and policy makers across the water sector on how best to confront the challenges of water stress in the ASALs in light of climate variability. The study also elicits interest for academicians in the interactions between performance of water harvesting systems and climate variability with a view to finding out further how they affect each other. This increases the body of knowledge and forms a basis upon which further studies can be done.

II. Methodology

2.1 Area of study

Matungulu district in Machakos County formed the study area. It's located between latitudes1^{o}S to2^{o}S and between longitudes 37^{o}to 38^{o}E.It borders Kangundo to the south, Yatta to the north, Mwala to the East and Kathiani to the south west. The District is divided into three administrative Sub-Countys namely Matungulu, Tala and KyeleniSub-Countys (figure 3.1). The area is in a semi-arid region in Kenya, already experiencing water stress and highly susceptible to climate variability impacts especially on water resources. No similar research had been done in the past in the same region hence more relevant for such a study. Matungulu Sub-County has a population of 21725[8], area size of 40km$^{2.}$divided into Katheka, Matheini, Kingoti, Kambusu and Mwatati sub-locations, with 2086 households. The main activity for their livelihood is small scale grain farming in the low and rather dry areas and a mixture of grain farming and cash crop farming in the high altitude areas of gently sloping terrain.

2.2Research design

The research design used was descriptive survey of on-farm water harvesting systems being used by households within the Sub-County. This design was considered for this study because it involves specific predictions, with narration of facts and characteristics concerning theparticular technique performance [9].Descriptive survey studies are designed to obtain pertinent and precise information concerning the status of a phenomenon and whenever possible to draw valid conclusion from the facts discovered.

2.3 Sampling design

According to[10],population refers to an entire group of individual's events or objects having common observable characteristics. The target was all households using on-farm water harvesting systems in Matungulu

Sub-County. Since the population targeted was large and its members scattered all over the Sub-County, purposive sampling was used in this study to generate the data needed. Purposive sampling used ten percent (10%) of all the 2086 households. Two sub-Sub-Countys based on livelihood of the target population, that is cash crop farms (coffee) and grain crop farms (maize and beans) were used, 21 households for each livelihood strategy from each of the 5 sub-locations were sampled taking the odd-numbered items. This was designed to gather information from each and every representative member of the population [17].

2.4 Data collection

Primary data was collected using a structured questionnaire. The questionnaire contained both closed ended questions and a few open ended questions. Part I of the questionnaire included a short demographic questionnaire. Part II of the questionnaire included factors that influence performance of water harvesting as conceptualized in this study. The components included per factor were considered to be indicators of the impact on the performance.

2.5 Data analysis

Before analysis, the data was checked for completeness and consistency. Standard statistical tools-frequency, distribution, measures of central tendency was used. Inferential statistics such as coefficient of correlation were used to assess the relationship between the climate variability parameters (flash floods, droughts, erratic rainfalls) and the performance of the water harvesting systems(*Fanya-Juu*, Contour bunds, Contour ridges and Negarims).

III. Data Analysis and Discussions

3.1The on-farm water harvesting systems used by households

The on-farm water harvesting system practiced by the farmers in the area are Fanya-juu, Negarims, contour bunds, contour ridges and damming. The farmers who practiced Fanya-juu were 67 representing 63.81 per cent of all the farmers interviewed. This system of Fanya-juu was practiced by 29 (27.62 per cent) and 38 (36.19 per cent) males and females respectively. This shows that a greater percentage of female farmers practiced this system of Fanya-juu compared to the male farmers practicing it. Farmers with primary education level who practiced Fanya-juusystems were 20 (19.05 per cent), with 37 (35.24 per cent) and 10 (9.52 per cent) practicing Fanya-juu system having attained secondary and post-secondary education level respectively.

Negarim system of water harvesting was practiced by 38 (36.19 per cent) of the farmers interviewed. The male and female farmers who practiced Negarim system were 15 (14.29 per cent) and 23 (21.90 per cent) respectively.Negarim system of water harvesting was practiced by eight (7.62 per cent) of the farmers with primary education, with 29 (27.62 per cent) and one (0.95 per cent) of the farmers who had attained secondary and post-secondary education using the system.

