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INTEGRATED ANALYSIS OF WATER BALANCE IMPACT ON AGRICULTURAL PRODUCTION OF KIBAYA-CYUNUZI MARSHLAND IN RWANDA

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ABSTRACT

Rwanda, the country in quick progress of sustainable development and economy mostly based on agriculture, has to intensify the production system where hydrological and meteorological data for water resources management have to play their decisive role. This paper analyses the water balance impact to boost the agricultural production of Kibaya-Cyunuzi marshland. Specifically, this research aims to assess the movement, the storage and the disposition of water in Kibaya-Cyunuzi marshland, through the analysis of hydrological components, typical assessment of crop production and their impact relationship. To achieve this goal, integrated analysis was used. Kibaya-Cyunuzi marshland data was obtained from MINAGRI Reports 2010, RADA and RAB program developed, Cooperative of rice production (COPRIKI CYUNUZI) and KAZO meteo-station in Ngoma district where a satellite image was analyzed and statistical and hydrological analyses of the existing and acquired data was done by using the methods such as Thiessen polygons method, water balance equation, pan measurements and some programs such as MS Excel, Arc Map. After all analysis, the water portioning, quantitative, the annual average for hydrological components and water balance of Kibaya Cyunuzi marshland were displayed. The result showed that the change in storage is -2.85mm

(-19,389.43m^3) per year and 93.98mm (639,978.14.m^3) in long rainy season, the negative 182.90mm (-1,245,560.85m^3) in long dry season, 3.14mm(21,384.04m3) in short rainy season and 82.96mm(564,937.14m3) in short dry season. The deep and integrated analysis showed that water balance changes seasonally where the storage is below than zero in long dry season, higher in short dry(82.96mm) than in short rainy season(3.14mm). This water balance variation and the higher crop water requirement ranging from **34.77 to 463.65mmm** have impacts on agricultural activities and require strong irrigation policies. The production rate is at 75% (rice) in rain-dry season, 10 %(maize), 8% (vegetables), 5 %(beans) and 2 %(soy). The knowledge of hydrology of the marshland play an important key role in agriculture(crop allocation and production management) and in master planning for Ngoma and Kirehe districts during flooding prevention, irrigation projects, decision and policy making for water resources management and other related marshland developing projects.

KEYWORDS: Integrated approaches, inflows, outflows, water balance, Kibaya marshland, Rwanda.

1. INTRODUCTION

The hydrological approach is a physical, sequential, dynamic system which operates within a set of physical laws that control the movement, storage and disposition of water within the system and which derives its energy from the spatial imbalances between incoming and outgoing radiations.

Availability of water is fundamental to man's existence and therefore towns, cities and villages are generally located around water bodies such as rivers and lakes. On the other hand, water can become a threat to the health and welfare of settlements as result of pollution, infestation, floods etc. Because water is such an indispensable, its effective development and management have become an important goal of society.

The availability of water is estimated by the knowledge of water balance and hydrological components. That is why this research project is coming to give approaches which can be used jointly with water balance to develop and boost the agricultural sector of KIBAYA marshland; by identifying the portions of its inflows, outflows and storage. That could contribute to the sustainable development of different activities carried out in the marshland itself.

However, Rwandan marshlands are faced with many problems such as erosion, flooding, poor maintenance of existing irrigation systems, uncompleted irrigation projects, lack of competent irrigation support services and lack of detailed knowledge about water management(inflows, outflows and storages based) in fragile valley agro-ecosystems, knowledge on which improved management can be based. The rapid population growth is increasing the water demand for domestic, agricultural, and industrial uses and leads to water scarcity in Eastern province and Rwanda in general.

2. DESCRIPTION OF STUDY AREA

Kibaya-Cyunuzi is a meso scale marshland of approximately 681hectares (6.81km^2) and coordinates ranging from 2^{0}12' to 2^{0}51' Latitude south and 30.7580^0 Longitude East, in the altitude less than 1500m and benefited by more than 2,856 neighboring inhabitants (WMO, 2018).

