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ESTIMATION OF GROUND WATER RECHARGE FOR IRRIGATION WATER BUDGET PLANNING IN KANZENZE SWAMP

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ABSTRACT

Groundwater is the dynamic local water source for agriculture, industry, wildlife and human development activity. Hence, in order to sustain long-term groundwater use, make intelligent groundwater allocation decisions and water budget planning, develop on-farm water management strategies, the estimation of the net groundwater recharge from agricultural areas like Kanzenze swamp is paramount important. The study findings therefore showed that Ground Water Recharge estimation for the study area ranges from 33.85mm to 52.96mm while the average mean of ground water recharge is about 45.06mm per year. The coefficient of ground water recharge is ranging from 3.41% to 5.27% while average mean recharge coefficient is 4.06% recharged to ground water level yearly. However, monthly basis planning have advantages for farmers' water budgeting. It revealed that highest recharge coefficient is recorded in months of March, April and November representing 17.22% and 17% of the mean monthly rainfall while the lowest recharge coefficient is recorded during the period of June, July and February representing 16.17%, 15.73% and 16.71% of the average monthly rainfall. Thus, it is recommended that utmost farmers around the Kanzenze swamp should plan the irrigation activities and minimizes unnecessary water use consumption in such way that in June and July there is water enough water even taught there is shortage of rainfall. It meant that priori irrigation systems should be applied to obtain optimum moisture content and water table levels for effective crop production mainly horticultural crops in season C rather than season A and season B of cultivation in Rwanda.

Contribution/Originality: This study is one of very few studies which have investigated the Estimation of ground water recharge for irrigation water budget planning in Kanzenze swamp to solve the farmers' problems in use of water during agricultural seasons alongside the swamp.

1. INTRODUCTION

Groundwater is often the main basis of both drinking and irrigation water in arid and semiarid areas. It is the dynamic local water source for agriculture, industry, wildlife and human development activity [1-3]. The groundwater dynamics reflects the response of the groundwater system due to external factors such as groundwater consumption, water storage, climate condition, and other human activities [4, 5]. For sustainable use of groundwater resources, Quantifying recharge from agricultural use and planning is important due to the different factors identified by Ebrahimi, et al. [6] not only limited to estimation of the real water losses but also to the total infiltration ought to be identified as recharge rate and estimation of the genuine revenue of water in agricultural use. Hence, in order to sustain long-term groundwater use, make intelligent groundwater allocation decisions and water budget planning, develop on-farm water management strategies, the estimation of the net groundwater recharge from agricultural areas like Kanzenze swamp is paramount important. The studies about groundwater recharge in a catchment or on a regional scale are crucial for determining the quantitative status of groundwater resources. Existing studies including technical reports in Rwanda about groundwater in the Upper Akagera Catchment focused only on the groundwater quality [7] but not on the quantity. The spatially distributed water budgets, including the recharge, have not been broadly ascertained and properly understood. Over water utilization from the river can cause the water balance to be fluctuated and the ground water level may diminish when there is no rainfall [8]. In addition, lack of appropriate techniques useful to estimate groundwater recharge draw backed the water budgeting for irrigation and domestic use and predicting water table level fluctuation. The widely techniques used included water table fluctuation methods [9-11] Darcy's law, tracer techniques, mathematical models as well as the combination of several methods [12, 13]. Now days, mathematical model and tracer technique are some of the usual methods for estimating groundwater recharge. Currently, there is no specific study that has been undertaken to assess the net ground recharge based on precipitation of the Kanzenze swamp by adopting a specific quantifying methods. The present study was designed to assess the recharge contribution and the rate of net ground water recharge from precipitation using Chaturvedi formula in Kanzenze swamp of Akagera Upper catchment of Rwanda in 2019.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

This subject was undertaken on behalf of Prediction and simulation to estimate ground water recharge in Kanzenze swamp for proper water budget and planning to achieve sustainable irrigation in Rwanda. Kanzenze Swamp is located in Bugesera District, Ntarama sector where it is drained to Akanyaru River at Rurambi marshland geographically located at coordinates of -2.0613 and 30.0877 respectively. According to District Agricultural Report, 2003 Kanzenze marshland comprised with four main areas including Muzi, Karugenge, Nyamabuye and Karumuna sites. The total area of the swamp is about 501 ha in which 300 ha are arable areas. Map of Kanzenze swamp is shown in Figure 1 with four sites using Arc GIS 10.5 respectively.