The sampled farmers who practiced contour bunds were 22 representing 20.95 per cent of all the farmers interviewed. This system of contour bunds was practiced by 14 (13.33 per cent) and 8 (7.62 per cent) males and females respectively. This shows that a greater percentage of male farmers practiced this system of contour bunds compared to the female farmers practicing it. Farmers with primary education level who practiced contour bunds system were two (1.90 per cent), with 20 (19.05 per cent) and none who had attained secondary and post-secondary education level respectively practicing contour bunds system.

Contour ridges system of water harvesting was practiced by 21 (20.00 per cent) of the farmers interviewed. The male and female farmers who practiced contour ridges system of water harvesting were seven (6.67 per cent) and 14 (13.33 per cent) respectively, showing that the female farmers practicing this system of contour ridges doubled the males carrying on the contour ridges system. Contour ridges system of water harvesting was practiced by five (4.76 per cent) of the farmers with primary education, with 11 (10.48 per cent) and five(4.76 per cent) of the farmers who had attained secondary and post-secondary education practicing contour ridges system.

Thus the Fanya-juu system followed by Negarims systems of water harvesting were most reportedly being practiced by the farmers in the area irrespective of their gender and level of education attained. More males preferred the contour bunds systems compared to females, while a greater proportion of female farmers opting for contour ridges system in relation to male farmers.Two female farmers, who had attained post-secondary education reportedly, practiced damming as a way of harvesting water to supplement rain fed agriculture.

Reasons given for water management by the respondents varied. The reason for practicing water harvesting system by 30 (28.57 per cent) of the respondents wasto trap water for crop irrigation. This is in line with the suggestion by[14, 5,1, 3]that rain water can be used to irrigate. In addition 40 (38.10 per cent) reported that it was to check, control and minimize soil erosion, while 37 (35.24 per cent) reported that it was intended for increasing moisture conservation and take water to the roots. Similar views were given by[18]who said that the availability of water in the root zone is increased by water harvesting.[2] established the same findings that rainwater harvesting techniques could improve the soil water content of the rooting zone. These reasons were similar to those established by[15]on adoption of water-efficient technologies to 'harvest' water, conserve soil moisture and improve water management to prevent water erosion.

3.2Extent to which intensified erratic rainfalls affects the performance of on-farm water harvesting systems in checking surface run-off

In addressing the objective the researcher focused on three different aspects. The first aspect was onthe reduction of rainwater run-off control capacity under different on-farm water harvesting techniques due to erratic rainfall. Second was looking at the difference in yield production during well distributed rain seasons and erratic rain seasons. Thirdly by investigating, the farmers' perception on the effectiveness of water harvesting systems used based on observed yield production during well distributed rain seasons and erratic rain seasons.

3.2.1 Reduction of rainwater runoff control capacity due to erratic rainfall

In relation to the reduction of rainwater run-off control capacity under different on-farm water harvesting techniques due to erratic rainfall, 50 (47.62 per cent) and 48 (45.71 per cent) of the respondents strongly agreed and agreed respectively that erratic rainfall reduces the rainwater run-off control capacity ofFanya-juu system. Only two (1.90 per cent) of the farmers interviewed disagreed.

Under the Negarims technique of water harvesting 40 (38.10 per cent) and 39 (37.14 per cent) strongly agreed and agreed respectively that erratic rainfall indeed leads to reduction in the rainwater run-off control capacity. Only eight (7.62 per cent) disagreed with an equal number strongly disagreeing that erratic rainfall reduces the rainwater run-off control capacity under the Negarim technique. This shows that there exists a similar response by the farmers in the Fanya-juu and Negarim systems.

Table 3.1: Reduction of rainwater runoff control capacity due to erratic rainfall

		Strongly agree	Agree	Disagree	Strongly disagree	Not sure
Fanya- juu	Freq (%)	50 (47.62)	48 (45.71)	2 (1.90)	0 (0.00)	5 (4.76)
Negarims	Freq (%)	40 (38.10)	39 (37.14)	8 (7.62)	8 (7.62)	10 (9.52)
Contour bunds	Freq (%)	25 (23.81)	52 (49.52)	8 (7.62)	3 (2.86)	17 (16.19)
Contour ridges	Freq (%)	24 (22.86)	44 (41.90)	19 (18.10)	1 (0.95)	17 (16.19)

