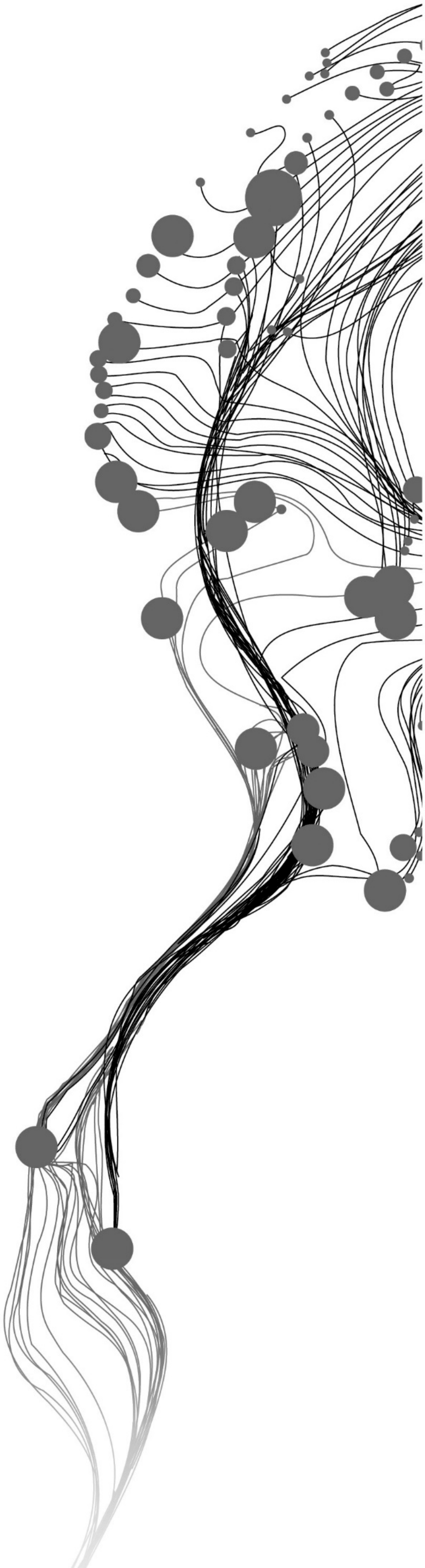
EVALUATING THE FARMERS' NEED AND ACCURACY OF SEASONAL RAINFALL FORECAST FOR FOOD SECURITY APPLICATIONS IN KARAMOJA, UGANDA.

LOKONGO PAULINA PETER
February 2019

SUPERVISORS:
Dr. ir. A. Vrieling
Dr. ir. Janneke Ettema



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LOKONGO PAULINA PETER
Enschede, The Netherlands, February 2019

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SUPERVISORS:
Dr. ir. A. Vrieling
Dr. ir. Janneke Ettema

THESIS ASSESSMENT BOARD:
Dr. A.D Nelson (Chair)

Dr. ir. L.G.J., Boerboom (Luc) (External Examiner, ITC)

ABSTRACT

Food security is a major problem in the world, where the growing population is expected to increase to nine billion in 2050 and as a result, the global population will need more food. In Africa where food security mainly relies on rain-fed agriculture, farmers face many challenges in making farm decisions due to unreliable rainfall causing crop failure and poor yields. To ensure food security, accurate and timely seasonal rainfall forecast is a significant factor in rainfed agriculture-based countries such as Uganda which employs 75% of the population. Food production is affected by a prolonged dry spell and heavy rains during the growing season which crop reduces crop yields. The main objective of this study was to evaluate the needs of farmers in Karamoja for rainfall information and forecasts and assess if satellite rainfall products and seasonal rainfall forecasts have sufficient accuracy to meet these needs. First, 48 farmers in five areas of Karamoja drylands agro-ecological zone were interviewed on their need for and use of rainfall information and forecasts. They predominantly indicated to require seasonal rainfall forecasts relating to the months of agricultural practices (land preparation, crop planting, growing period and harvest). These findings informed the evaluation of the six satellite rainfall products and European Centre for Medium-Range Weather Forecasts ECMWF SYS-4 seasonal forecasts. Analyses were done both for the predominant planting month (March) and for the total seasonal rainfall during March-September. Forecasts made on 1 March were used corresponding to a one month (March) to seven-month lead time (March-September totals). Root mean square error, bias and correlations for all variables varied with the period and rain gauge stations. The variability of different stations over various statistics of the satellite rainfall products in the month for March and March-September made it unreliable to evaluate the forecasts. For the ECMWF SYS-4 seasonal forecasts performed well in the month of march and in March-September performance was poor due to the low accuracies. Conclusion is that the participatory approach used in this study provides a better understanding for demand-driven rainfall and forecast information, ECMWF SYS-4 seasonal forecasts provides the possibility information that may support farmers' agronomic decisions in 1-lead Month (March) due to high accuracies, however for the march-September forecasts is not useful at all because of the low accuracies.

KEYWORDS:
Food security, seasonal rainfall forecasts, satellite rainfall products, Farmers' needs Agro-ecological zones and Karamoja, Uganda.

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LIST OF ABBREVIATIONS

CAO	Chief Administrative Officer
CGMS-IPWG	International Precipitation Working Group
DESA	Department of Economic and Social Affairs
DFO	District Forest Officer
ECMWF SYS-4	European Centre for Medium-Range Weather Forecasts System 4
ENSO	El Nino-Southern Oscillation
IPC	Intergovernmental Pane; On Climate Change
NUSAF 3	Northern Uganda Social Action Fund 3
OPM	Office Of the Prime Minister
UBOS	Uganda Bureau of Statistics
UNMA	Uganda Meteorological Authority

1. INTRODUCTION

1.1. Background and justification of the study

Several definitions on food security exists, according to the Food Agricultural Organization of the United Nations, (1996), Food security is defined "as a situation when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life". To ensure sustainable food security, different conditions must be practised making sure food is available, accessible, utilised and stable with the favourable climate. The world's growing population is expected to increase to nine billion in 2050, and as a result, the global population will need more food (DESA, 2018).

Farmers try to increase their income on food production and by so doing they face a great challenge as it relies more on natural resources that make livelihoods very sensitive to climate changes such as; shifting rainfall and temperature patterns which could lead to the decline in crop yields and hence food shortages (Kansiime & Mastenbroek, 2016).

Food security in Uganda is independent on rain-fed subsistence agriculture for both livestock and crops such as millet, cassava, banana, maize, and sorghum (Rowhani, Lobell, Linderman, & Ramankutty, 2011). Irrigation systems are poorly developed in Uganda, and largely absent in regions like Karamoja (Nakalembe, 2018). Agriculture contributes to 85% of the export earnings and rural employment (Jury, 2018). Uganda continues to experience poverty, hunger, and malnutrition (Ssewanyana & Kasirye, 2010). 60.8% of the population is in the Karamoja region where most households rely on the market for food, and they are likely to face stress (*IPC*, 2017).

Food insecurity and malnutrition in Uganda remain a national problem. It has led government and donor agencies to provide food aid to the regions. 75% of pregnant mothers and children in the Karamoja region benefit from the said programme (IRIS, 2017). Karamoja is the only semi-arid region in the country that is highly drought and flood-prone due to low and erratic rainfall (Nakalembe, Dempewolf, & Justice, 2017). These weather-related events require planning ahead of time of its occurrence, through establishing a well reliable and timely early warning system, especially in disaster-prone areas.

The Uganda Meteorological Authority under the ministry of water and environment periodically releases rainfall outlooks and decadal agromet-hydrological bulletins. These bulletins show rainfall performance for the current month and the first 10 days of subsequent months. The bulletins are distributed to every government authority and district Local governments for dissemination to communities. However, the use and knowledge of forecast information by farmers are not known. The seasonal climate forecast is utilised to predict the upcoming season's rainfall from the beginning of the cropping season and harvest period (Nidumolu et al., 2016).

Uganda has limited meteorological capacity in terms of functional weather stations. Since early warning systems for agriculture rely on a variety of data, rainfall and climate observations are essential to provide reliable information on seasons (OPM, 2011). Weather forecasts information is used to communicate the meteorological conditions of the area over the next few days, weeks, or months. While, the seasonal rainfall forecast can be communicated too over more months ahead through the provision of the continuing averages (Chen & Georgakakos, 2015).

Farmers depend on rainfall and can benefit from an accurate and timely forecast for food production. Rainfall forecasting remains a scientific challenge across the globe. To have knowledge on the amounts and spatial distribution of rainfall is essential for both ecological and hydrological modelling such as; flood prevention, drought estimation, farming seasons (sowing, flowering, and harvest) among others (Gouvas, Sakellariou, & Xystrakis, 2009). The information of accurate weather forecast when properly interpreted and well communicated can provide a means to help the affected people manage or build resilience to shocks on the impacts to affect planning and decision making (Usman, Archer, Johnston, & Tadross, 2005).

Rainfall forecast is a probability of the future occurrence of rainfall on the period which could range from daily, seasonal to decades or longer. The spatial scales vary from local to regional and global (Jang & Hong, 2014). These predictions could be departures from the average mean normal conditions for the upcoming seasons (Chen & Georgakakos, 2015). With available information, accurate decisions could be made to aid food security and early warning systems. Rainfall forecasting involves a combination of models such as; observations, expert knowledge on the changes and patterns, and computer models. Rainfall measurements are very important for evaluating the skill of the rainfall forecasts on a monthly and seasonal scale. Rainfall is measured using ground observations (rain gauges) and remotely sensed products (satellite). Rainfall measurements go up to 24-hour period ending at 9 am local time while rainfall forecasts end at 12 UTC.

Satellite rainfall products have been used widely in place of ground observations in many studies such as; hydrological modelling, early warning systems and food security purposes among others (Andronache, 2018). However, the low density of reliable weather stations that provide accurate measurements over a long period and errors contained in the satellite products limits their use. More so the estimates partially do not continuously sample rain events. The images are affected by errors such as; "inability to monitor local variations in rain storm intensity, non-rain bearing cirrus clouds, a mismatch in gauge position and centre of pixel" (Flitcroft, Milford, & Dugdale, 1989). These errors must be taken care of during the validation time to get accurate results.

The major advantage of using remotely sensed product is the improved spatial distribution compared to weather stations. The products contain two types of sensors commonly used in the estimation of rainfall algorithms, with it is particular strengths and weaknesses. Thermal infrared (TIR) sensors on geostationary satellite produce high spatial coverage with continuous temporal coverage, around the globe at every one hour or less. TIR is created on the cloud top brightness temperature is valuable in the distinction between raining and non-raining; however poor in estimating actual rainfall amount due to the inability to penetrate the clouds. Whereas, Passive Microwave (PM) sensors on polar-orbiting satellites identify the precipitation particles by scattering due to the large ice particles present in the clouds. PM is good at estimating the rainfall amount due to the increased direct physical relationship between the sensor signal and rainfall, however, runs at the much lower temporal frequency and coarser spatial resolution (Thiemig et al., 2012). In addtion, to influence the strength of the sensors, most satellite products seek to combine the favourable characteristics of the different data sources using various combining strategies (Diem, Hartter, Ryan, & Palace, 2014; Asadullah, McIntyre, & Kigobe, 2008; Kizza, Westerberg, Rodhe, & Ntale, 2012; Dembélé & Zwart, 2016). With the current availability of satellites, it is vital to assess their quality owing to precision and uncertainty, as well as their advantages and disadvantage, before they can be combined into the operational application for decision-making such as Early warning for severe weather, drought, flood monitoring, disaster risk management, climate change adaptation, integrated water resources management, and large-scale water balance estimations, which are of interest in Africa (Thiemig et al., 2012)

There are several attempts to compare satellite rainfall products with rain-gauge measurements; Dembélé & Zwart, (2016), observed a better correlation of six products at monthly scale. They obtained correlations of; RFE r of 0.96, CHIRPS r = 0.95, PERSIANN r = 0.93, ARC r = 0.96 and TRMM3B42 r of 0.94. Also, a study conducted in Ethiopia in the Upper Blue Nile shows CHIRPS exhibiting better performance compared to other products with a high correlation of 0.81 (Ayehu, Tadesse, Gessesse, & Dinku, 2018).

Asadullah et.al.,(2008) compared five satellite products (CMORPH, PERSIANN, RFE 2.0, TRMM 3B42 and TAMSAT) against rain gauged data in four regions in Uganda (Lake Victoria, the central, the Mount Elgon and the Northern Highlands) and observed TRMM3B42, RFE and PERSIANN perform better with coefficient of above 0.74. Also (Diem, Hartter, Ryan, Palace, et al., 2014) observed underestimation of rainfall by the three products (ARC, RFE and TRMM3B42), they further found satellite products unable to perform in areas of mountains and valleys, where the warm orographic rain is in abundant. Dinku et al., (2007) noted that to obtain the best product it depends on the application used. Moreover, the satellite products do not have any forecast information in them, as they are observations. This is a Key reason to investigate the farmers' needs for rainfall forecast.

The accurate estimation of rainfall necessitates having a well-distributed network of meteorological stations with rain gauges (Goovaerts, 2000). To evaluate the rainfall forecast qualitative and quantitative methods can be used (Jolliffe & Stephenson, 2012). On the other hand, to know the correct forecasts; consistency, quality and value are needed. Forecast quality includes; Bias, association, accuracy, skill, reliability, resolution, sharpness, discrimination and uncertainty (Stanski, Wilson, & Burrows, 1989).

The seasonal forecast provides information on how likely it is that the coming season will be wetter, drier, warmer or colder than normal. The seasonal forecast is increasingly used in many agricultural areas; such as the seasonal average, for the growing season that can potentially influence a farmer's decision about the type of crops to plant ahead of time, or useful tool for the charitable organisation to lobby for food in drought-prone areas around the globe. Mwangi et al., (2014) in their research on forecasting drought in East Africa used the European Centre for Medium-Range Weather Forecasts (ECMWF) products observed over 50% of stations having significant skill in OND season in both lead times (2 than lead time 1). They also noticed that SYS-4 had the higher skill for not dry (normal and wet) category and associated with the cool pool over equatorial Pacific, hence skill full for La Nina conditions associated with dry conditions in East Africa. However, data scarcity and difficulty to obtain a long-term dataset proved a reality to check the performance for the system in the key region for drought monitoring.

However, several studies still point out that, access to seasonal weather forecast is still limited in Sub-Saharan Africa (Feleke, 2015). He observed 39% of farmers had no access to weather information due to lack of awareness and limited knowledge. Also, results show that half of the farmers were aware of the weather information from radio, newspapers and TVs. Nyadzi et al., (2019) observed the importance of hydro-climatic information need depending on the frequency of use and farming type. Also observed information service having a need to introduce the results from the forecasts system to the end users to increase trust in the use.

1.2. Problem statement

Agriculture in rain-fed areas could benefit from accurate and timely measurements of rainfall forecast. At present the precise rainfall forecast needs for farmers in Karamoja is unknown. Due to the lack of accurate rainfall ground observations, satellite rainfall estimates are used, of which their quality is also unknown. Besides, it is also not known that the existing rainfall forecasts are accurate to meet those needs effectively.

Also, the sparse meteorological networks with rain gauges in many parts of Africa just like Uganda are limited and unevenly distributed. Farmers depend on rain-fed agriculture for both livestock and crop cultivation.

The study aims to assess the farmers' needs and accuracy of ECMWF-S4 seasonal forecast to evaluate observations for Karamoja. It assesses to what extent the forecast can meet their needs when compared with rain gauge station data or using remotely sensed rainfall products for multi-temporal time series of 2001 to 2012. This research will explore the different gridded satellite products from previous studies using monthly totals.

The findings from this study will be of great help in selecting the best performing satellite product to estimate rainfall in Karamoja and giving the recommendations to farmers' organisation and meteorological authority on when to communicate the forecast to farmers. This will address the usability of seasonal rainfall forecasts for agricultural application.

1.3. Objectives of the study

1.3.1. General objective

To evaluate the needs of farmers in Karamoja for rainfall information and forecasts and assess if satellite rainfall products and seasonal rainfall forecasts have sufficient accuracy to meet these needs.

1.3.2. Specific objectives

a. To assess farmers' knowledge of and need for rainfall forecasts
b. To assess which satellite rainfall product compares best with ground rainfall measurements for stations in Karamoja, when focusing on the rainfall-derived parameters of interest to farmers.
c. To assess the accuracy of an existing rainfall forecast for Karamoja, based on various lead times and the main rainfall parameters of interest to farmers for timely agronomic decision making.

1.3.3. Research questions

Specific objective 1

a. What type of information do farmers need from the rainfall forecast for agronomic decisions?
b. How is the forecasts meeting the farmers' needs?

Specific objective 2

c. Out of various existing satellites rainfall estimates, what is the best performing product for estimating rainfall in Karamoja as compared to station data
d. How well did the satellite values correspond to the observed values?
e. How does the average magnitude of the satellite compare to the average magnitude of the observed data?
f. What is the weighted average magnitude of the satellite errors?

Specific objective 3

a. Which forecast is good enough to predict rainfall amounts in Karamoja?
b. How well did the satellite values correspond to the observed values?
c. How does the average magnitude of the forecast compare to the average magnitude of the observed data?
d. How well did the satellite values correspond to the observed values?
e. What is the weighted average magnitude of the forecast errors?

2. STUDY AREA AND DATA

2.1. Location

The study was performed in the Karamoja sub-region, located in the northeast part of Uganda, between latitude1° N- 4° N and longitude 33° E - 35° E. Karamoja has seven districts: Napak, Kotido, Nakapiripirit, Abim, Moroto, Kaabong, and Amudat (Figure 1). Karamoja covers 10% of Uganda's land with savanna vegetation composed of shrubs, predominantly Acacia species, and grasses. Karamoja is referred as to semi-arid characterised by unreliable rain seasons, long dry spells and droughts, which commonly causing unsuccessful harvest in the region. Karamoja's rainfall is erratic and unimodal, with annual average rainfall ranging between 300 mm in the pastoral zone to 1200 mm in the western areas (Nakalembe, 2018). The area experiences one long rainy season (March to August) and short rains (September, October and some part of November). It is bimodal in a kind due to slightly lower rainfall in June whereas; the month of December, January and February are very dry and windy (Figure 2) shows rainfall distribution in the region.