Rainfall is the most important source of ground water recharge in the country. The most commonly used methods for estimation of ground water recharge in Rwanda include empirical methods and ground water level fluctuation method. This study is pertained to one tube well installed around Kanzenze swamp of Akagera upper catchment and one of the relationships to be applied to quantify the net recharge of the tube well is given by Chaturvedi Formula [14]. Based on the water level fluctuations and rainfall amounts, derived an empirical relationship to arrive at the recharge as a function of annual precipitation. Thus the estimated net ground water recharge of the swamp is now given by:

$$R = 2.0(P - 15)^{0.4} \quad (1)$$

This formula was later modified by further work at the U.P. Irrigation Research Institute, Roorkee and the modified form of the formula is written as follow:

$$R = 1.35(P - 14)^{0.5} \quad (2)$$

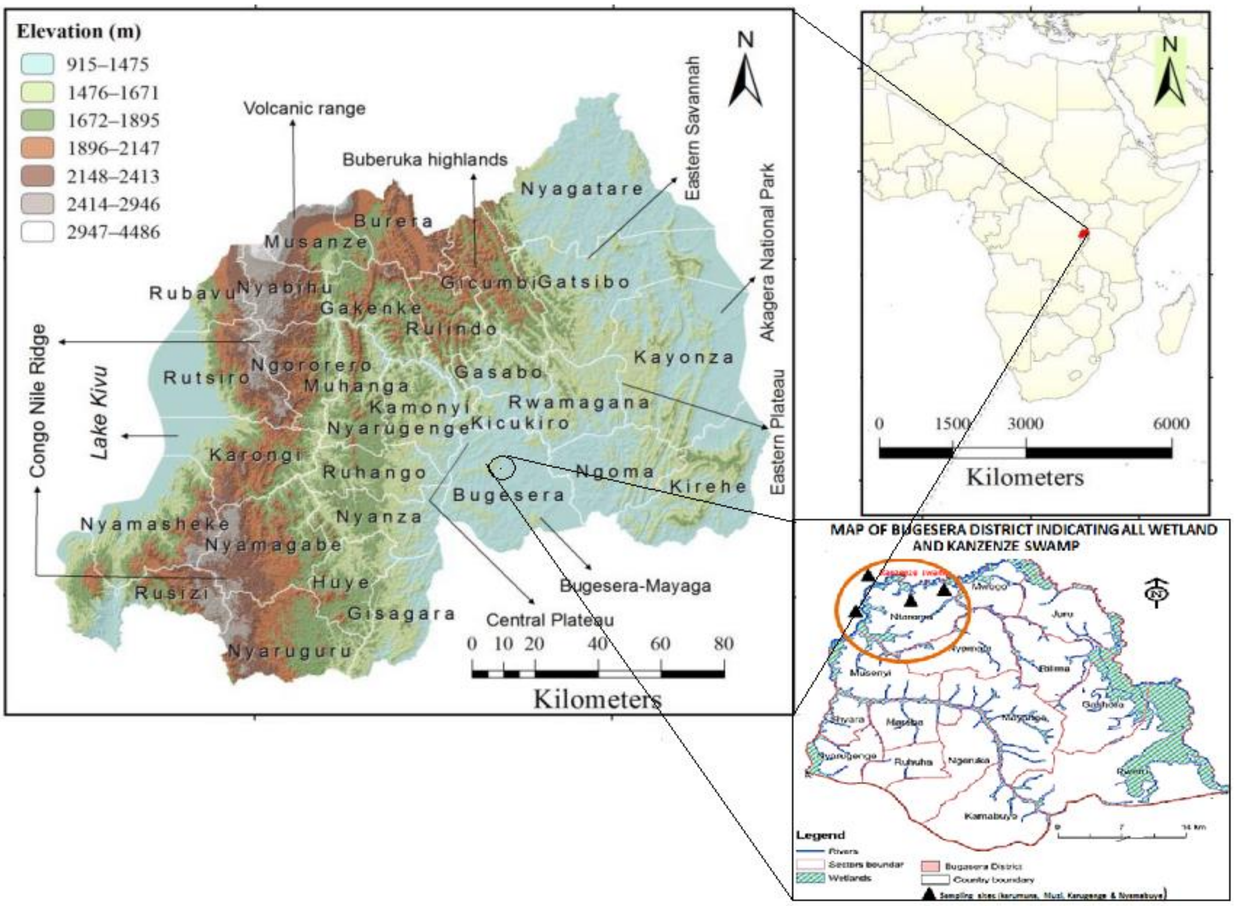

Figure-1. Kanzenze swamp showing study area sites.