The Kibaya-Cyunuzi marshland, located in Eastern province (9,813.3617Km^2) of Rwanda (26,338Km^2), is located between two (2) districts in eastern of Ngoma and west of Kirehe district.(Minagri, Annual report on agricultural development in Rwanda, 2010).

The delineation of this marshland has been done by using GIS-software, Digital Elevation Model (DEM) and the Topographic Map for determination of marshland area and identifying its characteristics are shown on the map of Kibaya-Cyunuzi marshland boundaries below.

3. METHODOLOGY

The data used in the study were provided by the Ministry of Agriculture and Livestock (MINAGRI), the Rwanda Agriculture Board (RAB) and Rwanda meteorological office/Kazo station. The topographic map, DEM map, land use and land cover; crop production factors were obtained ESRI-Rwanda, FAO Standard, and University of Kibungo (UNIK) production center and others were manually recorded.

3.1. Hydrological Analysis & Water balance of Kibaya-Cyunuzi Marshland

The detailed analysis of crop water requirement used CROPWAT model; water balance, average annual precipitation, average monthly precipitation in the marshland was conducted through the delineation of KIBAYA-Cyunuzi marshland from the whole catchment and determine its total surface area using Arc Map. Establish water portioning among the hydrological cycle components: Each component of hydrological cycle was calculated with its appropriate formulas and show its monthly quantity. The water balance equation was drawn to evaluate the availability of water and propose the system of irrigation in the marshland.

INFLOWS - OUTFLOWS = STORAGES

***P - (ET + Q) = ΔS*……………………………………………………………….** *(1)*

- **Inflow**: constituted by precipitation (P), import defined as water channeled into a given area and groundwater inflow from adjoining areas.
- **Outflow:** constituted by surface runoff flow *(Q)*, export defined as water channeled out of the same area, evaporation and transpiration *(ET).*
- **Change in Storage:** occurred as change in groundwater, soil moisture, surface reservoir water and depression storage and detention Storage.

3.1.1. Analysis of rainfall and Catchment information

The inflows/ rainfall in $m^3$was determined by multiplying the gauge recorded rainfall in mm by the all sub-catchment area for a period of one (1) year (January –December 2018).

Table 3.1: Rainfall in Kibaya-Cyunuzi marshland at 681ha (January-December, 2018).

Month	Gauge Rainfall (mm)	Rainfall (m^3)=P(mm)*Area
January	134.8	917,988
February	130.4	888,024
March	123.2	838,992
April	145.5	990,855
May	132.0	898,920
June	15.8	107,598
July	0.85	5,789
August	0.25	1,703
September	37.60	256,056
October	137.94	939,371
November	152.0	1,035,120
December	148.80	1,013,328
Monthly average	**96.595**	**657,812**
Annual average	**1159.14**	**7,893,743**

From the above table 3.1 showing how the rainfall varied monthly in Kibaya-Cyunuzi marshland, the maximum rainfall of 152.0 mm (1,035,120 m^3) was found in November and the minimum of 0.25mm in August(1,703m^3). The monthly average rainfall was found to be 96.595mm (657,812 m^3) and the total annual average rainfall was 1,159.14mm (7,893,743m^3).

The outflows/evapo-transpiration and runoff discharges in Kibaya-Cyunuzi marshland are influenced by water evaporation and crop (rice, soy, beans, etc) transpiration. Water from the open channels are used for irrigation of crops like rice, soy, beans,…etc.

The soil water stress coefficient (K_S) equal to 0.83 (Anyemedu, 2007)and the actual adjusted crop factor was calculated from the typical crops shown in the Table 3.2.

Table 3.2 Actual adjusted crop factors for agricultural value chain.