Similar trends also emanated from the farmers' responses pertaining to the effect of erratic rainfall on the rainwater run-off control capacity under contour bunds and ridges systems. In the case of contour bunds system 25 (23.81 per cent) of the respondents strongly agreed while 52 (49.52 per cent) agreed that erratic rainfall reduce the rainwater run-off control capacity. The farmers who disagreed with the assertion were eight (7.62 per cent) and three (2.86 per cent) strongly disagreeing. Contour ridges system was not an exception as the farmers who strongly agreed were 24 (22.86 per cent), while 44 (41.90 per cent) agreed to the reduction of rainwater run-off control capacity due to erratic rainfall. The farmers who disagreed were 19 (18.10 per cent) while only one (0.95 per cent) strongly disagreeing with the claim that erratic rainfall reduces the rainwater runoff control capacity, under the contour ridges technique of water harvesting.

From the frequency and percentage tabulations least affected by erratic rainfall is the Fanya-juu technique, according to 98(93.33 per cent) of the farmers interviewed, followed by Negarim technique as reported by 79 (75.24 per cent), then contour bunds technique77 (73.33 per cent) and lastly contour ridges technique according to 68 (64.76 per cent) of the farmers interviewed. The analysis also depicts that the effect of erratic rainfall on rainwater run-off control capacityfor both contour bunds and contour ridges techniques of water harvesting was not known by a relatively greater proportion of farmers.

The correlation matrix in table 3.4 gives a correlation coefficient in relation to runoff control capacity of 0.1718 for fanya-juu, 0.4901 for negarims, 0.5042 for contour bunds, and 0.5828 for contour ridges. The associated probability values (p-values) for fanya-juu, negarims, contour bunds and contour ridges are 0.0874, 0.0002, 0.0001, and 0.0001 respectively in relation to reduction of rainwater run-off control capacity due to erratic rainfall. Hence, reduction of rainwater run-off control capacity due to erratic rainfall is positively and statistically significantly correlated to negarims, contour bunds and contour ridges on-farm water harvesting techniques at the five per cent level of significance.

Table 3.2: Correlation matrix for reduction of rainwater runoff control capacity

		Runoff control capacity	Fanya-juu	Negarims	Contour bunds	Contour ridges
Runoff control capacity		1				
Fanya-juu		0.1718	1			
	p-value	0.0874				
Negarims		0.4901*	0.3520*	1		
	p-value	0.0002	0.0007			
Contour bunds		0.5042*	0.3523*	0.2928*	1	
	p-value	0.0001	0.0009	0.0072		
Contour ridges		0.5828*	0.1188	0.3685*	0.6971*	1
	p-value	0.0001	0.2759	0.0006	0.0001	

Note: * indicates 5 % level of significance

Table 3.2 further shows that reduction of rainwater run-off control capacity due to erratic rainfall is positively correlated to the fanya-juu(r=0.1718) system though not supported by statistical test of significance (p=0.0874). The results show that rainwater run-off control capacity due to erratic rainfall reducesunder the negarims, contour bunds and contour ridges systems of water harvesting. The worst affected run-off control capacity due to erratic rainfall was contour ridges system(r=0.5828), followed by contour bunds(r=0.5042) and finally the negarims system(r=0.4901). The statistical test of significance shows that the fanya-juu system is not affected by erratic rainfall since its probability value (p-value) is greater than 5% hence its reduction in rainwater run-off control capacity is not significant.

3.2.2 Difference in yield production by rain seasons

Pertaining to yield production during well distributed rain seasons and erratic rain seasons, 20.95 per cent of the farmers noted that there exists a very high difference in the yield between the stated rain seasons. In addition, 53.33 per cent of the farmers mentioned that the difference in yield production during well distributed rain seasons and erratic rain seasons was high. Hence, based on their views, 74.28 per cent of the farmers interviewed concurred that yield realized during well distributed rain seasons is quite different compared to the realized yields during erratic rain seasons.

Table 3.3: Difference in yield production during different rain seasons

Difference	Frequency	Percent
Very high	22	20.95
High	56	53.33
Low	25	23.81
Very low	2	1.90

A relatively small percentage (23.81) of farmers said that the difference in yield production during well distributed and erratic rain seasons was low, with only 1.90 per cent stating that the difference was very low.