Source: NISR-CGIS-NUR, 2008.
CGIS: Collected Geographic Information System.
NUR: National University of Rwanda.
NISR: National Institute of Statistics of Rwanda.

Referring to Equation 1 and Equation 2, the R is the net recharge due to precipitation during the year (mm) and P is the annual precipitation. The Chaturvedi formula has been widely used for preliminary estimations of ground water recharge due to rainfall. It may be noted that there is a lower limit of the rainfall below which the recharge due to rainfall is zero. The percentage of rainfall recharged commences from zero at P = 14 inches, increases up to 18% at P = 28 inches, and again decreases [15]. After, the researcher identified the recharge coefficient of the swamp by taking the ratio of ground water recharge to precipitation, it is expressed in percentage

$$Recharge\ coefficient = \frac{GWR}{P} \times 100$$

Where GWR is the ground water recharge (mm) and P is the precipitation (mm).

3. RESULTS AND DISCUSSIONS

The analysis was based on the estimation of Kanzenze river ground recharge fluctuation due to precipitation within the period of 30 years since 1990 to 2019.

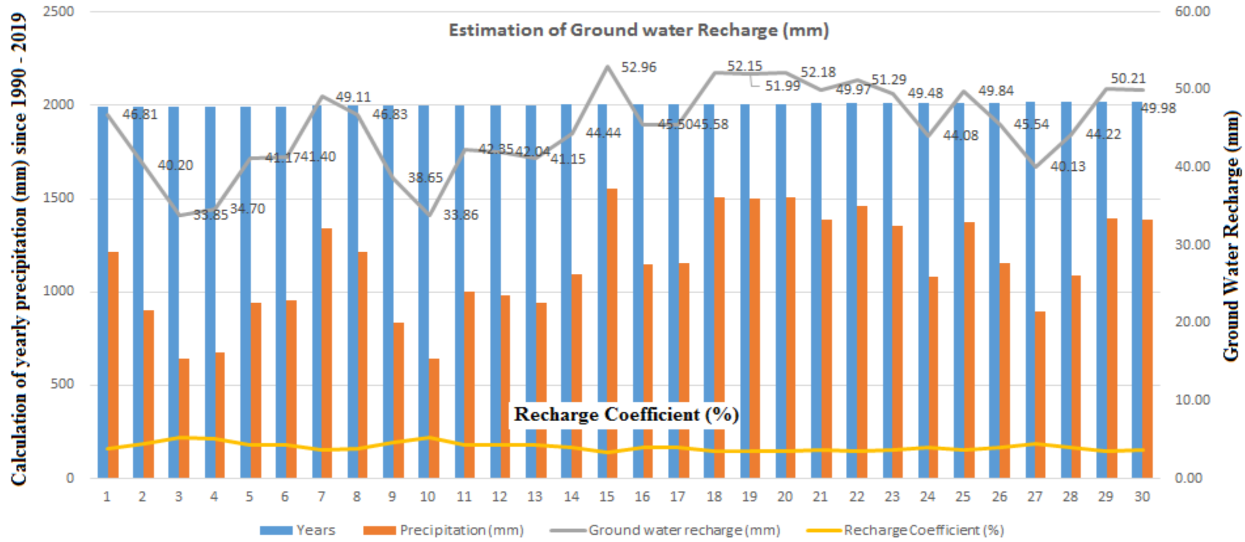

Figure-2. Estimation of ground water recharge in Kanzenze swamp.

Based on summary of descriptive statistics provided in Table 1. It shows that the yearly precipitation is ranging between 642.56mm to 1552.77mm (observed in the period of 1992 and 2004) while the average mean precipitation is about 1144.28mm/ year and the associated standard deviation of 268.63m. The ground water recharge in this area of Kanzenze swamp is ranging between 33.85mm to 52.96mm while the average mean of ground water recharge is about 45.06mm per year; the corresponding standard deviation is 5.57m which is small value compared to total precipitation during the same year of precipitation. The coefficient of ground water recharge is ranging from 3.41% to 5.27% with the corresponding average mean coefficient of 4.06% which are recharged to ground water level per year corresponding to 45.05mm/ year from the precipitation since 1990 to 2019. It revealed that the net recharge coefficient is ranging between 0% and 10% as maximum since 1990 to 2019 Figure 2. This is an indication that there water table fluctuation due to lower level of water table which affected the root zone development due to high fluctuation of rainfall to recharge ground water in the study area. There is a need to set a model for precipitation and ground water recharge to predict and simulate the quantity of water recharged in the Kanzenze swamp system to avoid depletion of crop rooting zone through mathematical modelling.