Crop nature	Area occupied (%)	Fcrop(Kc)	Actual Kadj=Ks*fcrop*area (%)
Rice paddy	67.4	1.2	0.68
Eucalyptus	0.2	0.7	0.001
Soy beans	12.5	0.9	0.094
Maize& coffee	2.35	0.8	0.002
Banana	1.02	1.1	0.009
Sorghum	0.6	0.2	0.0009
Tomatoes	4.74	0.8	0.032
Cassava	0.8	0.6	0.004
Sugarcane	0.1	1.1	0.0009
Sweet Potatoes	7.27	1.2	0.073
Open water	3.02	1.3	0.033
K_{adj}=(∑Ks*Kc)/n			**0.93**

The actual adjusted crop factor found for different agricultural value chain in Kibaya marshland was found to be **0.93**.

This shows the great influence of crops in catchment water consumption and helped in determination of outflow (actual evapo-transpiration volume).

3.1.2. Analysis of Evapo-transpiration and Catchment information

The reference evapo-transpiration and actual evapo-transpiration were respectively calculated by multiplying evaporation with pan coefficient (Kc) of 0.66 (FAO, 2010) and the reference evapo-transpiration by the actual adjusted crop factor.

The evapo-transpiration volume (m3) was calculated by multiplying its value in mm by the area of the sub-catchment and results are presented in Table 3.3.

$E_{ref}=Kc*E_p$ ………………………………………………….. (2)

Eact (mm)=Kadj*E_{ref} ………………………………………… (3)

Eact(m_3) = Eact(mm)*Area……………………………….…..(4)

With Er=Reference Evaporation

Ep=Class A Pan Evaporation (monthly recorded)

Kc=pan coefficient

Kadj= 0.93 referred to table above.

Table 3.3: Actual evapo-transpiration (outflows) of Kibaya-Cyunuzi marshland (January-December, 2018).

Month	Pan Evaporation E_p (mm)	Reference Evapotranspiration E_{ref}(mm)	Actual Evapotranspiration E_{act}(mm)	Actual Evapotranspiration E_{act} (m^3)
January	78.4	51.744	48.1	327,710.3
February	69.6	45.936	42.7	290,926.5
March	58.01	38.2866	35.6	242,480.5
April	37.45	24.717	23.0	156,540.2
May	90.9	59.994	55.8	379,960.0
June	94.2	62.172	57.8	393,753.9
July	100.8	66.528	61.9	421,341.8
August	117.3	77.418	72.0	490,311.4
September	97.06	64.0596	59.6	405,708.7
October	86.01	56.7666	52.8	359,519.9
November	89.3	58.938	54.8	373,272.0
December	67.58	44.6028	41.5	282,482.9
Monthly average	**82.30**	**54.26355**	**50.5**	**343,667.3**
Annual average	**986.61**	**651.1626**	**605.6**	**4,124,008.1**

The maximum actual evapo-transpiration(Eact) was found to be 72.0mm(490,311.3m^3), occurred in August and the minimum actual evapo-transpiration was found to a value of 23.0 mm occurred in April. The monthly average actual evapo-transpiration was rounded to 50.5mm(343, 667.3m3) and annual average actual evapo-transpiration in the marshland was found to be 605.6mm(4,124,008.1m3). The analysis of the evapo-transpiration is effectively on climate, exposure and crop rate basis from data recorde by the class A evaporation pan.