Crop production in Karamoja is mainly rain-fed, and dependant on two crops: sorghum and maize, other crops grown include; beans, groundnuts, rice, sweet potatoes, cassava, and Bananas. Most of the farming is subsistence on small plots of farms near the homesteads. The soils in Karamoja are generally sandy, loamy and alluvial soil type. Decision on various farming practices are influenced by different factors; the indigenous knowledge (elders), neighbourhood and Weather information broadcasted on radio.

According to Akwango et al., (2017), Karamoja sub-region has four livelihoods zones (Figure 1. Map of Karamoja drylands agro-ecological zone.). These include; the Karamoja livestock-sorghum-bulrush-millet referred to as agro-pastoral covering Moroto, Kotido, and Nakapiripirit. The zone receives an annual rainfall of approximately 500-800mm with sandy, loamy soils. The second zone is south Kitgum Pader simsim-groundnuts-sorghum-livestock which extends to Abim and some parts of Napak district, and it is commonly known as the wetter zone of fertile loamy soils. The average rainfall for this zone ranges from 800-1200mm annually and growing season extends from March to October. The eastern lowland maize, beans, rice zone extends to Napak and Nakapiripirit districts and the central, and southern Karamoja pastoral livelihood zone only found in Moroto district. They receive an average annual rainfall of less than 300-500mm with sandy and low fertile soils.

Livestock is the major source of livelihoods for most Karamojong's who move from place to place looking for pasture and water for their animals. This practice is a supplement to continuous crop failure and source of income for food security. However, Livestock are used in crop production as oxen. The poverty level in Karamoja is high. According to the recent report from the Uganda Bureau of standards statistics, about 74.5% live below the national absolute poverty line compared to 19.7% for the rest of the country (UBOS, 2013).

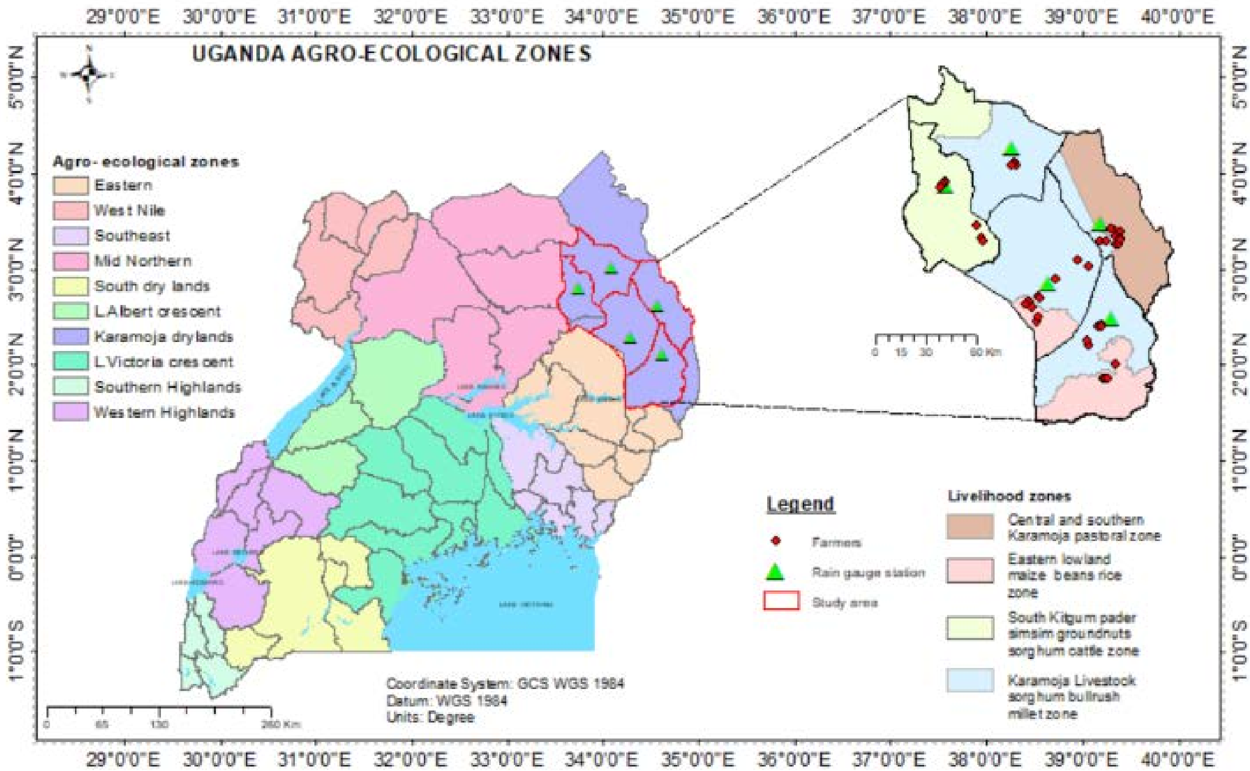

Figure 1. Map of Karamoja drylands agro-ecological zone.

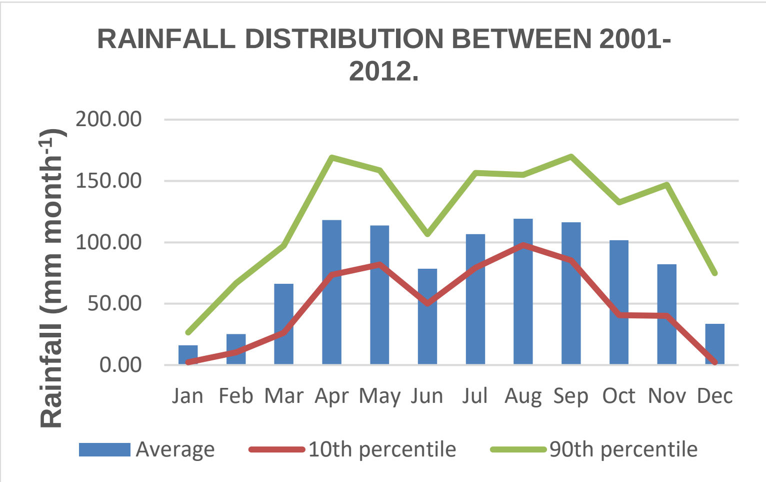

Figure 2. Monthly rainfall (in mm) averaged over the Matany, Alerek, Moroto, Nakapiripirit and Kotido rain gauge stations for the period 2001-2012.

2.2. Data

The datasets used in this study, consists of farmers' forecast needs inventory from the field work using questionnaires designed by the student, monthly rainfall data for Alerek, Matany, Moroto, Nakapiripirit and Kotido rain gauge stations from the Uganda Meteorological Authority (2001-2012), satellite rainfall products for ARC, RFE, CHIRPS, PERSIANN-CDR, MSWEP and TRMM (2001-2012) accessed from ITC server/CGMS-IPWG and the European Centre for Medium-Range Weather Forecasts (ECMWF-S4) seasonal system 4 forecast for the month of March to September (1-7 month lead time). Lead time is the total period required to provide forecasts information.

2.2.1. Farmer's forecast needs data

The farmer's forecast needs requirements data (seasonal forecast for planting, sowing, flowering, and harvesting), was obtained using structured interview questionnaires designed based on documents by Siniscalco & Auriat, (2015) and previous studies (Okonya, Syndikus, & Kroschel, 2013). The interviews concentrated in the Karamoja drylands agro-ecological zone (Appendix A. Uganda Agro-ecological zones) The data collected included: (1) Location; (2) data on agricultural practices (crop type, beginning of land preparation, harvest period, time to start first crop planting, irrigation practices); (3) general knowledge on rainfall forecast and information needs required (awareness on rainfall forecast, how to determine the rainfall forecast, type of rainfall forecast needed) and (4) socio-demographic data (age, sex and education level). "The socio-demographic data were not used in the study apart from Education level (Appendix B.) supporting material for interview guide). The criteria used to select the farmers were the NUSAF3 group list in the district and sub-county (Appendix C) for Uganda's level of hierarchy), willingness to participate in the interviews and practised farming in the five groups selected randomly in the villages within the study area. Each district had one farmer group comprising of 11 members, and a total of 48 farmers were interviewed.

2.2.2. Rain gauge data

The time series of monthly rainfall measurements were obtained for five stations for the period 2001-2012. Table 1 details of the rain gauge stations used for analysis, equally distributed to the five districts used for farmers interviews. The criteria for searching rainfall data was initially to use stations found within the Karamoja drylands agro-ecological zone with multiple years of daily data. However, because daily rainfall station data could not be obtained at a reasonable cost locally nor gap-free consistent time series existed in the Global Telecommunication System data from the World Meteorological Organization. The focus shifted to monthly rainfall data. For each of the five stations, 12 years of monthly precipitation observation data were obtained freely from the Uganda National Meteorological Authority (UNMA) under the Ministry of Water and Environment. All the five rain gauge stations were local stations; Matany hospital, Alerek, and Kotido are operated manually while Moroto and Nakapiripirit are automatic and had missing data of 31% (Figure 1 the location of the stations within the study area) and Appendix D. percentage of missing data. However, sometimes the automatic stations face challenges on the power supply, and vandalism of equipment especially solar panels is very common; hence limited use (Byamukama et al., 2015)

Table 1: Overview of five rain gauge stations in Karamoja sub-region used for evaluation

Station reference	Station name	District	Type	Lat	Lon	Elevation.
8734020	Matany Hospital Hydromet	Napak	RF	02.29'N	34.29'E	4300m
8734000	Moroto	Moroto	AWS	02.33'N	34.36'E	5000m
87330130	Alerek	Abim	RF	02.48'N	33.43'N	3700m
8734011	Nakapiripirit	Nakapiripirit	AWS	02.14'N	34.39'E	4200m
8634002	Kotido Hydromet	Kotido	Hydro	03.01'N	34.10'E	4000m

RF – rainfall station, AWS – Automatic weather station, Hydromet – hydrometeorological station, LAT-latitude, and LON – longitude.

2.2.3. Satellite rainfall archives

The satellite rainfall products used in this study were selected based on existing scientific papers analysing rainfall products. Six products from (Dembélé & Zwart, 2016) and (Beck et al., 2017) were selected, Table 2 details of the six satellite products used. These include; Africa Rainfall Estimate Climatology version 2

(ARC 2.0), Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS), Precipitation Estimates from Remotely Sensed Information using Artificial Neural Networks (PERSIANN), Africa Rainfall Estimation version 2 (RFE 2.0), Tropical Rainfall Measuring Mission (TRMM 3B42 v7) and Multi-Source Weighted-Ensemble Precipitation (MSWEP).

The Africa Rainfall Estimation version 2 (RFE 2.0) is developed by the NOAA Climate Precipitation Centre (CPC, mainly produced for famine early warning systems networks for disaster monitoring activities over. Input data for RFE 2.0 comprises of four sources: (1) daily Global Telecommunications System (GTS) rain-gauge data, (2) Advanced Microwave Sounding Unit (AMSU)-based rainfall estimates, (3) Special Sensor Microwave Imager (ISSM/I)-based estimations, and (4) the Geostationary Operational Environmental Satellite (GOES) precipitation index (GPI) calculated from cloud-top infrared (IR) temperatures on a half-hourly basis. Africa Rainfall Estimate Climatology version 2 (ARC 2.0) is very similar to that of RFE Hower, uses inputs from two sources: (1) 3 hourly geostationary IR data centred over Africa from the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) and the quality-controlled GTS gauge observations reporting 24 hours rainfall accumulations over Africa. However, differences existists between ARC and RFE in the use of polar-orbiting PM and geostationary IR data. ARC uses 3 hourly IR instead of 30 min and does not include PM estimates, which RFE does. (Huffman, Adler, Arkin, Chang, Ferraro, Gruber, Janowiak, McNab, Rudolf, Schneider, et al., 1997).

The Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) is developed by the US Geological Survey (USGS) and climate Hazard Group at the University of California, (UCSB). The inputs used for CHIRPS creation were; the Climate Hazard Precipitation Climatology (CHPCLim), quasi-global geostationary TIR satellite observations from two NOAA sources, the CPC and the National Climatic Data Centre (NCDC) and atmospheric model rainfall fields from the NOAA Climate Forecast System, version 2 (CFSv2). The TRMM 3b42 product from NASA; and in situ precipitation observations obtained from a variety of sources including national and regional meteorological services (Funk et al., 2015).

The Precipitation Estimates from Remotely Sensed Information using Artificial Neural Networks Climate Data Record (PERSIANN-CDR) was built by scientists at the Centre for Hydrometeorology and Remote sensing, University of California (Ashouri et al., 2015). Input data for the PERSIANN-CDR algorithm comes from (1) Gridded Satellite Data (GridSat-B1) from the International Satellite Cloud Climatology Project (GPCP) v2.2.

The Tropical Rainfall Measuring Mission (TRMM) is a joint space mission between NASA and the Japan Aerospace Exploration Agency (JAXA) designed to monitor and study tropical and sub-tropical precipitation and associated release energy. The broadly used outputs are the TMPA 3 hourly (TRMM 3B42) accumulated to daily, and monthly (TRMM 3B43) products (Maidment et al., 2013). The TMPA inputs are a variety of sensors and sources: the TRMM Precipitation Radar (PR), the TRMM Microwave Imager/Sounder (SSMIS) are both on Defense Meteorological Satellite Program (DMSP), the AMSU-B and the Microwave Humidity Sounder (MHS) both on the NOAA satellite series, the IR data collected by the international constellation of geosynchronous earth orbit (GEO) satellites, and the GPCP precipitation gauge analysis from the Global Precipitation Climatology Centre (GPCC). Some of these sensors are no longer functional (Katiraie et al., 2017). The product only exists for areas between 50° N and 50° S. The TRMM3B42 v7 product has been used in this study.

Multi-Source Weighted-Ensemble Precipitation (MSWEP), is a global precipitation dataset with 3-hourly temporal and 0.25° spatial resolution, designed for hydrological modelling. The MSWEP was designed to optimally merge the highest quality precipitation data sources available as a function of time scale and location. MSWEP long-term mean were based on the CHPclim dataset. A correction for gauge- under-catch and orographic effects were introduced, and the temporal variability of MSWEP was determined by weighted averaging of precipitation anomalies from seven datasets; two based on interpolation of gauge observations (CPC Unified and GPCC), three on satellite remote sensing (CMORPH, GSMap-MVK, and TMPA 3B42RT), and two on atmospheric model reanalysis (ERA-Interim and JRA-55) (Beck et al., 2017). The Datasets used in this study were downlaoded from ITC/server under the International precipitation working Group (IPWG) website http://ipwg.isac.cnr.it/data/datasets.html. For the period 2001 to 2012.

Table 2: Satellite rainfall products taken from a study in Africa adapted from (Dembélé & Zwart, 2016) for the period 2001-2012.

Satellite product	**Temporal coverage**	**Spatial coverage**	**Spatial resolution**	**Temporal resolution**	**Reference**
ARC v2.0	1983-present	Africa	0.1°	daily	(Huffman et al., 1997)
CHIRPS v2.0	1983-present	Near global	0.05°	daily	(Funk et al., 2015)
PERSIANN-CDR	1983-present	Near-global	0.25°	daily	(Ashouri et al., 2015)
RFE v2.0	2001-present	Africa	0.1°	daily	(Huffman et al., 1997)
TRMM 3B42 v7	1998- present	Near global	0.25°	3-hourly	(Maidment et al., 2013)
MSWEP	1979-present	Global	0.25°	daily	(Beck et al., 2017)

2.2.4. Rainfall seasonal forecast data

The seasonal rainfall forecast data used in this study was from the European Centre for Medium-Range Weather Forecast (ECMWF) Seasonal Forecast System 4 and downloaded freely from the climexp.knmi.nl website. The ECMWF-S4 was because of the role it plays in WMO global producing centre for long-range forecasting ad seen in the main factor affecting health and food production in many tropical and sub-tropical countries (Mwangi et al., 2014). The forecast is an ensemble mean of 50 members issued at the beginning of each calendar month up to 7 months ahead using simulations of initial conditions perturbations derived from a combination of atmospheric singular vectors and an ocean analysis. The forecast is a fully coupled system based on the integrated Forecast System (IFS) cycle 36r4 atmospheric model version with TL255 corresponding to roughly 80km spatial resolution. The forecasts performed well in seasonal forecasting when used by other previous studies in forecasting seasonal rainfall in Africa (Nyadzi et al., 2019; Mwangi et al., 2014).

3. METHODS

This research were conducted in three steps: First, farmer interviews (n=48) were conducted to obtain the farmers' forecasts needs using a structured questionnaire. In the second step, evaluation of the accuracy of six satellite rainfall products with monthly rainfall data from five stations using 12 years (2001-2012) of data based on the months of interest from the farmers' interviews. These were done through pairwise comparison of rainfall amounts to choose the best satellite rainfall products concerning the farmers' needs, as well as to evaluate if the satellite products would be an accurate basis to be used for evaluation of the rainfall forecast. Thirdly evaluation of the accuracy of the existing ECMWF Seasonal System 4 using one to seven months lead time for the months preferred by the farmers. To examine whether the seasonal forecasts could provide accurate information to meet the needs of Karamoja farmers for agronomic decision making.