Table-1. Monthly ground water against recharge coefficient.

Months	Average Rainfall per month in each year	Monthly ground water recharge	% GWR (Recharge/ Rainfall)
January	109.44	13.19	17.09
February	83.73	11.27	16.71
March	123.14	14.1	17.22
April	122.64	14.07	17.22
May	114.89	13.56	17.14
June	63.13	9.46	16.17
July	53.01	8.43	15.73
August	81.06	11.05	16.65
September	76.97	10.71	16.56
October	102.13	12.67	17
November	121.54	14	17.21
December	97.08	12.31	16.93

3.1. Estimation of Monthly Ground Water Recharge

Small holder farmers are likely to plan agricultural activities based on monthly and quarterly basis. Water budget and planning was also linked to monthly rainfall derived from yearly precipitation from the period of 1990 to 2019 (30 years). Mathematical computation techniques and high analytical skills in excel application were useful to convert rainfall for 30 years into monthly rainfall in order to deduct the monthly ground water recharge and corresponding recharge coefficient Table 2 and Figure 3.

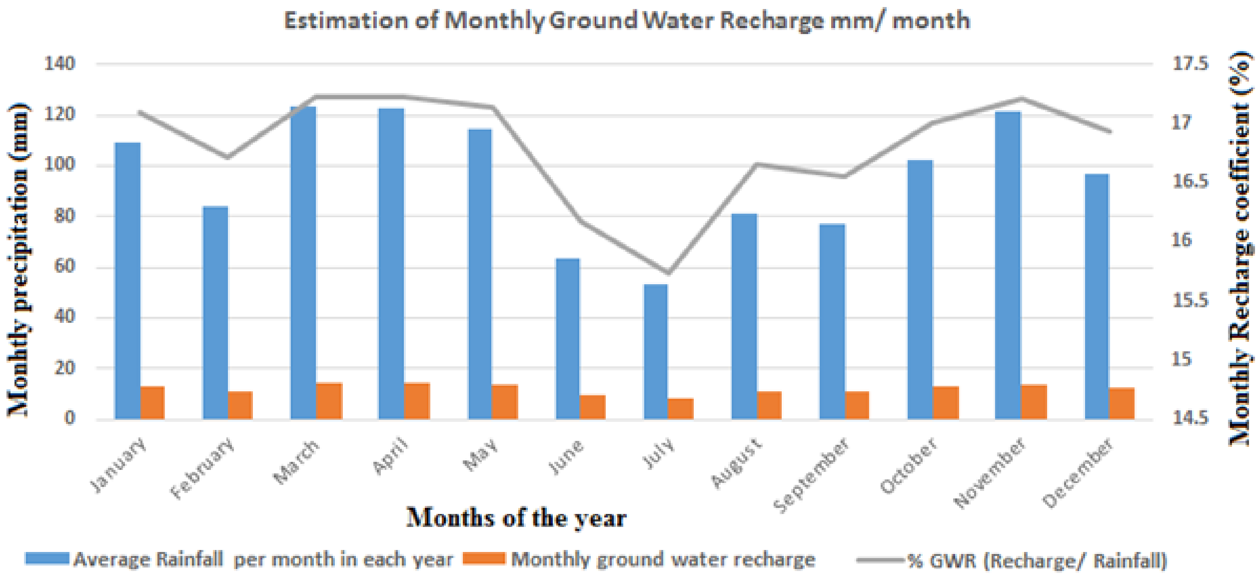

Figure-3. Estimation of monthly rainfall and monthly ground water recharge in Kanzenze swamp.