3.2.3 Effectiveness of water harvesting systems used based on observed yield

The farmers who reported that the Fanya-juu water harvesting system was very effective based on observed yield production during well distributed rain seasons and erratic rain seasons were 23.81 per cent. In addition, 72.38 per cent of farmers stated the Fanya-juu system as effective, with only one (0.95 per cent) mentioning that there is no difference in observed yield production during well distributed rain season and erratic rain seasons.

Farmers who rated the Negarims system as being very effective and effective were 21.90 per cent and 66.67 per cent respectively. Only a small percentage of 4.76 of the farmers said there is no difference under the Negarims systems on observed yield production during well distributed rain seasons and erratic rain seasons. Contour ridges and contour bunds systems were rated as being very effective by 11.43 per cent and 14.29 per cent of the farmers respectively. The percentage who rated the two contour systems (ridges and bunds) as effective represented 61.90 and 57.14 of all the farmers interviewed. Notably 11.43 per cent and 14.29 per cent said there is no difference in observed yield production during well distributed rain seasons and erratic rain seasons under the contour ridges and contour bunds systems respectively.

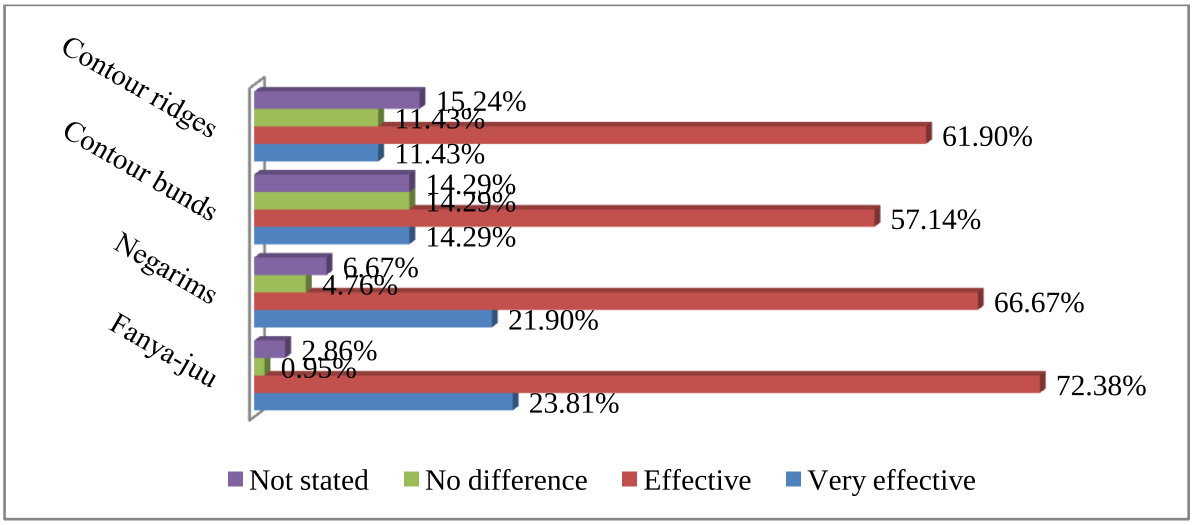

Figure3.1: Effectiveness of water harvesting systems used based on observed yield

Hence the effect of water harvesting systems as pertains to the observed yield production during well distributed rain seasons and erratic rain seasons percentage-wise stood at Fanya-juu (n=101,96.19 per cent),Negarims (n= 93,88.57 per cent), then the contour ridges system (n=77,73.33 per cent)and lastly the contour bunds system at(n=75,71.43 per cent).

Table 3.4: Correlation matrix for effectiveness of systems used based on observed yield

		Observed yield effectiveness	Fanya-juu	Negarims	Contour bunds	Contour ridges
Observed yield effectiveness		1				
Fanya-juu		0.2284*	1			
	p-value	0.0191				
Negarims		0.0528	0.0966	1		
	p-value	0.5930	0.3267			
Contour bunds		0.0207	0.2761*	0.1463	1	
	p-value	0.8341	0.0044	0.1365		
Contour ridges		0.0206	0.1704	0.1031	0.6409*	1
	p-value	0.8346	0.0823	0.2953	0.0001	

Note: * indicates 5 % level of significance

The correlation matrix in table 3.4 gives a correlation coefficient in relation to effectiveness of observed yield production of(r= 0.2284,p=0.0191) for fanya-juu,(r= 0.0528,p=0.5930) for negarims,(r=0.0207,p=0.8341)for contour bunds, and(r=0.0206,p=0.8346) for contour ridges. The results showtheobserved yield production is positively and statistically significantly correlated to the fanya-juuon-farm water harvesting techniqueat the five per cent level of significance and positively correlated to the negarims, contour bunds and contour ridges systemsof on-farm water harvesting though not supported by statistical test of significance. This reveals that based on observed yield production the fanya-juu system of on-farm water harvesting is the most effective technique during both well distributed rain seasons and erratic rain seasons.