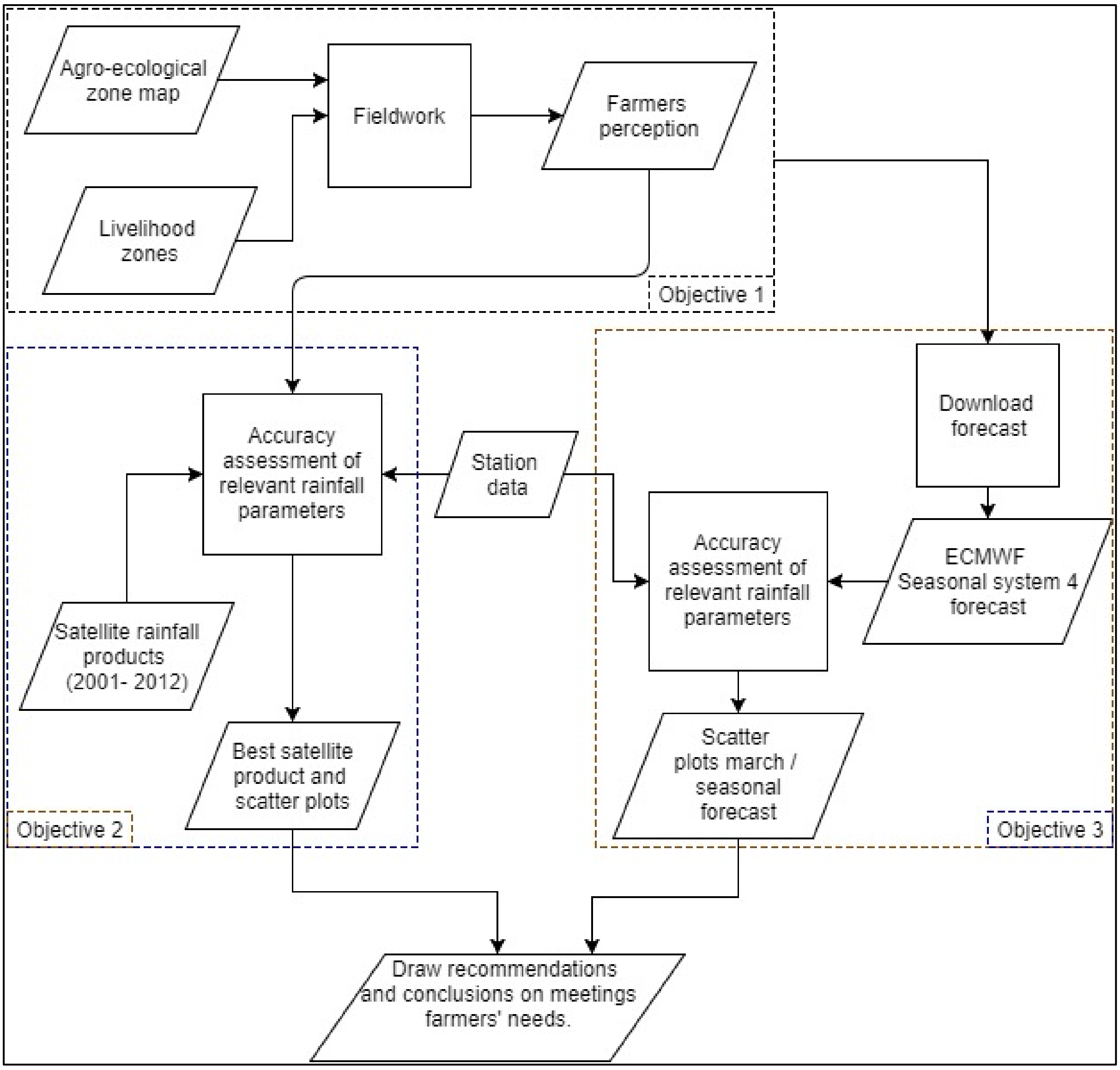

Figure 3. Flow chart for evaluating the farmers' need and accuracy of the seasonal forecast for agronomic decision making.

3.1. Farmers' forecast needs

The main reason was to collect data on farmers needs for agronomic decision making, structured interview questionnaires were designed based on Siniscalco & Auriat, (2015) and previous studies (Okonya et al., 2013). The interviews concentrated on the Karamoja drylands agro-ecological zone. The data collected included: (1) location; (2) data on agricultural practices (crop type, beginning of land preparation, harvest period, time to start first crop planting, irrigation practices); (3) general knowledge on rainfall forecast and information needs required (awareness on rainfall forecast, how to determine the rainfall forecast, type of rainfall forecast needed, bulletin information) and (4) socio-demographic data (age, sex and education level). However, in this study, the socio-demographic data were not used.

For this study the five districts represented the above mentioned agro-ecological zone in the sub-region, they were selected based on the literature and students' knowledge of the study area and relating to the mentioned livelihood zones. The fieldwork concentrated on Napak and the neighbouring districts due to time limits and financial constraints. Site identification was carried out on 23rd September 2018. Using the satellite images that were loaded in the tablet with Locus Map to help in navigating in the five districts. The district officials guided on the selection of the sub-county and the farmers to attend the interviews from different villages.

A total of 48 farmers were interviewed Figure 1. Map of Karamoja drylands agro-ecological zone. location of interviews. The interviews consisted of both open and close-ended questions (Appendix B. questionnaire guide). The interviews was tested on the five field assistants selected at each district (
Appendix G.) has details of contacts. The purpose was to see whether the questions were understood and to make the assistants aware of the type of the research conducted. The purpose of the assistants was to guide and introduce the student to the farmers. In the district of Abim and some part of Kotido where the student did not understand the language, one assistant was used to interpret the questions and filled five questionnaires. In Moroto one assistant helped in filling five questionnaires due to the distances between villages. The assistants selected were already those working with the Northern Uganda Social Action Fund (NUSAF3) program and community mobilizers under the Office of the Prime Minister (OPM). The OPM is a central body of government where most cabinet ministers sit and control most of the centrally managed projects implemented in the districts. NUSAF 3 is a livelihood project meant to improve household income support after several insurgencies. They are known staff to the community which gave confidence to the farmers while reducing high expectations of payments for fieldwork after interviews. Since the period for the harvest of the main crops was already over, all the farmers had interviews at their households (Appendix H.) shows individual farmers interviews in their respective places and a harvested crop field. The total of 30 questionnaires were filled by the student and 18 were filled by the field assistants.. Each farmer interviews lasted for about 20-30 minutes, the answers were transcribed by the student and field assistants, on the questionnaires and there was no audio recorded.

In the sampling process, it was a decision to have an equal number of farmers in each of the five districts used in the study. These individual farmers were randomly selected from the group members record in the village. Each farmer group consisted of eleven members as formed by the Northern Uganda Social Action Fund (NUSAF 3) in the districts and this was multistage sampling. The purpose was to draw conclusion on the farmers' forecast inventory needs and link farmers interviews to the evaluation of the accuracy of satellite rainfall products and the selected seasonal forecast with rainfall observations to see how they address the needs of farmers for agronomic decisions. The data were coded and entered in Excel sheet.

3.2. Data analysis

After completing farmer interviews, Statistics Package for Social Sciences (SPSS 24) software programme were used for analysis and descriptive statistics were generated and interpreted, and frequency test was done to count the respondents on different variables according to my objectives. The most relevant information was the type of rainfall forecast needed, timing for agricultural practices, type of the crops grown, awareness on the rainfall forecast and sources of rainfall information.

3.3. Evaluation of satellite rainfall products

The rainfall data from five rain gauge stations were used to evaluate the accuracy of satellite rainfall products. Data were extracted using the GDAL library Python and analysed from six different sources.
Comparative analysis were done for all the six satellite rainfall products for seven wet months important for agronomic practices from the period 2001-2012. Focus was on those months purposely identified by farmers during the interviews conducted as being important for land preparation, crop planting, growing season and harvesting.

Extraction of satellite estimates and comparison with rain-gauge data was conducted using a point to pixel analysis (Liechti, Matos, Boillat, & Schleiss, 2012), for seven wet months. The daily data for satellite rainfall products were aggregated to monthly totals to match with the monthly rainfall data obtained from five stations. The station's data in all period of 12 years of study had some missing data but at least less than 5% monthly observations lacking see
Appendix I. percentage for missing data per product and stations from the period 2001-2012.

3.3.1. Evaluation statistics

The statistic used to evaluate the six rainfall products were the same as those listed in the 3rd Algorithm inter-comparison Project of the GPCP (Ebert, 1996). It included continuous and pairwise comparison statistics to evaluate the performance of the satellite products in estimating the amount of rainfall using scatter plots with a Coefficient of determination (R^2) assessment (1 and 4), explains how good the regression model when compared to the ground observations. It evaluates how well the estimates corresponded to the observed values. However, they two statistics are calculated differently. The two statistical indicators in Equation 2 and three below were used for pairwise comparison too. (2) The root mean square error (RMSE) is a commonly used measure of differences between two variables – it measures the average magnitude of the estimate errors; Lower RMSE values indicate greater central tendencies and generally smaller extreme errors; a value of 1 is a perfect score. And (3) The Bias is used to show the degree to which the measured values are over or underestimated (Duan, Bastiaanssen, & Liu, 2012). It measures the average estimate magnitude compares to the ground rainfall observations. A value of 1 is the perfect score; a bias above 1 indicates an aggregate estimate overestimation and below 1 and underestimation of the ground precipitation amounts.

However, using several statistics consideration should be given to some statistics over others depending on the application of satellite products (Patricio et al., 2015). Mostly for flood forecasting and hydrological purposes, it is important to avoid underestimations of rainfall amounts and then avoid Bias < 0, and for drought monitoring, overestimations must be avoided, then avoid Bias > 0. Products with high R^2 , r and low RMSE have to be thought for general purposes.

Where; Continuous statistics (Gi, gauge rainfall measurement; G, average gauge rainfall measurements; Si, satellite rainfall estimate; S, average satellite rainfall estimate; SSE, the sum of squared errors of S; SST, the sum of squared errors of G and n, number of data pairs)

$$R^2 = 1 - \frac{SSE = \sum_{i=1}^{n}(S_i - \hat{S}_i)^2}{SST = \sum_{i=1}^{n}(G_i - \hat{G}_i)^2} \quad (1)$$

$$\text{RMSE} \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - G_i)^2} \quad (2)$$

$$\text{Bias} = \frac{\sum_{i=1}^{n} S_i}{\sum_{i=1}^{n} G_i} \quad (3)$$

$$r = \frac{\sum_{i=1}^{n}(G_i - G)(S_i - S)}{\sqrt{=} \sum_{i=1}^{n}(G_i - \hat{G}_i)^2 \sqrt{\sum_{i=1}^{n}(S_i - S)^2}} \quad (4)$$

3.4. Evaluation of the accuracy of seasonal rainfall forecast

The data from the European Centre for Medium-Range Weather Forecast (ECMWF) System 4 Seasonal forecasts was from the 2001 to 2012 data. This period were selected due to the months linked to planting, growing season and harvesting with the available satellite rainfall estimates and observations.
Since the data available was from January 1981 to December 2016 at global coverage, yet this study focused on 12 years, data visualization was done using Panoply software to select the correct number for each month to be entered in to R programming language, interaction with different software to extract the data for the study area were done.

The data for monthly precipitation of the forecast values were extracted using ArcGIS version 10.6.1 for five respective rain gauge stations in the study area which was 70 by 70km pixel size, and the values were in kilogram per meter squared per second ($kg/m^2/s$) which was converted into millimetre (mm per month) by taking density of water as using the density function (Equation 5) and multiplying the value with the minutes, hours and total number of days in the month. Two stations appeared in one-pixel (Matany and Moroto) having the same monthly rainfall forecast values;

$$1\ L\ of\ water = 1kg/1m2 \quad (5)$$

1kg/1 and knowing that one litre is $1dm^3$: $1kg/m^3 = 1\ l/m^2 = 1dm^3\ /m^2 = 0.001\ m^3/m^2 = 0.001\ m = 1mm$.
The seasonal forecast of 1st March to September were used for five pixels corresponding to the rain gauge locations from 2001 to 2012 monthly. The purpose was to predict the total amount of rainfall for March before the season and total rainfall amounts of the season in seven months.
Comparative analysis used such as; scatter plot analysis, and three statistical indicators were calculated to evaluate the performance of the forecast in estimating rainfall amounts. (RMSE, r, and Bias) Refer to the previous Equation 1-3 Section 3.2. These methods were used by other previous studies (Brown et al., 2014; Shaykewich, 2002) in forecast verification. There is a prove that, regression models are simple and easy to use when compared to other geostatistical models. On the other hand, to know the correct forecast consistency, quality and value are needed. Forecast quality includes; (Bias, association, accuracy, skill, reliability, resolution, sharpness, discrimination and uncertainty (Murphy & Epstein, 2002).

4. RESULTS

4.1. Farmers' forecast needs

The main objective was to assess farmers' knowledge of and need for rainfall forecasts, from the farmers' interviews, the main crops type are sorghum and maize, also cultivated are cassava, rice, bananas, and millet. (Figure 4). The majority of farmers stated that the choice of crops cultivated was because it is their main staple food. The size of farmland cultivated varies from less than 1 hectare, 1-3 hectare and 4-6 respectively. However, farming most farmers have been practicing for the last 5 and 10 years. From the results, farmers obtain rainfall information via radio, TV, extension worker, phone, environment officer and other sources as presented in Appendix H 70.6% of farmers did not directly use a forecast themselves but instead relied on neighbours and their own experience. It is the common practice that farmers' decisions are influenced by others. From the farmers who trusted the forecasts obtained via radio, they pointed out that, some of the information announced is inaccurate, that is why their own experience and neighbourhood is important.

Therefore, some farmers use indigenous knowledge to forecasts rainfall with indicators such as; animal intestines, Karamoja calendar, and standing clouds. Karamoja calendar which the farmers refer to as January to December and each month has a name of an activity performed within that period which farmers follow accordingly. On animal intestines the farmers said it is an activity performed by the foretellers who sacrifice a bull or a ram in the shrine at the beginning of the season; as they read the information on the intestines, they can predict the coming season. Additionally, for standing clouds, the farmers said they look at the dark colour which shows that it will rain. Furthermore, out of the 48 farmers interviewed, 53% of the farmers had no formal education, while 20% attended primary school, 12.5% attended secondary, and 2% had a university education. The results show that the category of farmers in the study area are highly not educated.

For the majority of the farmers, planting season starts in March, while others in May. Others plant in August and October. Although preparation of land starts in January, the majority of the farmers prepare their land in February and March. There is a connection between preparation and cultivation because the majority of the farmers also cultivate in March. This implies most farmers prepare and cultivate at the same time as illustrated in (Figure 5). Most of the farmers start harvest in September; however, there are other crops harvested in November and December (Figure 6). Besides, crops have different water needs, according to FAO crops such as; maize require 500-800 mm/total growing period, sorghum/millet require 450-650 mm While bananas require 1200-2200 mm. http://www.fao.org/docrep/S2022E/s2022e07.htm. Meaning in a situation where there is a shortage of rainfall for the crops out of the stated amount in the growing period, crops may not mature and could affect crop yield. 13.2% of farmers irrigated their farms, and 81.6% did not irrigate their farms.

Based on the farmer's awareness and crop practices, the results show that 87.7% of farmers needed seasonal forecasts, and 2.1% needed the forecast daily (Figure 7). Out of those that needed seasonal forecasts, 61.7% agree that the forecast is a requirement for crop farming. Most farmers prepare the land for cultivation in the stated months regardless of the type of the crop and crop cycle. 61.7% agree that they require rainfall forecast for land preparation while 4.3% did not agree. Also 65.2% of farmers agree that the forecast influence their decision to plant crops. However, farmers were asked the rating of the forecast information they receive: 61.9% said the forecast is useful, while 7.1% said the forecast is timely, 16.7% mentioned that the forecast is accurate and 14.3% said that, they did not know. In this study interviews obtained were general therefore there were no specific questions on crops, for instance, detailed information on types of crops planted.

Generally, looking at the results, most farmers preferred the month of March as the onset of the season.

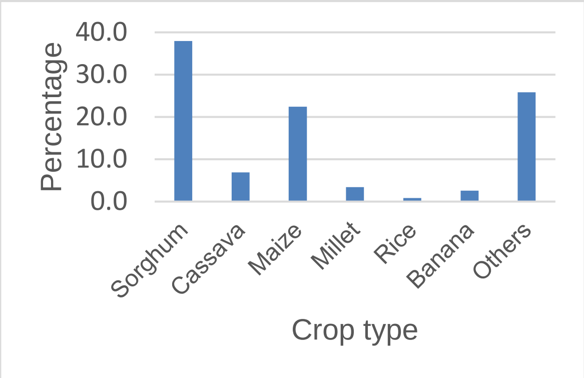

Figure 4. Crop type

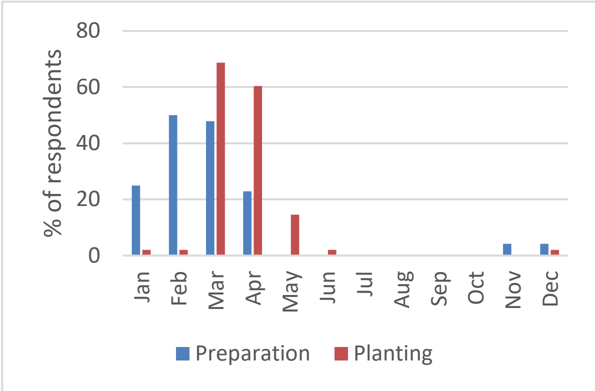

Figure 5. Figure land preparation and planting

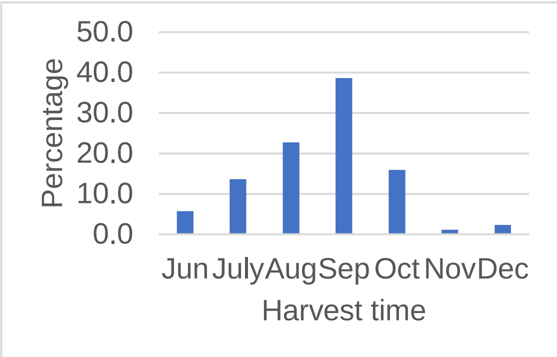

Figure 6.