The monthly groundwater recharge rate was calculated by based on raw data from Rwanda Metrological Agency (RMA) for 30 years. The Modified Chaturvedi formula (MCF) was adopted as mathematical approach to get the recharge rate in mm. The highest monthly average mean groundwater recharge in the Kanzenze swamp of Akagera upper catchment was recorded in months of March, April and November with estimated value of 14.1mm, 14.07 and 14mm, representing 17.22% and 17% of the mean monthly rainfall recorded in 30 years (1990 to 2019); while the lowest monthly average mean groundwater recharge were recorded during the period of June, July and February with estimated monthly ground water recharge of 9.46mm, 8.43mm and 11.27mm. The associated recharge coefficient were 16.17%, 15.73% and 16.71% of the average monthly rainfall recharge to ground water (Quarterly). Hence, farmers around the Kanzenze swamp should plan in such way that in June and July there is water table decrease due to shortage of rainfall and unnecessary water use consumption should be minimized.

3.2. Predicted and Simulated of Groundwater Recharge Fluctuation of Kanzenze Swamp

Information below prediction and simulation of yearly mean ground water recharge compared to tea precipitation variation over the period of 30-years in Kanzenze swamp as controlled by Kanzenze hydrological station from 1990 to 2019 respectively. For data prediction and simulation, X- axis represents early mean precipitation recorded in each year while Y- axis represents ground water recharge in mm. The results from table curve computer software package was used to generate the predicted ground water recharge and the corresponding mathematical model and its coefficient of determination (R^2) for test of goodness. Raw data from Rwanda Metrological Agency (RMA) for 30 years were entered in table curve where X- axis represents yearly mean precipitation recorded in each year while Y- axis represents ground water recharge in mm.

The role of prediction is to forecast the net groundwater recharge through the use of Chaturvedi approach as developed in chapter three within the alongside of the Kanzenze swamp to estimate the variation of water compared to yearly average mean precipitation and groundwater recharge that may be accrued and to take mitigation measures. To predict the fluctuation of groundwater recharge consists of replacing the values of associated x (explanatory variables) and angular coefficient of each term used in the model and thereafter, the simulation has to be taken regarding the percentage residual (difference between observed minus predicted values).

Table-2. Predicted and simulated of groundwater recharge fluctuation of Kanzenze swamp.

SNo	Rainfall (mm)	GWR(Observed)	GWR (Predicted)	Difference (O-P)
1	642.56	33.846	33.84484	0.001
2	643.23	33.864	33.86306	0.001
3	674.67	34.700	34.70385	-0.004
4	833.78	38.653	38.6488	0.004
5	897.44	40.126	40.11931	0.006
6	900.7	40.200	40.19005	0.010
7	943.06	41.149	41.14208	0.007
8	943.96	41.169	41.16201	0.007
9	954.41	41.399	41.39276	0.006
10	983.84	42.042	42.036	0.006
11	998.21	42.352	42.34662	0.006
12	1080	44.077	44.07361	0.003
13	1086.84	44.218	44.21501	0.003
14	1097.49	44.437	44.43427	0.003
15	1150.01	45.501	45.50004	0.001
16	1151.98	45.541	45.53953	0.001
17	1153.72	45.576	45.57438	0.001
18	1216.39	46.812	46.81202	0.000
19	1217.1	46.826	46.82585	0.000
20	1337.56	49.114	49.11507	-0.001
21	1357.14	49.476	49.47697	-0.001
22	1377.11	49.842	49.84332	-0.001
23	1384.04	49.969	49.96982	-0.001
24	1384.52	49.978	49.97856	-0.001
25	1397.03	50.205	50.20605	-0.001
26	1457.51	51.291	51.29142	0.000
27	1497.27	51.993	51.99251	0.000
28	1506.03	52.146	52.14571	0.000
29	1507.93	52.179	52.17887	0.001
30	1552.77	52.957	52.95563	0.001
Mean	1144.277	45.05459	45.0526	0.001989
SD	268.6282	5.572093	5.573382	0.003164
Min	642.56	33.84598	33.84484	-0.00413
Max	1552.77	52.95666	52.95563	0.009585

The computation of variance, standard deviation and coefficient of variation were considered. Based on findings from Table 2, the observed and predicted groundwater recharge fluctuation ranged between 45.05459mm/ year to 45.0526mm/year which indicates that there is high variation of net groundwater recharged to the Kanzenze swamp compared to annual average mean rainfall to increase the water table level. The factors like soil textures, types and catchment characteristics may affect the net ground water recharge to available aquifers.