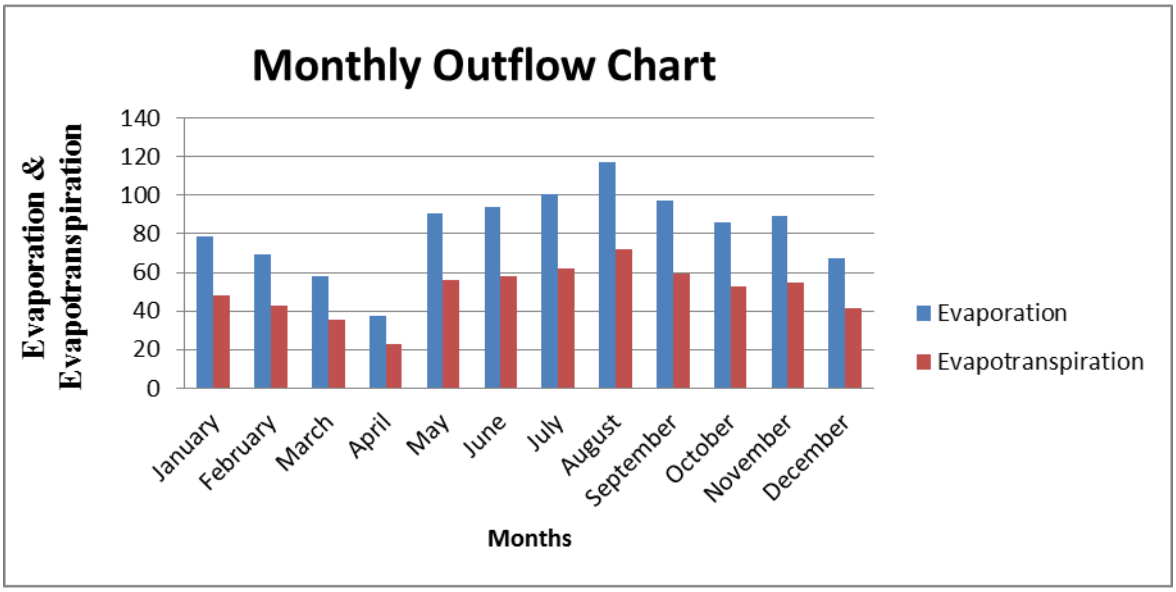


Figure 3.1: The monthly variation of Evapo-transpiration in Kibaya-Cyunuzi marshland.

The components of outflow of the marshland are mainly composed by the evaporation and crop transpiration that overall becomes evapo-transpiration and runoff that flow out the ground surface of the marshland (water bodies like: lakes, rivers,…).

3.1.3. Analysis and estimation of runoff (Q)

Runoff is the total quantity of water draining into a stream, reservoir, river or ocean after losses by evaporation, infiltration and interception expressed as:

- Cm of water over the area (overland or surface flow)
- Total volume (m^3)=depth*area
- Stream discharge

Actually, the runoff from rainfall is estimated by:

Flow measurement techniques including a float and stop clock, use of current meters (propeller flow velocity measurements), use of tracers and hydraulics structures (weirs & Flumes) in the discharge equation of

Q = A*V ……………………………………..*(5)*

nalysis of rainfall and catchment information by use of runoff coefficient, Infiltration methods, rational method, overland flow hydrograph and unit hydrograph method.(Dosi, 2001).

In this research, the runoff was estimated by use of runoff coefficient (K) as it was calculated on small projects. The discharge runoff (Q in mm) was calculated in table 4.4 by the formula:

Q=K*P………………………………………………………………...... *(6)*

With Q: runoff discharge, P: rainfall/precipitation and K: runoff coefficient in the range of: **0.1(**sandy soil**) ≤K≤0.85** (paved land). (J.W, 2007).

Table 3.4: Runoff/discharge determined in Kibaya-Cyunuzi Marshland (K=0.48).

Month	Rainfall P (mm)	Runoff Q (mm)	Runoff Q (m^3)
January	134.8	64.70	440,634.24
February	130.4	62.59	426,251.52
March	123.2	59.14	402,716.16
April	145.5	69.84	475,610.40
May	132	63.36	431,481.60
June	15.8	7.58	51,647.04
July	0.85	0.41	2,778.48
August	0.25	0.12	817.20
September	37.6	18.05	122,906.88
October	137.94	66.22	450,898.27
November	152	72.96	496,857.60
December	148.8	71.42	486,397.44
Monthly average	**96.59**	**46.36**	315,749.74
Annual average	**1159.14**	**556.39**	3,788,996.83

The detailed analysis of runoff from rainfall of Kibaya-Cyunuzi marshland shows that the maximum runoff is 72.96mm (496,857.60 m^3) in November and minimum was 0.12mm (817.20 m^3) in August. The runoff contributes more in irrigation and mechanization of the marshland.