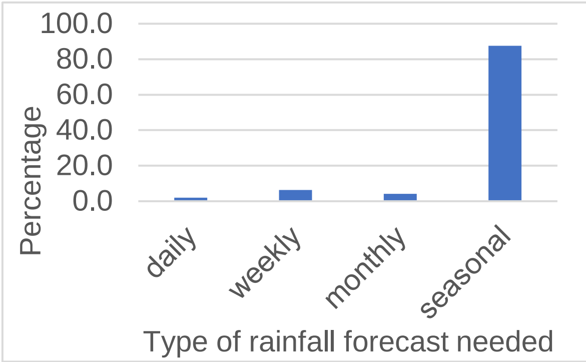

Figure 7. Rainfall forecasts needs.

4.2. Evaluate the performance of satellite rainfall products

The main objective is to assess which satellite rainfall product compares best with ground rainfall measurements for stations in Karamoja. Seven months (March, April, May, June, July, August and September) were selected for analysis. These months were selected as being relevant to agricultural practices of farmers on land preparation, crop planting, growing seasonal and harvesting period. Comparison of seven months of the aggregated daily satellite-based rainfall data for ARC, MSWEP, PERSIANN, RFE, TRMM and, CHIRPS to monthly totals for 12 years were done. Using monthly rainfall totals, precipitations from six data sets were compared at the point-pixel based station locations for March and seasonal (total amount of rainfall in all the seven months).

4.2.1. Accuracy of March

The month of March was selected based on the period the farmers start land preparations and crop planting from the farmers' interviews. Also, referring to rainfall distribution in Figure 2, is the start of the growing season, (Section 4.1). The monthly rainfall totals for March per station, per product, were compared and the scatter plots for all the products were plotted and analysed. (Figure 8 the scatter plots for rain-gauge observations against six satellite products at point-based location scale. For other stations (see Appendix I-M). Table 3 - 6 shows statistical indicators computed and the standard errors from the coefficient of determination (R^2) with the green colour as best results and red colour as the worst results. To choose the best satellite product; despite the various statistical indicators calculated, the results are evaluated based on the R^2, RMSE and Bias; less attention was given to r since it addresses the same question just like R^2.

General the TRMM3B42 data has the poor agreement with rain gauge data with R^2 of -1.75; overestimation was also reflected in the Bias values of 2.53, the RMSE is (113.30 mm month^{-1}) indicating that the product is unreliable.
The CHIRPS data show a better agreement with rain gauge data with R^2 of 0.78. The Bias of 0.08 reflects underestimation slightly. The RMSE percentage is less than TRMM3B42 but still too high with a value of (28.03 mm month^{-1}) thus the CHIRPS data is also unreliable.
The smallest RMSE (18.83 mm month^{-1}) from PERSIANN in overall from all stations, shows greater central tendencies and smaller extreme errors in the data. However, with the lowest accuracy R^2 of 0.27, thus the product is unreliable.

Overall overestimation by ARC products is observed from the Bias values (1.01), mainly when monthly rainfall is greater than 100 mm, while underestimation is evident when the rainfall is less than 100 mm.
The positive bias indicates the estimated value exceeds the observed value on the average, while negative bias corresponds to underestimation the observed value on the average.

Based on the above results, we conclude that different satellite products, could not be used to evaluate the seasonal rainfall forecasts in Karamoja due to their unreliable accuracies when compared with observations in various stations in the month of March.

Table 3: Statistical indicators on the Coefficient of determination (R^2) for March for the year 2001-2012 in five stations.

Dataset	Alerek	Matany	Moroto	Nakapiripirit	Kotido
ARC	0.5	0.54	0.64	0.6	0.47
MSWEP	0.35	0.47	0.6	0.41	0.36
CHIRPS	**0.55**	**0.73**	0.69	**0.78**	**0.56**
PERSIANN	0.51	0.62	0.68	0.66	0.27
RFE	0.41	0.43	0.48	0.48	0.37
TRMM	-3.16	-2.12	-1.75	-2.11	-3.04

Table 3. Statistical indicators on the Root mean square error (RMSE) for March for the year 2001-2012 in five stations.

Dataset	Alerek	Matany	Moroto	Nakapiripirit	Kotido
ARC	38.92	34.21	43.55	41.46	34.62
MSWEP	55.98	32.58	35.41	40.98	44.06
CHIRPS	39.46	41.38	31.67	40.07	28.03
PERSIANN	27.93	32.91	20.15	35.73	18.83
RFE	29.81	29.61	27.04	31.11	22.33
TRMM	78.56	77.07	88.72	71.08	113.3

Table 4. Statistical indicators on the Bias scores for March for the year 2001-2012 in five stations.

Dataset	Alerek	Matany	Moroto	Nakapiripirit	Kotido
ARC	1.01	1.04	1.44	0.81	1.18
MSWEP	0.91	0.9	1.12	0.74	1.4
CHIRPS	0.72	0.08	0.82	0.66	0.66
PERSIANN	0.71	0.71	0.99	0.64	0.95
RFE	0.98	1.05	1.26	0.93	1.03
TRMM	2.09	1.9	2.53	1.76	3.47

Table 5. Statistical indicators on the Pearson correlation coefficient (r) for March for the year 2001-2012 in five stations.

Dataset	Alerek	Matany	Moroto	Nakapiripirit	Kotido
ARC	0.71	0.85	0.77	0.67	0.73
MSWEP	0.6	0.77	0.81	0.73	0.77
CHIRPS	0.74	0.06	0.79	0.89	0.75
PERSIANN	0.76	0.79	0.8	0.81	0.74
RFE	0.73	0.69	0.79	0.7	0.79
TRMM	0.43	0.26	0.39	0.28	-0.07

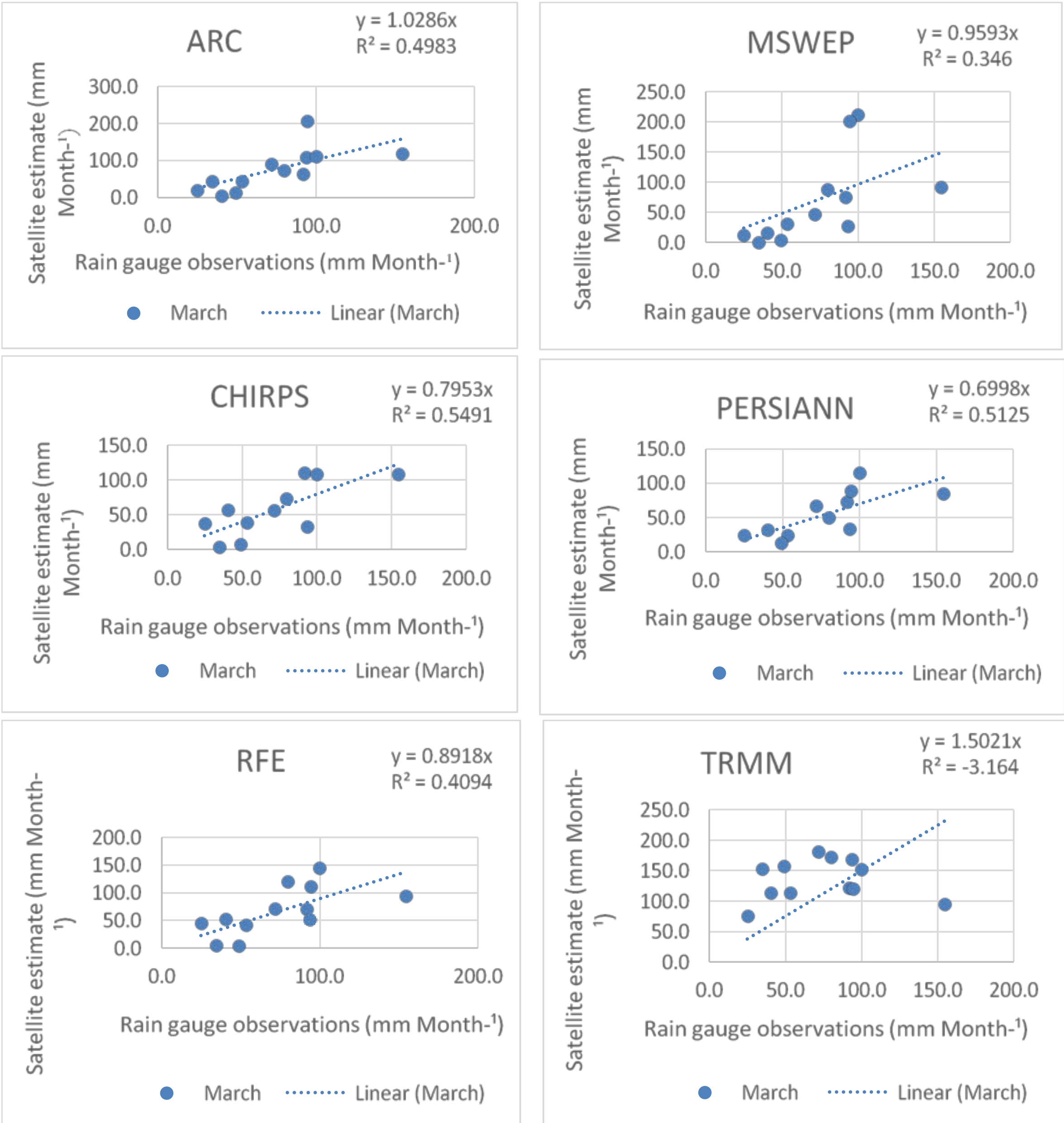

Figure 8. Scatter plots of March monthly rainfall from Alerek rain-gauge station against ARC, MSWEP, CHIRPS, PERSIANN-CDR, RFE and TRMM3B42, for other stations see Appendix I-M.

4.2.2. Seasonal analysis for seven months (March to September).

The monthly rainfall precipitation estimates for seven months (March to September) were summed up to obtain total seasonal rainfall for both the rain gauge and the six satellite products. Figure 9 shows the scatter plots from rain-gauge stations against each of the satellite-based rainfall estimates and the standard errors from R^2 .(for other stations see Appendix N-R) Table 6-9 shows details of all the statistical indicators calculated, the best results are highlighted in green colour and the worst results in red. However, there was poor agreement observed between the rain-gauge and satellite rainfall products ($R^2 < 0.5$) in the seven-month season. To choose the best satellite product estimating rainfall amounts in the total season; despite the various statistical indicators calculated, the results are evaluated based on the R^2, RMSE and Bias; less attention was given to r since it addresses the same question just like R^2.

General the CHIRPS data has the poor agreement with rain gauge data with R^2 of -0.01; overestimation are also reflected in the positive Bias values of 0.67, the RMSE is (131.51 mm month^{-1}) indicating that the product is unreliable.

The PERSIANN-CDR data show a better agreement with rain gauge data with R^2 of 0.68. The Bias of 0.07 reflects underestimation slightly. The RMSE percentage is less than CHIRPS but still too high with a value of (34.23 mm month^{-1}) thus the CHIRPS data is also unreliable.

The smallest RMSE (14.36 mm month^{-1}) from TRMM3B42 in overall from all stations, shows greater central tendencies and smaller extreme errors in the data. However, with lowest accuracy R^2 of negative values showing an underestimation of rainfall amounts in the total season, thus the product is unreliable.

Overall underestimation by CHIRPS products was observed from the Bias values (0.67). Several stations that had negative R^2 values was due to forcing the intercept to start from zero.

Based on the above results, we conclude that different satellite products could not be used to evaluate the seasonal rainfall forecasts in Karamoja due to their unreliable accuracies when compared with observations in various stations in the seven-month season.

Table 6. Seasonal statistical indicators for Coefficient of determination (R^2) of 7 months (March to September) for the year 2001-2012 in five stations against six satellite products.

Dataset	Alerek	Matany	Moroto	Nakapiripirit	Kotido
ARC	-0.72	0.01	0.40	0.37	-0.09
MSWEP	-0.17	0.13	0.26	0.43	-0.12
CHIRPS	0.03	-0.15	-0.01	0.14	-0.13
PERSIANN	0.68	-0.15	-0.28	0.18	-0.51
RFE	-0.20	-0.07	0.10	-0.38	0.24
TRMM	-0.78	-0.31	-0.66	-0.95	-2.95

Table 7. Seasonal statistical indicators for Root mean square error (RMSE) of 7 months (March to September) for the year 2001-2012 in five stations against six satellite products.

Dataset	Alerek	Matany	Moroto	Nakapiripirit	Kotido
ARC	19.93	22.55	15.45	35.74	22.71
MSWEP	28.69	30.35	21.56	36.3	21.23
CHIRPS	131.51	40.76	34.39	44.97	33.91
PERSIANN	87.73	47.84	34.23	61.82	36.06
RFE	20.93	28.2	19.3	37.9	17.47
TRMM	54.77	30.46	14.36	37.98	27.12

Table 8. Seasonal statistical indicators for Bias scores of 7 months (March to September) for the year 2001-2012 in five stations against six satellite products.

Dataset	Alerek	Matany	Moroto	Nakapiripirit	Kotido
ARC	0.07	0.09	0.10	0.07	0.05
MSWEP	0.10	0.09	0.08	0.06	0.09
CHIRPS	0.19	0.67	0.09	0.08	0.10
PERSIANN	0.16	0.07	0.09	0.07	0.11
RFE	0.07	0.07	0.08	0.05	0.07
TRMM	0.03	0.07	0.09	0.07	0.06

Table 9. Seasonal statistical indicators for Pearson correlation coefficient (r) of 7 months (March to September) for the year 2001-2012 in five stations against six satellite products.

Dataset	Alerek	Matany	Moroto	Nakapiripirit	Kotido
ARC	0.26	0.40	0.50	0.59	0.35
MSWEP	0.22	0.40	0.62	0.74	0.56
CHIRPS	0.25	0.85	0.18	0.35	0.02
PERSIANN	0.89	0.42	0.23	0.62	-0.18
RFE	0.34	0.13	0.42	0.21	0.54
TRMM	0.01	0.19	0.31	0.62	-0.29

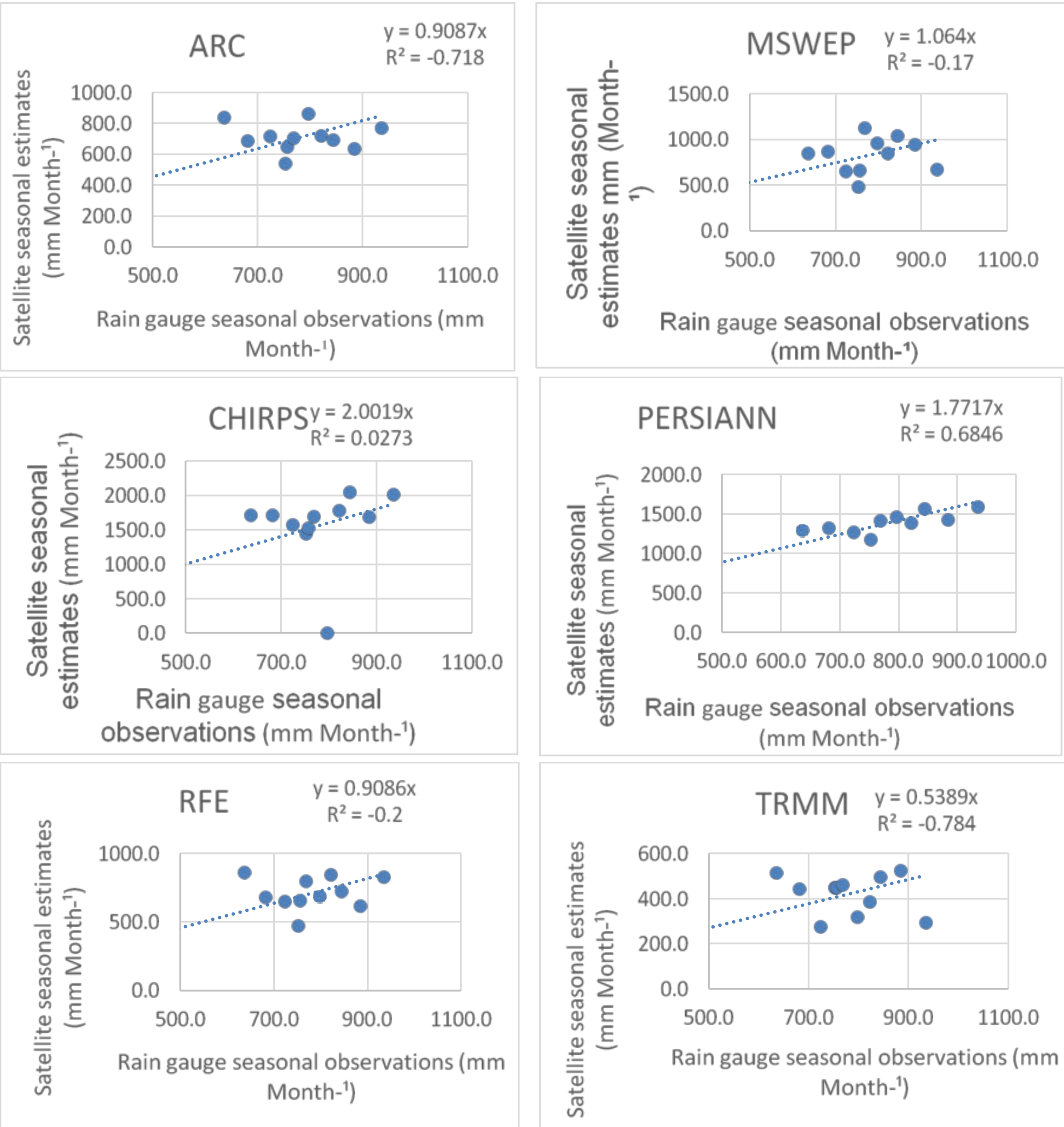

Figure 9. Scatter plots of seasonal rainfall total from Alerek rain gauge station against ARC, MSWEP, CHIRPS, PERSIANN-CDR, RFE and TRMM3B42, for other stations see Appendix N-M.