The Coefficient of determination (R^2= 0.9999 or 99.99%) and this implies that mathematical model is well fit and there is no need to look for another model. This is an implication that there is a small variation of groundwater recharge over the period of 30 years (1990-2019). These results agree with the research findings done in Ogun and Oshun River Basins, Nigeria basing on Modified Chaturvedi formula (MCF) who showed that about 16% to 18% of the areal rainfall of the study area became groundwater recharge fell within the interval (2 – 20%) of a study carried out by Oke, et al. [16] on the groundwater recharge estimation using hydrograph. According to our findings, a significant relationship (R^2 = 0.9999) was observed between simulated and observed ground water due to precipitation Figure 4. These results indicate accuracy of model for studied swamp.

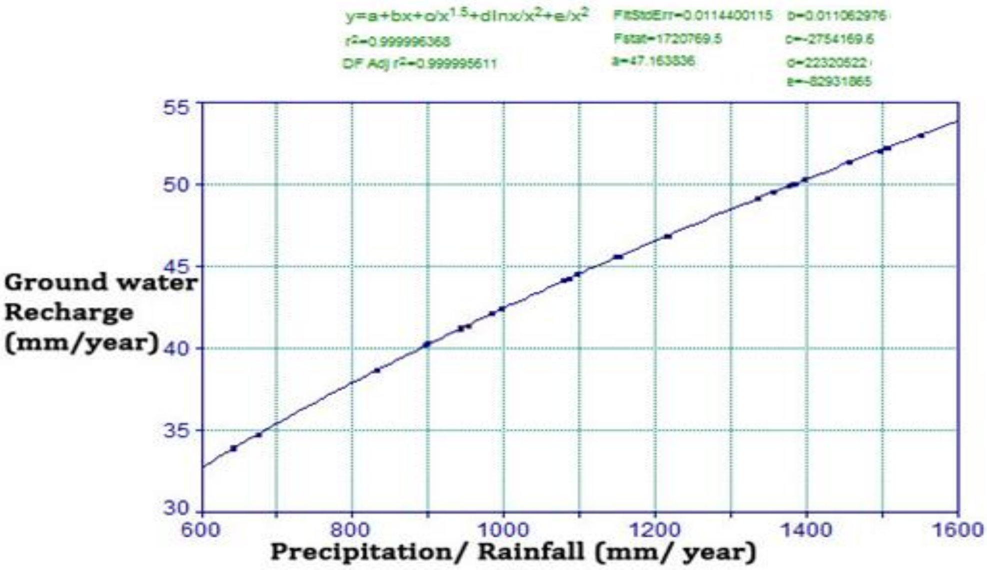

Figure-4. Relationship between precipitation and ground water recharge (R^2).

4. CONCLSION AND RECOMMENDATIONS

The application Modified Chaturvedi Formula (MCF) for estimating groundwater recharge was used and it requires data of specific period and the changes in the water table over time should be taken into consideration because it is the best field observation techniques which indicates shallow water tables that display sharp rises and declines. The study findings therefore concludes that yearly precipitation ranged from 642.56mm to 1552.77mm (observed in the period of 1992 and 2004) while the average mean precipitation is about 1144.28mm. Ground Water Recharge estimation for the study area ranges from 33.85mm to 52.96mm while the average mean of ground water recharge is about 45.06mm per year. The coefficient of ground water recharge is ranging from 3.41% to 5.27% with the corresponding average mean coefficient of 4.06% which are recharged to ground water level per year corresponding to 45.05mm/ year from the precipitation since 1990 to 2019. However, monthly basis planning have advantages for farmers water budgeting. The study findings shows that highest monthly average mean groundwater recharge in the Kanzenze swamp is recorded in months of March, April and November (Quarterly) with estimated value of 14.1mm, 14.07 and 14mm, representing 17.22% and 17% of the mean monthly rainfall while the lowest monthly average mean groundwater recharge is recorded during the period of June, July and February with estimated monthly ground water recharge of 9.46mm, 8.43mm and 11.27mm. The associated recharge coefficient was 16.17%, 15.73% and 16.71% of the average monthly rainfall recharge to ground water (Quarterly). Thus, it is recommended that utmost farmers around the Kanzenze swamp should plan in such way that in June and July there is water table decrease due to shortage of rainfall and unnecessary water use consumption should be minimized. It meant that priori irrigation systems should be applied to obtain optimum moisture content and water table levels for effective crop production mainly horticultural crops in season C rather than season A and season B of cultivation in Rwanda.

ABBREVIATIONS

GWR: Ground Water Recharge.

MCF: Modified Chaturvedi Formula.

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