3.2. Analysis of Water balance of Kibaya-Cyunuzi Marshland

Generally and world widely, the main components considered in the analysis of water balance of the marshland are precipitation (rainfall), runoff, evapo-transpiration, and change in storage. The change in storage Δs represents the quantity of water stored/infiltrated in the marshland and constitutes source of springs through seepage.

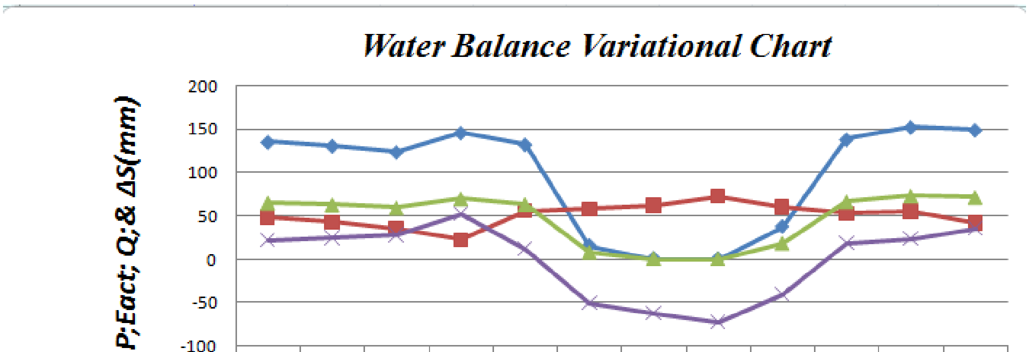
From the water balance equation (Eq.1), the table 3.5 summarizes the hydrology components of the marshland as well as the water balance insight and gives the idea on agricultural activities to be implemented on the seasonal basis.

Table 3.5. Water balance components in Kibaya-Cyunuzi marshland (Jan-December, 2018).

Month	Rainfall P (mm)	Evapotranspiration ETact(mm)	Runoff Q(mm)	Change in Storage ΔS (mm)	Change in storage ΔS (m^3)
January	134.8	48.1	64.70	21.97	149,643.48
February	130.4	42.7	62.59	25.09	170,846.01
March	123.2	35.6	59.14	28.46	193,795.32
April	145.5	23.0	69.84	52.67	358,704.42
May	132	55.8	63.36	12.85	87,478.40
June	15.8	57.8	7.58	(49.60)	(337,802.97)
July	0.85	61.9	0.41	(61.43)	(418,331.76)
August	0.25	72.0	0.12	(71.87)	(489,426.12)
September	37.6	59.6	18.05	(40.02)	(272,559.54)
October	137.94	52.8	66.21	18.94	128,953.22
November	152	54.8	72.96	24.23	164,990.36
December	148.8	41.5	71.42	35.90	244,447.65
Monthly average	**96.595**	**50.5**	**46.37**	**(0.27)**	**(1,842.79)**
Annual average	**1159.14**	**605.6**	**556.39**	**(2.85)**	**(19,389.43)**

The results from table 3.5 present annual rainfall of **1,159.14mm**, the annual evapo-transpiration of **605.6mm**, the annual runoff at outlet of **556.39mm**. Then, the water balance of Kibaya-Cyunuzi Marshland, which is given by the equation:

ΔS =P-Q-ET gave the annual average change in storage of **-2.85mm (-19,389.43m^3)**. The negative (values in parentheses) change in storage allowed to infer other variables influencing water balance in Kibaya-Cyunuzi marshland. Thus, this marshland received water from outside of the sub-catchment divisions. The sub-catchment might have groundwater recharge areas that extrapolated the topographic divisions and require additional water from irrigation to satisfy the crop water requirements.



	Janua	Febru	March	April	May	June	July	Aug	Sept	Octo	Nov	Dec
Rainfall	134.8	130.4	123.2	145.5	132	15.8	0.85	0.25	37.6	137.94	152	148.8
Evapotranspiration	48.1	42.7	35.6	23	55.8	57.8	61.9	72	59.6	52.8	54.8	41.5
Runoff	64.7	62.59	59.14	69.84	63.36	7.58	0.41	0.12	18.05	66.21	72.96	71.42
Change in Storage	21.97	25.09	28.46	52.67	12.85	-49.6	-61.43	-71.87	-40.02	18.94	24.23	35.9

Figure 3.2: The variation of the inflows and outflows of Kibaya-Cyunuzi marshland.