4.3. Evaluate the accuracy of seasonal rainfall forecast

4.3.1. 1-month lead time forecast analysis (March)

The main objective is to assess the accuracy of an existing rainfall forecast for Karamoja, based on various lead times and the main rainfall parameters of interest to farmers for timely agronomic decision making. To perform the evaluation, the ECMWF-S4 seasonal forecasts were selected based on the farmers' forecasts needs. Based on the forecasts needs and ground observations for evaluation, the month of March was chosen as the lead time for 1-month. Also, March-September were selected as lead time covering seven months. These months were selected based on the importance of agricultural practices. Due to the unreliability of satellite rainfall products to evaluate the seasonal rainfall forecasts based on the previous analysis, monthly ground observations were selected for analysis at March and seasonal totals.

The monthly rainfall totals for the month of March per station and forecasts were compared using the method stated in Section 3.2 and the scatter plots for all the stations were plotted and analysed. Figure 10 shows scatter plots of March monthly ECMWF Seasonal System 4 forecast for the whole period (2001-2012) against ground-based observations. Table 10 shows statistical indicators computed and the standard errors from the coefficient of determination values (R^2) with the green colour as best results and red colour worst results. Despite the various statistical indicators calculated, the results are evaluated based on the R^2, RMSE and Bias; less attention was given to r since it addresses the same question just like R^2.

Generally, the ECMWF-S4 data has the poor agreement with rain gauge data with $R^2<0.5$. Overestimation is reflected in the Bias values of 1.15, the highest RMSE is (53.37 mm month^{-1}) indicating that the forecasts unreliable.

The ECMWF-S4 forecasts data show a better agreement with rain gauge data with R^2 of 0.46. The Bias of 0.01 reflects underestimation. The RMSE value of (35.22 mm month^{-1}) is less than (53.37 mm month^{-1}) but still too high; thus the ECMWF-S4 data is unreliable.
The smallest RMSE in overall from all stations shows greater central tendencies and smaller extreme errors in the data. However, with the lowest accuracy R^2 of 0.3, thus shows the forecasts is unreliable.

In overall overestimation by ECMWF-S4 forecast is observed from the Bias values (1.15).
Based on the above results we conclude that different stations have varying patterns both in satellite rainfall products and ECMWF-S4 forecast, hence yielding different accuracies.

Table 10. March ECMWF-S4 forecast statistical indicators for five pixels stations in the year 2001-2012.

Station	R^2	RMSE	Bias	r
Alerek	0.45	40.35	0.01	0.67
Matany	0.45	53.37	0.44	0.67
Moroto	0.15	41.12	0.62	0.39
Nakapiripirit	0.46	51.48	0.51	0.68
Kotido	0.3	35.22	1.15	0.55

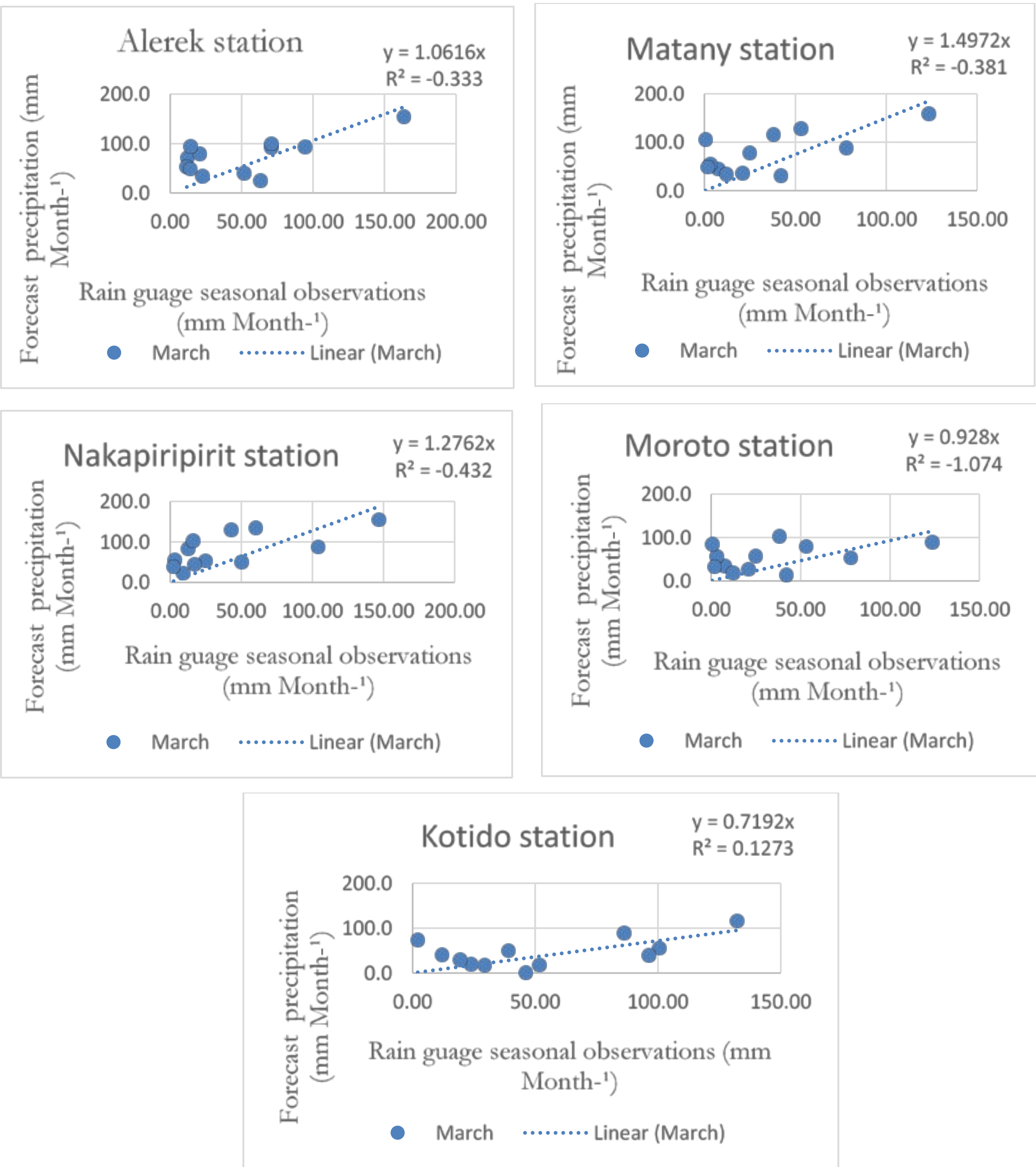

Figure 10. Scatter plots for March 1-month lead time forecast for five pixels rain gauge stations.

4.3.2. Seven-month lead time forecast analysis (March to September)

The monthly rainfall precipitation estimates for seven months (March to September) were summed up to obtain total seasonal rainfall for both the rain gauge and the ECMWF-S4 seasonal forecasts. Figure 11 shows scatter plots of seasonal monthly ECMWF Seasonal System 4 forecast for the whole period (2001-2012) against ground-based observations. Table 11 shows statistical indicators computed and the standard errors from the coefficient of determination values (R^2) with the green colour as best results and red worst results.

The analysis of seven months was performed to see the ECMWF-S4 seasonal forecast performance in estimating the amount of rainfall in the total season. To perform the evaluation the R^2, RMSE, Bias and r was calculated and analysed. However, little attention was given to r since they address the same question with the R^2 as mentioned previously. The analysis of R^2 was to evaluate how well the estimates corresponded to the observed values. However, poor agreement was observed between the rain-gauge and ECMWF- S4 forecasts ($R^2 < 0.5$) in both stations in the seasonal analysis.

General the ECMWF-S4 data has the poor agreement with rain gauge data with R^2 of 0, in the seasonal analysis. Underestimation is reflected in the positive Bias values of 0.05, the highest RMSE is (52.62 mm month^{-1}) indicating that the forecast is unreliable. The ECMWF-S4 forecasts data show a better agreement with rain gauge data with R^2 of 0.12. The Bias of 0.76 reflects underestimation. The lowest RMSE value of (27.33 mm month^{-1}) is less than (52.62 mm month^{-1}) but still too high; thus the ECMWF-S4 data is still unreliable.
The smallest RMSE in overall from all stations shows greater central tendencies and smaller extreme errors in the data. However, with the lowest accuracy R^2 of 0, thus shows the forecasts is unreliable.

Overall overestimation by ECMWF-S4 has observed from the positive bias exceeds the observed value on the average, while negative bias corresponds to under forecasting the observed value on the average. The general observation is that a combination of a season made up of seven months decreased the skill. Moreover, the stations had good Bias scores closer to 1 except for Moroto and Kotido which had 0.05 and 0.10 respectively.
In comparison, it was observed that PERSIANN product which performed better in the seasonal analysis was from the station of Alerek using the R^2; while the ECMWF-S4 best performance is within the same station. However, the station of Nakapiripirit performed better than other stations in the total season. To know which forecasts performance best in Karamoja to meet farmers' needs, we observed that, the Month of March forecasts skill is better than the seasonal forecasts based on the above analysis.

Table 11. ECMWF-S4 Seasonal forecast statistical indicators per rain gauge station for the year 2001-2012.

Station	R^2	RMSE	Bias	r
Alerek	0.12	35.31	0.76	-0.35
Matany	0.06	52.62	0.60	-0.25
Moroto	0.03	28.72	0.05	-0.17
Nakapiripirit	0.08	44.17	0.74	-0.28
Kotido	0	27.33	0.10	-0.01

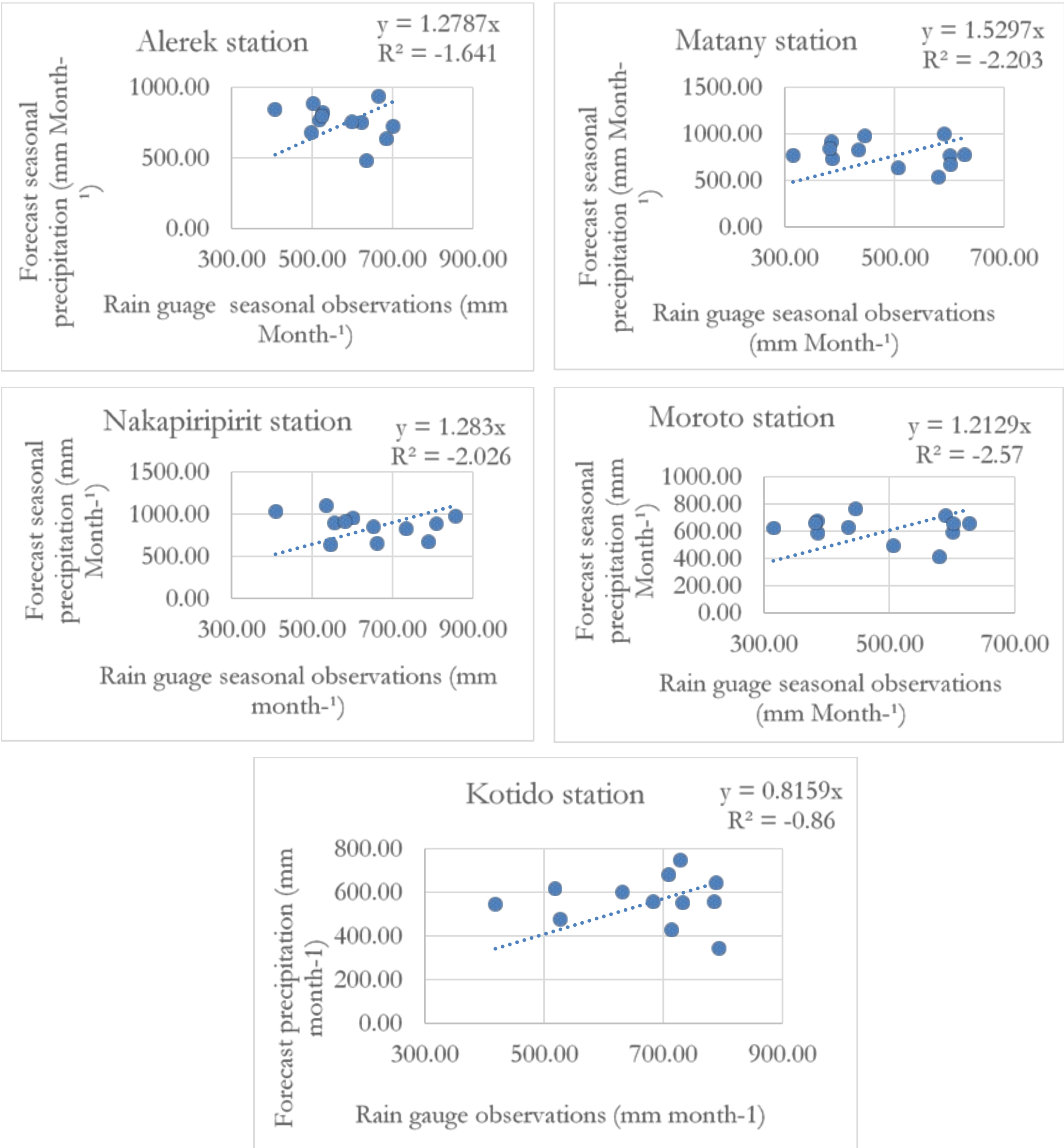

Figure 11. Scatter plots of seven months lead time seasonal forecast against five pixels rain gauge stations

5. DISCUSSION

The forecast information needs by smallholder farmers are growing due to the changing climatic condition that have resulted in weather variability witness in the change in timing, frequency and intensity of rainfall during the growing season. Uganda National Meteorological Authority currently provides and distribute this forecast information through bulletin, radios and existing agricultural extension structure. Farmers, however, do not put an effort to access this information, in most cases, they rely on local knowledge and prediction by elders from the community for which they believe and trust. This research is similar to research done by Onyango, Ochieng, & Awiti, (2012) on viewpoints from farmers and fishers on the weather and climate information products in western Kenya. Therefore, in this study, we set out to explore and document forecast needs of farmers in Karamoja and consequently evaluate the accuracy of the prediction of rainfall by different satellites and ECMWF-S4 seasonal forecast to meet those needs.

The results show that farmers rely mostly on indigenous knowledge and radio to access weather-related information to meet their forecast needs. We note that farmers are interested in rainfall forecast mainly before the start of the growing season in the month of March and through the cropping period. The timing would help farmers prepare to tilt their land early in February and March to benefit from the onset of the rains. The result shows that there is a confusion between rainfall forecast and weather forecast from the information-based on radio awareness. Evidence on the need for rainfall forecasts information by farmers enable them to choose seasonal forecasts (total amount of rainfall during the season), and the months for agricultural practices match with the ECMWF SYS-4 forecasts, this pre-empts the selection of the month of March-September for the seven months analysis. Thus, justifying the relevance of forecast information in facilitating planning and development of the appropriate response to weather rainfall variability during the growing season. This finding points out to the fact that the temporal rainfall distribution is important as it determines the need for water after planting of the seeds, weeding and harvesting should are done.

In Karamoja mean onset date of the rainy season is 3rd week of March, this would follow that planting would start in the same decade, however, those who wait for rainfall onset to commence land preparation will start planting in April and growing period running until the end of September. However, because of the overlap between the 1st planting and 2nd planting season, the forecast needs as indicated by farmers should cover this window period during which cropping activities take place. Additionally, Karamoja being a semi-arid area, the amount of rainfall and consistency is very vital information. Although farmer needs did not capture this aspect, it is a component that needs to be included in the forecasts since this can aid in deciding which crops to be planted. For example, if there will be below average seasonal rainfall total, maize as a crop with high crop water requirement compared to millet will register low productivity, thus the benefit of forecast information.

The forecasts needs as indicated by farmers are of agricultural relevance; we explore the possibility of satellite-detected rainfall estimates in accurately predicting the rainfall for Karamoja. In this, we considered six satellites products comparing with gauge station dataset. The performance of six satellites were evaluated in reproducing rainfall against the five rain gauge observations; based on the interviews held with farmers, the month of March and seasonal monthly totals were used. The results show that different products performed differently depending on the location station. For example, CHIRPS in Alerek station had an R^2 of 55% and 78% in Nakapiripirit for the March comparison; this variation could perhaps be due to the contribution of local climatic forcing that affects the accuracy of the prediction, thus the difference. In general the performance of satellite in predicting the seasonal rainfall was poor for all the products. They revealed underestimation according to the bias indicator with the lowest being 0.05 in Kotido and 0.19 in

Alerek. Further supported R^2 that indicates negative values resulted from the forcing of the intercept to zero, thus indicating very poor performance of the model used. The poor seasonal prediction by the satellite products could perhaps be due to the existing influence of the lake convections from the surrounding lake Turkana and potentially the prevailing winds.

Meanwhile, for the month of March, we note an overestimation by different satellites in different districts according to the Bias results; For example, TRMM overestimated in all the stations, while the RFE overestimated in three stations except for Alerek and Nakapiripirit. Besides, ARC overestimated in four stations except for Nakapiripirit. This difference in accuracy performance could affect the reliability and utility of the product, thus have the potential of misleading the farmers on the agronomic decision and hence huge implication on crop production. Dinku, Ceccato, Grover-Kopec, et al.,(2007) performance of the products depends on the application used. Accordingly, the satellites that underestimate has potential application in drought assessment and monitoring while overestimating products for flood monitoring hence the possible utility of ARC in all the location except for Nakapiripirit for flood monitoring.