IV. Conclusions and Recommendations

4.1Conclusions

A greater percentage of female farmers practiced this system of Fanya-juu compared to the male farmers practicing it. A greater percentage of male farmers practiced the system of contour bunds compared to the female farmers practicing it. Female farmers practicing the system of contour ridges doubled the males carrying on the contour ridges system. The Fanya-juu system followed by Negarims systems of water harvesting were most reportedly being practiced by the farmers in the area irrespective of their gender and level of education attained. A greater percentage of the farmers view Fanya-Juu as the best suited for the gently sloping terrain of the study area. More males preferred the contour bunds systems compared to females, while a greater proportion of female farmers opted for contour ridges system in relation to male farmers. Two female farmers, who had attained post-secondary education reportedly, practiced damming as a way of harvesting water to supplement rain fed agriculture, with no male being said to practice dam construction. Damming limited use was attributed to the resources required to set them up and expertise.

Reasons provided on water management by the respondents varied. The reason for practicing water harvesting technique by 28.57 per cent of the respondents was to trap water for crop irrigation. In addition 38.10 per cent reported that it was to check, control and minimize soil erosion, while 35.24 per cent reported that it was intended for increasing moisture conservation and take water to the roots.

Further analysis of the data depicts that erratic rainfall reduces the rainwater run-off control capacity under the different water harvesting techniques. The reportedly least affected by erratic rainfall is the Fanya-juu technique at 93.33 % (r=0.1939, p=0.0571). The analysis depicts that the effect of erratic rainfall on rainwater run-off control capacity through both contour bunds at (r=0.5042,p=0.0001) and contour ridges(r=0.5828,p=0.0001) techniques of water harvesting is statistically weak though not known by a relatively greater proportion of farmers.Effectiveness of water harvesting system pertaining to the observed yield production during well distributed rain seasons and erratic rain seasons stood at (r=0.2284,p=0.0191) forFanya-juu system,(r=0.0528,p=0.5930) forNegarimssystem as eluded by 88.57 per centof the farmers,(r=0.0207,p=0.8341) for contourbunds system and (r=0.0206, p=0.8346, 71.4%) for contour ridges. The effectiveness of all the on-farm harvesting systems tested is statistically positive but only significant under the Fanya-Juu system.Thus, thefanya-juu system andnegarims systems of water harvesting were most reportedly being practiced by the farmers in the area irrespective of their gender and level of education attained. The fanya-juu system is not significantly affected by erratic rainfall on reduction in rainwater run-off control capacity.Based on observed yield production effects of water stress parameters on-farm water harvesting is positive but statistically insignificant during both well distributed rain seasons and erratic rain seasons except for fanya-juu.

4.2 Recommendations

Based on the findings of the study, the following recommendations were made;

i). Farmers need to be more sensitized and trained on use of contour bunds and contour and on how to monitor and evaluate their performance.

ii). To alleviate water stress exacerbated by erratic rainfall, farmers in the area should be encouraged through awareness creation to harvest water using the fanya-juusystem, sinceitis positive in effectiveness and statistically significant under different water stress factors.

Taking the limitations and delimitations of the study, the following areas were suggested for further research

i). Since the study was conducted in only one administrative sub-County, it would be vital before generalizing the policy recommendations, to replicate the study using a representative sample of farmers in other climatic regions of Kenya. This would establish the robustness of the findings and the resultant policy recommendations.

ii). There is need also to investigate the performance of different water harvesting systems based on other climatic variability factors such as decreasing temperatures and more than normal rains.

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Stephen KyaloMutiso, etal. "Effects of Intensified Erratic Rainfalls on the Capacity of On-Farm Water Harvesting Systems in Checking Surface Run-Off in Matungulu Sub-County, Machakos County, Kenya" *IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*, 13(3), (2020): pp 12-19.