Several attempts have been made to compare rainfall products and in-situ measurements (Dembélé & Zwart, 2016). Comparing the ECMWF-S4 forecasts with the analysis of satellite rainfall products in the month of March, it is observed that CHIRPS performed better than the rest of the product with R^2=78% in Nakapiripirit, on similar circumstances ECMWF-S4 forecast also performed better when compared to other location in the same station with the R^2=46%. However, when we consider Moroto station, we note relatively higher R^2 values by all satellite except TRMM, yet the forecast performed poorly accordingly registering negative values. The PERSIANN product according to the seasonal analysis, explained 68% of the interannual variability of the total rainfall in Alerek station, while the ECMWF-S4 explains 12% of the estimates. Despite the seasonal prediction performance, the total seasonal estimates are less valuable in informing the regular cropping activities such as weeding requiring monthly prediction.

Furthermore, the study found that ECMWF-S4 forecast had similar results in both Alerek and Matany, with R^2 of 0.45 were not very far from the best performing station (Nakapiripirit) in the month of March. The worst performing station was Kotido and Moroto. The poor accuracy could be due to seasonal variations and the quality of data used for analysis from local stations. Despite variation in the accuracy of the forecast in the different stations, RMSE in both stations showed that the errors had a normal distribution. Assuming the dense rain gauge network was used, the accuracy would possibly improve in both stations in all the lead times.

The ECMWF-S4 forecasts results show that there were high predictions in March, as 1-month lead time compared to the total amount of rainfall in the season for seven-month lead times in both rain gauge stations. Similar results were observed by (Nyadzi et al., 2019) where low correlation at an increasing lead time was seen. The previous study by (Mwangi et al., 2014) noted that prediction declines with increasing lead time and this limits its usefulness for farmers. Moreover, seasonal forecasts are more important to farmers. Also (Onyango et al., 2012) observed increasing rainfall variability having higher implications resulting into great risks for farmers.

The results show the inaccuracy of the forecast in the full season. The forecast before the season does not correspond well with rain gauge measurements over the season. Assuming that, the rain gauge data are of good quality, this means that it is not possible for farmers to rely on a forecast of total seasonal rainfall, which is made shortly before the rainfall season. Farmers who rely on March forecast could be made aware of the overestimation and underestimation of the forecast especially in the districts with underestimation of the stated stations: namely; Moroto and Kotido while the overestimation is in Napak, Abim and Nakapiripirit.

The performance of ECMWF S-4 was independent of the season and lead time, which is promising for meeting farmers needs in Karamoja. The poor performance of the forecasts in the season ($R^2 = 0.12$) could because of a limited number of stations as well as the quality of rainfall data used and seasonal variability in the study area. Since March forecast was better in forecasting rainfall amounts as 1-month lead time, the overall conclusion is that the right period for the farmers to receive the forecast information to help them make agronomic decisions is March. However, there are certain limitations.

Generally, satellite rainfall products performed better in the districts of Napak, Nakapiriprit and Moroto. Similarly, the EMWF-S4 forecast performed better in Abim, Nakapiripirit and Napak districts. This is because they are on the windward side and receive rainfall between 800-1200mm (Nakalembe, 2018).
This study has several applications.: Useful tool in decision making activities such as funds allocation for agricultural development. It is also a useful tool for enhancing food security, and Lastly, the same concept can be applied to other parts of the country not only Karamoja.

Despite the benefits of forecasting, certain limitations are observable such as few rainfall stations which limits the accuracy due to few samples for analysis. The quality of the rainfall data products when the forecast is not able to detect rainfall and this result into the generation of null values. The uncertainties associated with forecasting and a major limitation observed was that the questionnaire did not include questions on how specific forecasts were used in deciding and timely delivery of information. For instance, how, the forecast influences the choice of seeds purchased for planting and crop phenology. However, such a complete set of detailed questions would have required a longer time to collect data.

6. CONCLUSION

This study has looked at the needs of farmers for rainfall information, forecasts and assessed whether satellite rainfall products and seasonal rainfall forecasts have sufficient accuracy to meet these needs. Due to the lack of accurate rainfall ground observations, satellite rainfall estimates are used of which their quality is also unknown. Besides, farmers are not adequately aware of the existing rainfall forecasts and their accuracy to effectively meet those needs. Also, the sparse meteorological networks with rain gauges in many parts of Africa just like Uganda are limited and unevenly distributed. Farmers depend on rain-fed agriculture for both livestock and crop cultivation.

Our findings indicate that seasonal rainfall forecasts ranked higher inline to land preparation, crop planting, growing season and harvest according to the framers. Even though some other needs existed such as daily, weekly and monthly, but were poorly ranked. The majority of farmers carry out crop production in different months, with majority starting to plant in March as the onset of the season while harvesting highly in September. These information was not crop specific. The good performance of ECMWF-SYS-4, PERSIANN-CDR in March, and the performance satellite rainfall products over the sub-region for the same month is a good starting point to meeting the farmers' needs, due to high accuracy in March as 1-month lead time. Such information could be used to support the decision process when issuing weather advisories information and delivery within the sub-region.

The accuracy varied per rain gauge station and lead time considered for the analysis, although the March lead time recorded better results according to the R^2. These provides a potential to seasonal rainfall forecast information that improves the agronomic decisions. The ECMWF SYS-4 seasonal forecast, therefore, has the potential to provide farmers with information that improves their farm decision making. The need to evaluate monthly is more promising to the accuracy of both the satellites and the seasonal forecasts. The need to increase investments in forecast information and consistent records maintained in the study area. The available records would increase the spatial accuracy of information and availability of rainfall data. Also better methods of disseminating rainfall forecast information to the farmers are required possibly through the Local council village leaders.

Recommendations

Farmers are made aware of the uncertainites of the seasonal rainfall forecasts and satellite rainfall products as discussed above to avoid crop losses. Farmers' education on the seasonal rainfall forecasts is vital.

There is also a need to incorporate the analysis of daily rainfall estimates of the forecasts as it is important in understanding the daily growth of the plant.

The questionnaire should include questions regarding specific lead times and different crop phenology.

Further work will be required in testing the accuracy of the traditional forecast's knowledge, various lead times and crop phenology while incorporating crop water requirements and land size in crop farm decisions.

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APPENDICES

Appendix A. Uganda Agro-ecological zones

No.	Agro-ecological zones	District
1.	Southern Highlands	Kisoro, Kabale, Rukungiri, and Kanugu
2.	South drylands	Rakai, Sembabule, Mbarara, and Ntugamo
3.	Lake Victoria crescent	Masaka, Mpigi, Luwero, Kampala, Mukono, Kayunga, Wakiso, Kiboga, Nakasongola, Kalangala and Mubende
4.	Eastern	Pallisa, Tororo, Kumi, Kaberamido, Katakwi, Soroti, Mbale, Sironko and Kapchorwa
5.	Mid-Northern	Lira, Apac, Kitgum, Gulu and Padar
6.	Lake Albert crescent	Masindi, Hoima and Kibale
7.	West Nile	Arua, Moyo, Adjumani and Yumbe
8.	West Highlands	Bushenyi, Kasese, Bundibugyo, Kamuwenge, Kyenjojo and Kabarole
9.	South East	Jinja, Iganga, Bugiri, Busia, Kamuli and Mayuge
10.	Karamoja drylands	Moroto, Kotido, Nakapiripirit (Napak, Abim, Amudat and Kaabong)

Source: (Wortmann & Eledu, 1999).

Appendix B. Farmers perception on the rainfall forecast Interview questionnaire

FARMERS PERCEPTION ON THE RAINFALL FORECAST INTERVIEW QUESTIONNAIRE.

Category I. Geographic coordinate

Latitude………………………………	Longitude……………………….

Date………………………….	District…………………………….

County…………………………….	Parish…………………………….

Village………………………………

Category II. Agricultural practices

1. Crop type, acreage and crop farming

Crop type	Land size acreage	Duration in framing		
		<5 years	**5-10**	**>10 years**
Sorghum				
Cassava				
Maize				
Millet				
Rice				
Bananas				
others specify				

2. Why did you choose to cultivate this crop?

a). Drought resistant. ☐ Yes ☐ No ☐ don't know

b). Favourable soils ☐ yes ☐ No ☐ don't know

c). Easy marketing ☐ yes ☐ No ☐ Don't know

d). Staple food ☐ Yes ☐ No ☐ Don't know

e). others specify ……………………………………………………………………………….

3. How many times in a year do you cultivate the above-mentioned crop(s)

☐ Once ☐ two times

4. Give reasons for the above-mentioned responses from 3 above

…………………………………………………………………………………………………

……………………………………………………………………………………………..

5. Do you irrigate your crop farm?

☐ Yes ☐ No ☐ Don't know

6. Which type of crops are irrigated?

a. Maize ☐ yes ☐ No

b. Sorghum ☐ Yes ☐ No

c. Cassava ☐ Yes ☐ No

d. Millet ☐ Yes ☐ No

e. Bananas ☐ Yes ☐ No

f. Rice ☐ Yes ☐ No

g. Other specify…………………………………………………………...

7. How do you determine the time to start irrigation? (Example; rainfall stops)

a). Rainfall stops ☐ Yes ☐ No ☐ Don't know

b). Whenever there is a dry spell ☐ Yes ☐ No ☐ Don't know

b). Only during the dry season ☐ Yes ☐ No ☐ Don't know

c). Any other specify………………………………………

8. How do you determine it is time to start Land preparation? (Example; rainfall stops)

a). When the rainfall stops

b). Using the season (indigenous knowledge) ☐ Yes ☐ No ☐ Don't know

c). Any other please specify……………………………………

9. When do you begin land preparation for the first planting?

January				February				March			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
April				May				June			

W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
July				August				September			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
October				November				December			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4

10. How do you determine it is time to start crop planting? (Example; rainfall stops)

a). Rainfall stops ☐ Yes ☐ No ☐ Don't know

b). Heavy rainfall ☐ Yes ☐ No ☐ Don't know

c). Any other specify……………………………………

11. When do you start crop planting?

January				February				March			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
April				May				June			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
July				August				September			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
October				November				December			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4

12. How do you determine it is time to start harvesting? (Example; rainfall stops)

a). Rainfall stops ☐ Yes ☐ No ☐ Don't know

b). Heavy rainfall ☐ Yes ☐ No ☐ Don't know

d). Any other specify……………………………………

13. When do you harvest the crops on your farm?

January				February				March			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
April				May				June			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
July				August				September			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4

October				November				December			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4

Category III. Forecast requirements need

14. Are you aware of the rainfall forecast?

☐ Yes ☐ No ☐ Don't know

15. Do you use the rainfall forecast?

☐ Yes ☐ No ☐ Don't know

16. When do you use rainfall forecast?

a). Dry season ☐ Yes ☐ No ☐ Don't know

b). Wet season ☐ Yes ☐ No ☐ Don't know

17. How do you get a rainfall forecast?

☐ Radio ☐ TV ☐ Extension worker ☐ phone ☐ Environment Officer

18. What type of information do you need to know from the rainfall forecast?

☐ Daily ☐ Weekly ☐ 10 days ☐ Monthly ☐ Seasonal ☐ Annually

19. Do you depend on rainfall forecast for crop farming?

☐ Yes ☐ No ☐ Don't know

20. Rainfall forecast a requirement for crop farming

☐ very Agree ☐ Agree ☐ Disagree ☐ very disagree ☐ Don't know

21. Rainfall forecast determine your decision on Land preparation

☐ very Agree ☐ Agree ☐ Disagree ☐ very disagree ☐ Don't know

22. Rainfall forecast determine your decision on crop planting

☐ very Agree ☐ Agree ☐ Disagree ☐ very disagree ☐ Don't know

23. Rainfall forecast determine your decision on crop Weeding

☐ very Agree ☐ Agree ☐ Disagree ☐ very disagree ☐ Don't know

24. Rainfall forecast determine your decision to harvest

☐ very Agree ☐ Agree ☐ Disagree ☐ very disagree ☐ Don't know

25. Will information on rainfall forecast help you increase production?

☐ Yes ☐ No ☐ Don't know

26. How do you rate the rainfall forecast information you get?

☐ Timely ☐ Useful ☐ Accurate ☐ Don't know

27. Do you trust the forecasts done by rainfall forecasts?

☐ Yes ☐ No ☐ Don't know

28. What activities do you normally do whenever rainfall forecasts are done by experts?

a). Land preparation ☐ Yes ☐ No ☐ Don't know

b). Crop planting ☐ Yes ☐ No ☐ Don't know

c). Do nothing ☐ Yes ☐ No ☐ Don't know

Others specify………………………………………….

36. Have you seen the seasonal bulletins or outlooks information?

☐ Yes ☐ No ☐ Don't know

37. How often do you receive the bulletins or outlooks information?

☐ daily ☐ 10 days ☐ Monthly ☐ seasonal ☐ annually ☐ Never

38. The way rainfall forecast information is communicated is most appropriate?

☐ very Agree ☐ Agree ☐ Disagree ☐ very disagree ☐ Don't know

39. How do you use the rainfall forecast information on your crop farm?

☐ Land preparation ☐ crop planting ☐ crop weeding ☐ harvesting

☐ any other specify……………………………………………………………

Category IV. Socio-Demographic data

May I ask your age…………………………………

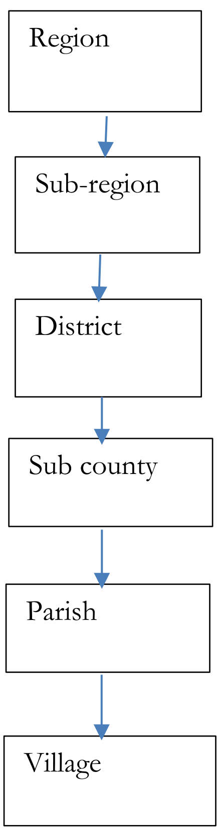
Sex of respondent ☐ Male ☐ Female

Education level

☐ Primary ☐ Secondary ☐ University ☐ tertiary ☐ other specialties

☐ No formal education

Appendix C. Administrative hierarchy of Uganda



Appendix D. Percentage of rainfall missing data for five stations for period 2001-2012.

Alerek	Matany	Moroto	Nakapiripirit	Kotido
17	17	17	33	75

Appendix E. Field assistant details used in the study.

No	Name	District	Sex	Tel.
1	Lomongin Ezekiel	Nakapiripirit	Male	+256771823220
2	Teko Christine	Moroto	Female	+256782220224
3	Komakech	Kotido	Male	+256789452300
4	Achia Agatha Christine	Napak	Female	+256789370359
5	Sagal Calisto	Abim	Male	+256786692483

Appendix F. Field photos



Farmers interviews conducted in individual household

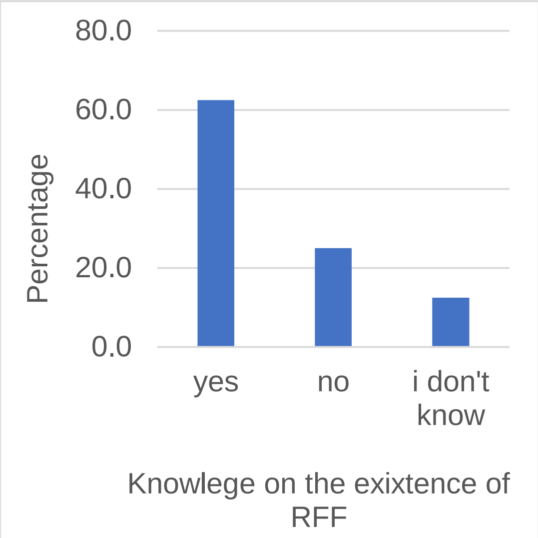
Farmers interview in Kotido

Harvested sorghum crop field.

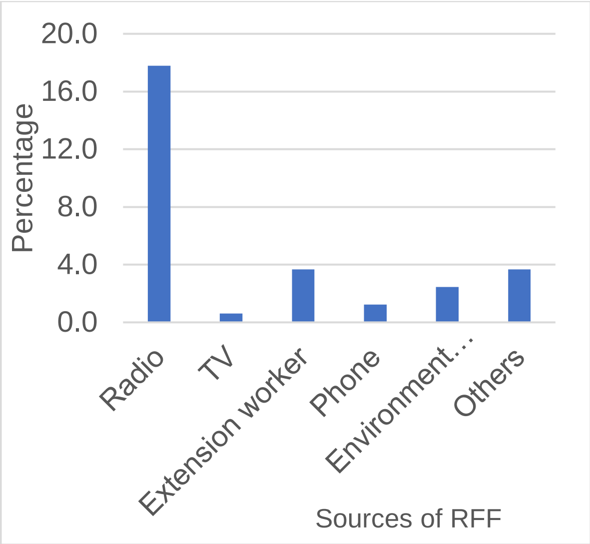
Appendix G. Percentage of satellite rainfall missing data for period 2001-2012.

Data set	Alerek	Matany	Moroto	Nakapiripirit	Kotido
ARC	58	75	67	58	92
MWSEP	17	8	8	8	8
CHIRPS	117	117	125	133	150
PERISANN	58	67	67	67	75
RFE	25	33	33	42	50
TRMM	25	0	0	0	33

Appendix H. Graphs from the farmers' interviews.

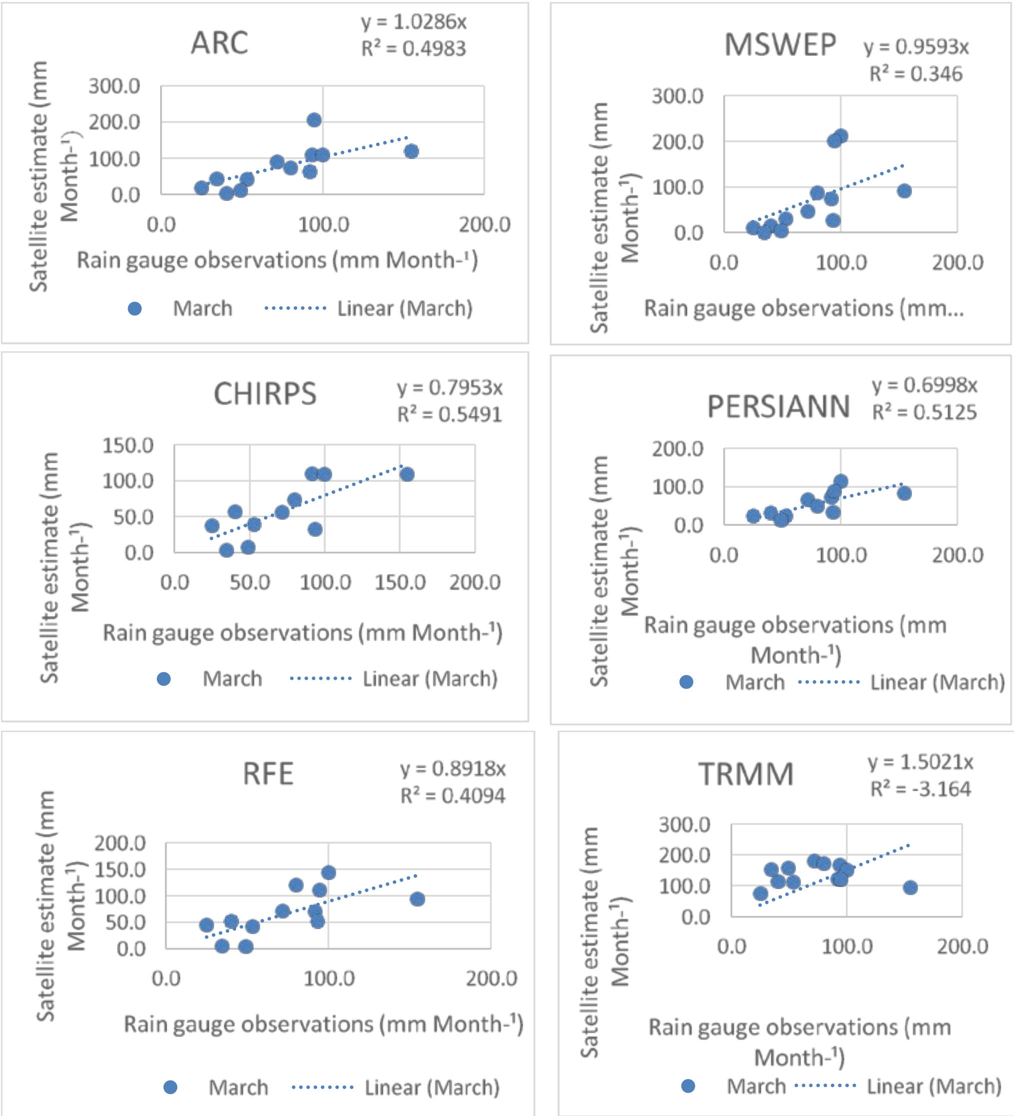


Awareness of the existence of rainfall forecasts

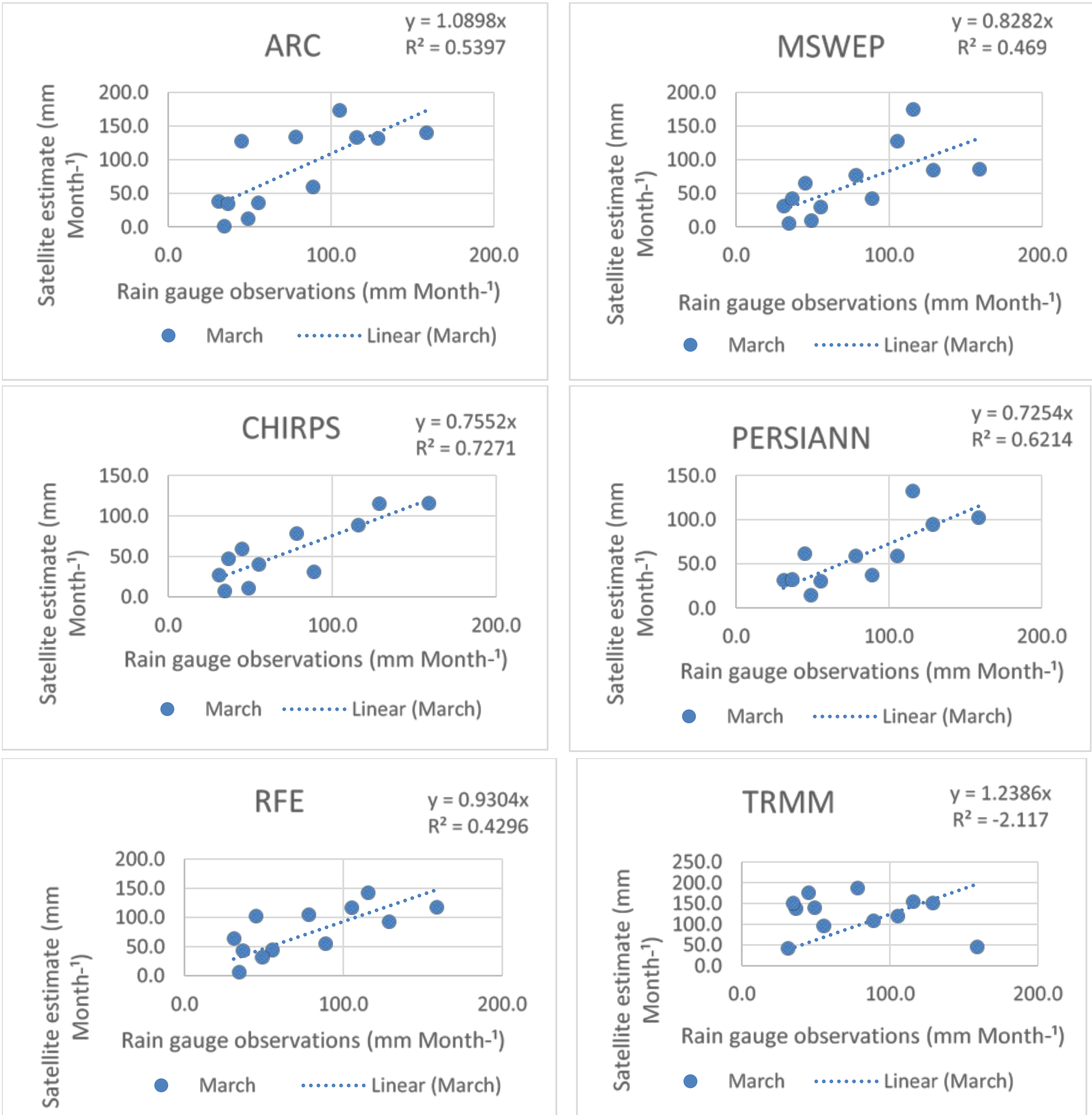


Source of rainfall forecasts

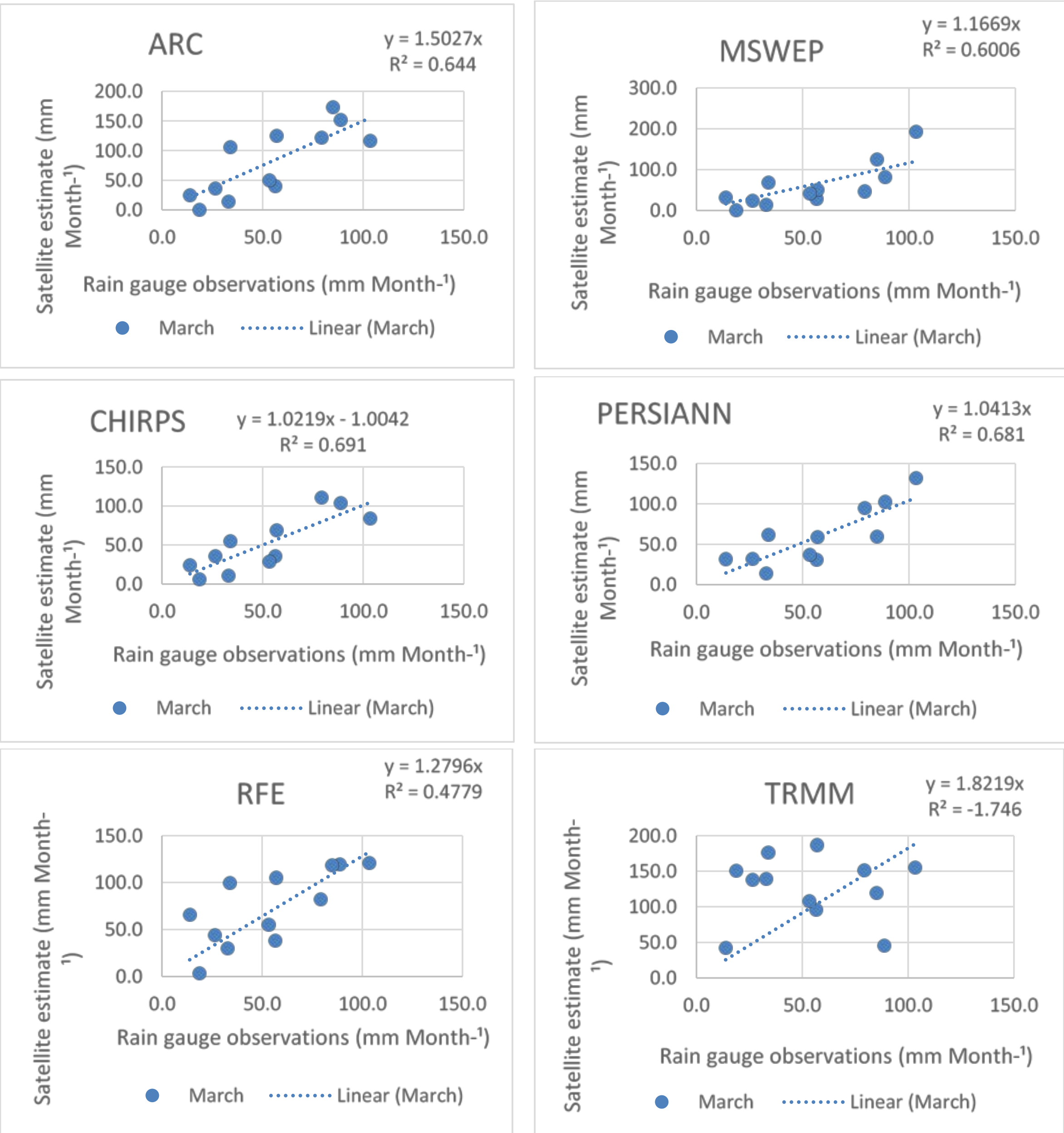
Appendix I. Scatter plots for the month of March during evaluating ARC, MSWEP, CHIRPS, PERSIANN-CDR, RFE, and TRMM3B42v7 against Alerek stations



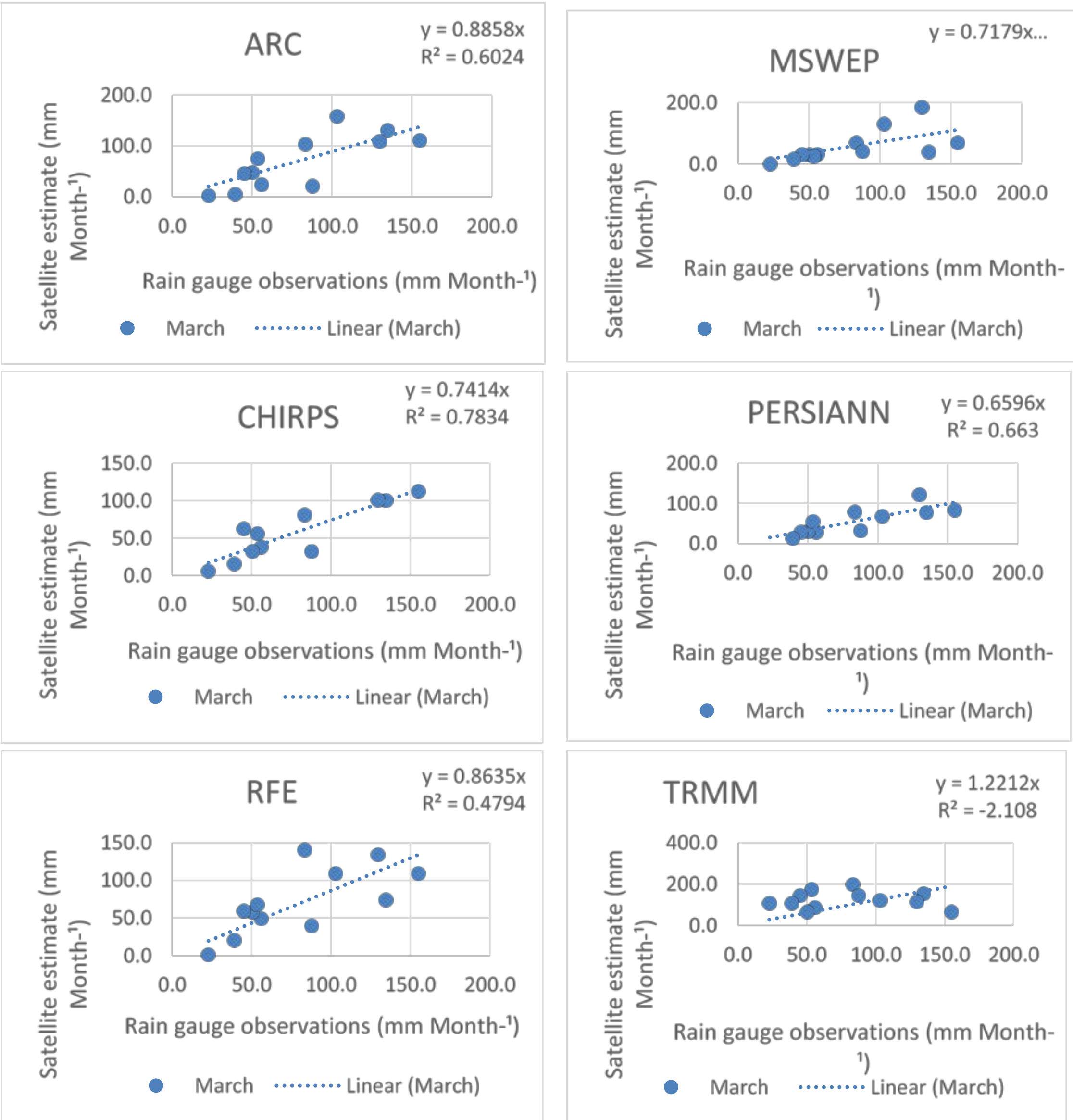
Appendix J. Scatter plots for the month of March during evaluating ARC, MSWEP, CHIRPS, PERSIANN-CDR, RFE, and TRMM3B42v7 against Matany station



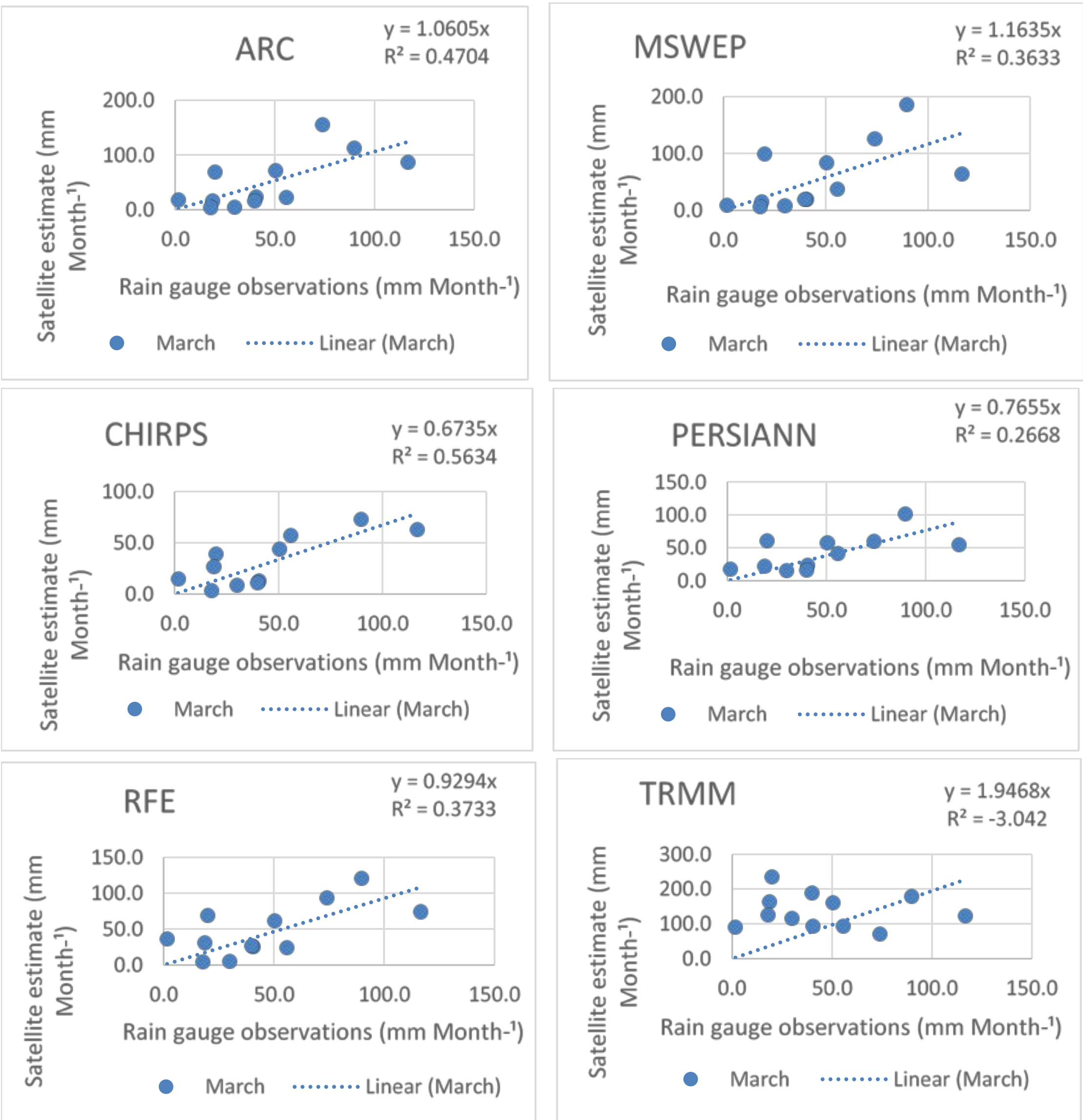
Appendix K. Scatter plots for the month of March during evaluating ARC, MSWEP, CHIRPS, PERSIANN-CDR, RFE, and TRMM3B42v7 against Moroto station



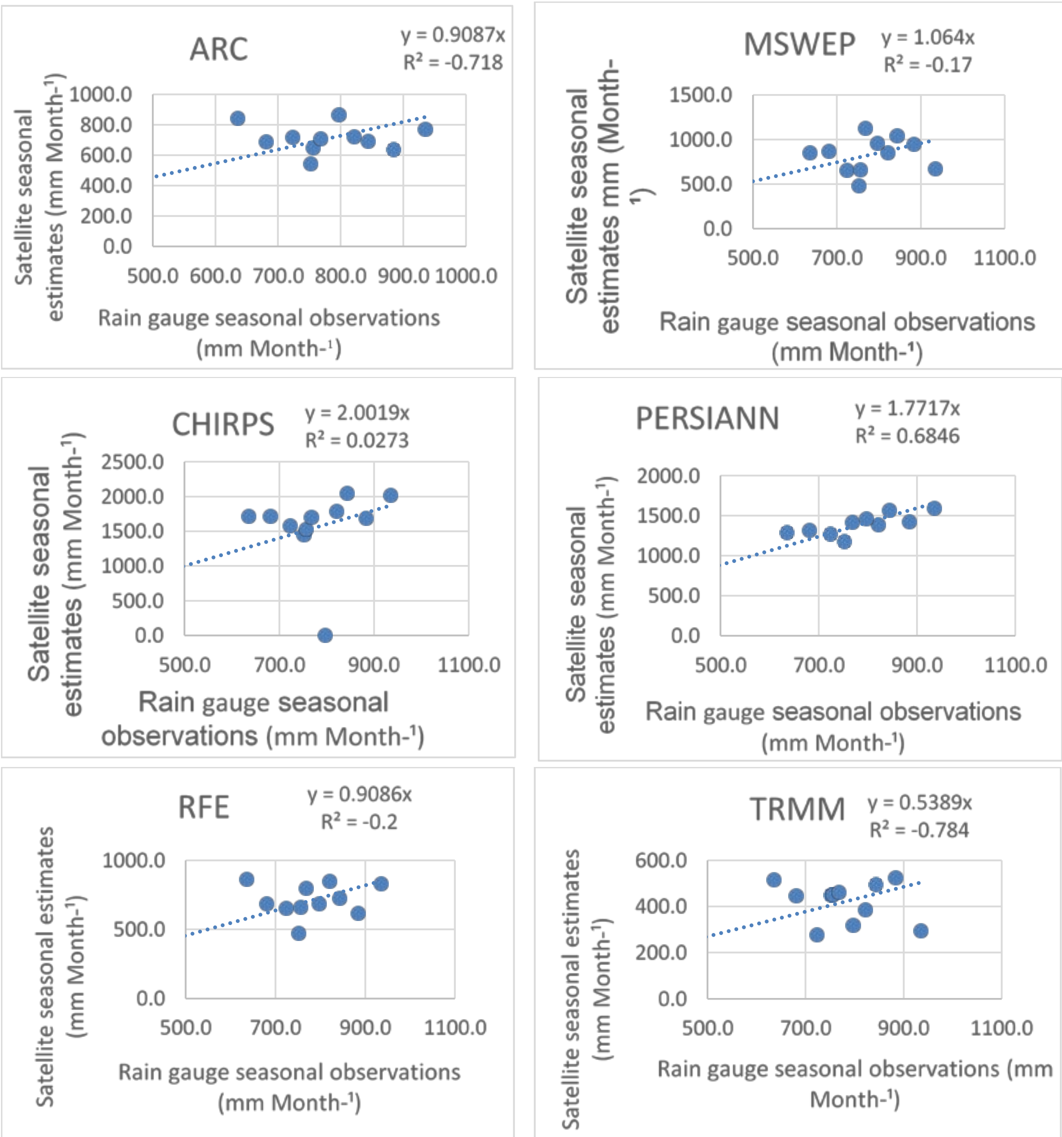
Appendix L. Scatter plots for the month of March during evaluating ARC, MSWEP, CHIRPS, PERSIANN-CDR, RFE, and TRMM3B42v7 against Nakapiripirit station



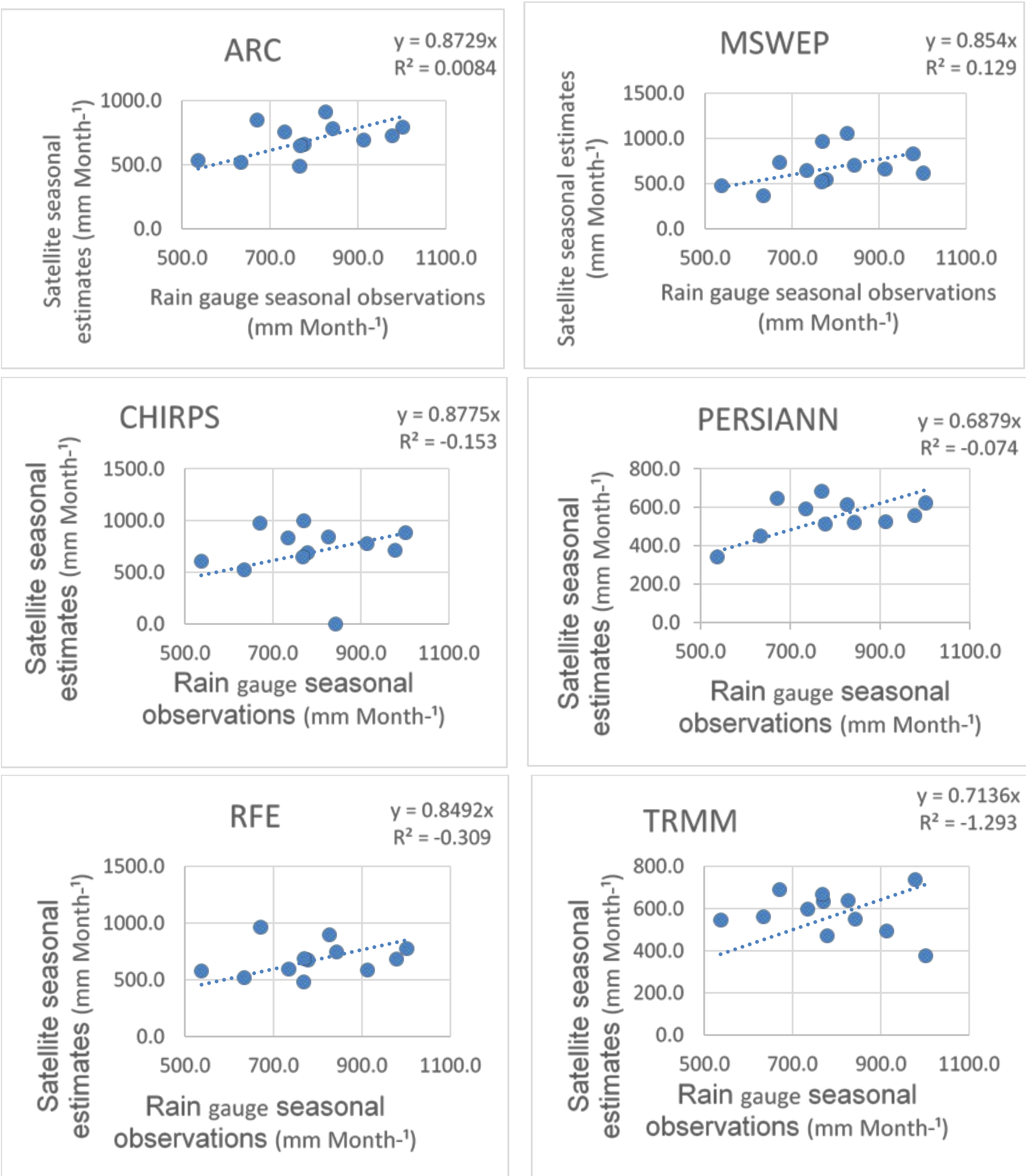
Appendix M. Scatter plots for the month of March during evaluating ARC, MSWEP, CHIRPS, PERSIANN-CDR, RFE, and TRMM3B42v7 against Kotido station



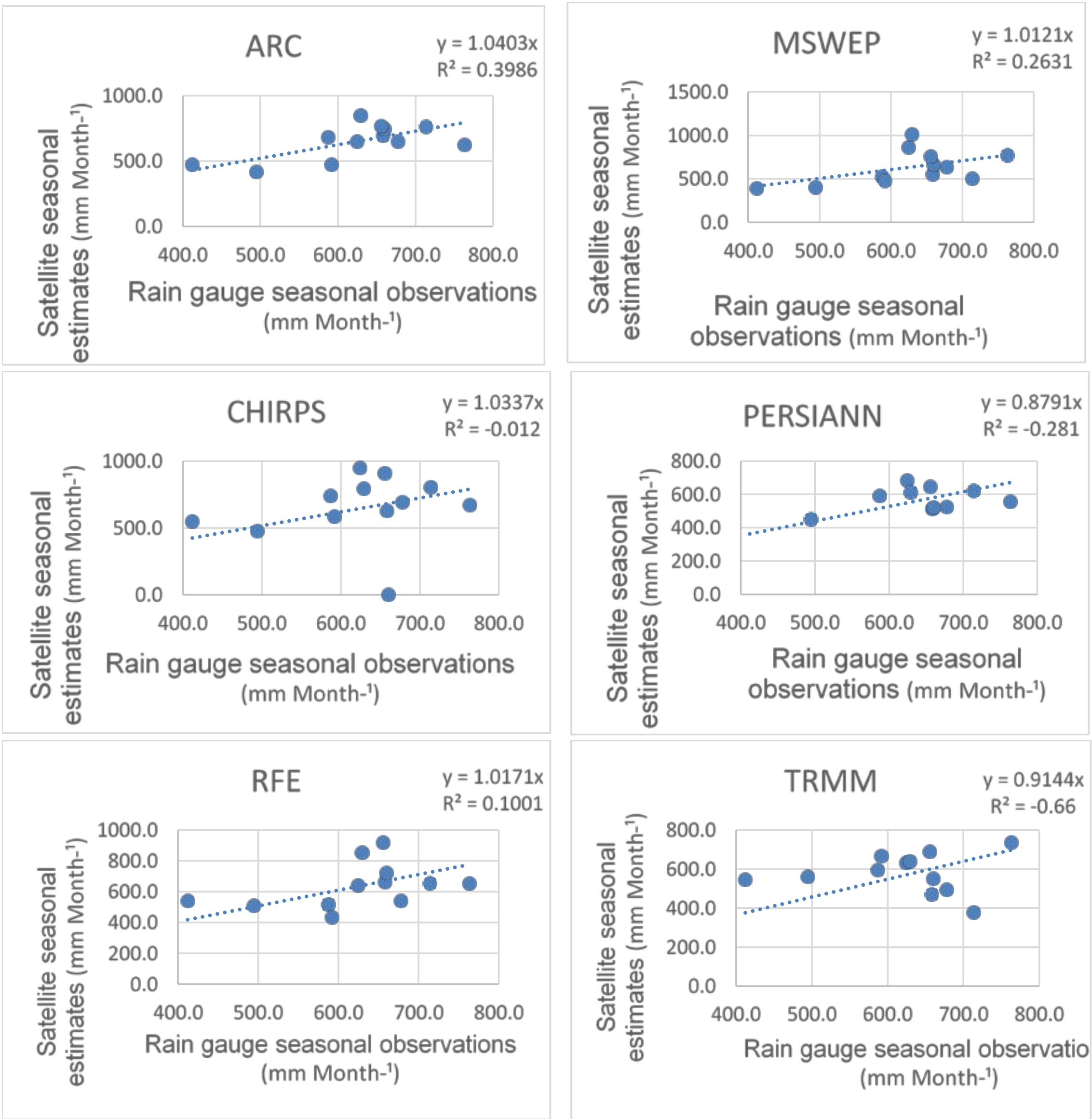
Appendix N. Scatter plots for the season during evaluating ARC, MSWEP, CHIRPS, PERSIANN-CDR, RFE, and TRMM3B42v7 against five stations Alerek.



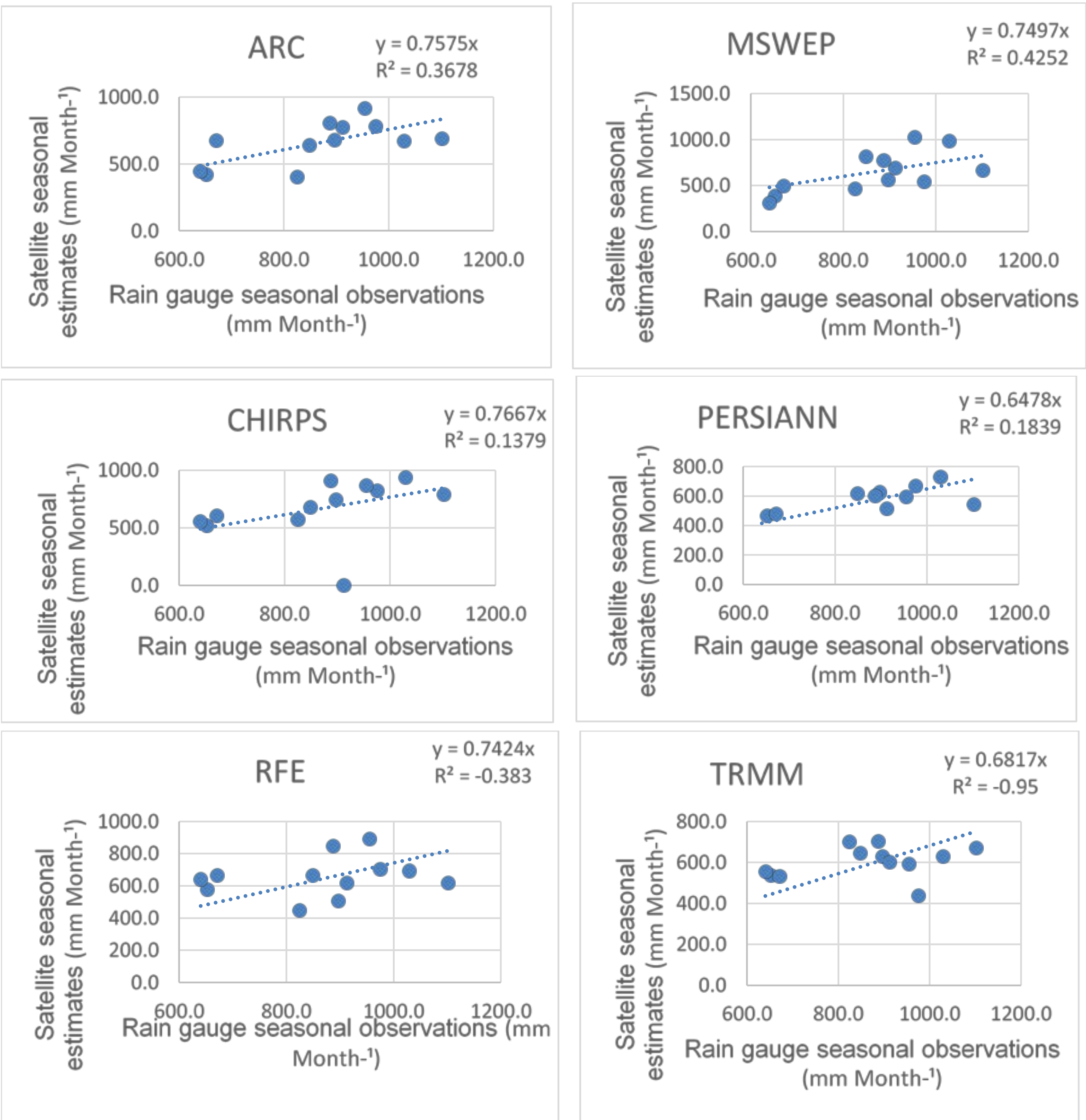
Appendix O. Scatter plots for the season during evaluating ARC, MSWEP, CHIRPS, PERSIANN-CDR, RFE, and TRMM3B42v7 against Matany station



Appendix P. Scatter plots for the season during evaluating ARC, MSWEP, CHIRPS, PERSIANN-CDR, RFE, and TRMM3B42v7 against Moroto station



Appendix Q. Scatter plots for the season during evaluating ARC, MSWEP, CHIRPS, PERSIANN-CDR, RFE, and TRMM3B42v7 against Nakapiripirit station.



Appendix R. Scatter plots for the season during evaluating ARC, MSWEP, CHIRPS, PERSIANN-CDR, RFE, and TRMM3B42v7 against Kotido station