The agricultural activities (rice growing) are the main water consumers in this marshland. These activities are in four alternative seasons. The table 3.6 shows how water balance components were seasonally varying in Kibaya-Cyunuzi marshland. Where we have the change in storage of the annual water balance(change in storage) of -2.83mm (-19,261.53m^3) and 93.98mm in long rainy season, the negative -182.90mm in long dry season, 3.14mm in short rainy season and 82.96 mm in short dry season.

Table 3.6. Seasonal variation of water balance in Kibaya-Cyunuzi marshland.

Seasons of Year	Rainfall P (mm)	Evapotranspiration ETact(mm)	Runoff Q(mm)	Change in Storage ΔS (mm)	Change in storage ΔS (m^3)
Long rainy season (March to May)	400.7	114.4	192.34	93.98	639,978.14
Long dry Season (June to August)	16.9	191.7	8.11	(182.90)	(1,245,560.85)
Short rainy Season (September-November)	327.54	167.2	157.22	3.14	21,384.04
Short dry Season (December to February)	414	132.3	198.72	82.96	564,937.14
Annual Water Balance				(2.85)	(19,261.53)

3.3. The marshland Agricultural crop production and Crop water requirement analysis

The crop water requirement influence the productivity of the Swamp and is influenced by the leaf Area index (LAI) as one of the most important factor in determining the interception capacity and a measure of the storage area in a canopy available to intercept the precipitation. The range of values of LAI for marshland vegetation is listed in table below:

Table 3.7: Typical values of the LAI for common land cover types.

Land cover	LAI
Bar soil	0.0-0.1
Sparse grass covers	0.1-1.0
Natural grass	0.5-3.0
Agricultural crops	1.0-4.0
Sparse forest	2.0-4.0
Rain forest	4.0-7.0
Dense plantation forest	6.0-12.0

The analysis of water in crop production started with modeling of FAO's CROPWAT model (8.0 version) which is a computer program used to determine crop water requirement, irrigation water requirement, irrigation scheduling and yield reduction due to water shortage in marshland for climatic and crop data. The production function was:

$$Y=\int (K, L, W, Z) \quad (7)$$

With Y: crop output under irrigation, K: capital; L: labor; W: water used; and Z: other none water inputs.

The agricultural crop presents a maximum of 40% of gross rainfall in the area.

Table 3.8: The crop water requirement (CROPWAT, 8.0 versions, 2018).

Typical crop	Crop water requirement Percent of gross annual rainfall
Grassland:	1%-5%
Agricultural crops:	3%-40%
Deciduous forest:	10%-25%
Coniferous forest:	15%-40%

Some agricultural crops have an interception capacity similar to dense forest canopies, but after they are harvested in the autumn, the crop cover can change significantly, reducing the loss and as result, the crop cover for agricultural area is often lowest during rainy season. This is crucial factor to be accounted when examining the annual water balance of Kibaya-Cyunuzi marshland.(Project, 2008).

Besides the rice paddy grown by around 2,856 small holder farmers in Kibaya-Cyunuzi marshland and members of COOPRIKI-CYUNUZI rice cooperative in CYUNUZI village, Gatore sector, Kirehe District of eastern province of Rwanda, the following crops are grown in the area: **Maize**: Twenty four inbred lines were advanced; **Sorghum**: 17 lines from preliminary trial were selected for advanced trial, **Wheat**: 84 lines have been selected and evaluated in the Swamp, **Beans(**5 Varieties released; 4 varieties have been identified as candidates for release in 2011);**Cassava**: Uniform Yield Trials (UYT) was established with 9 clones; 92 cassava clones); **Sweet potato**(8.95 ha planted to 4 improved varieties in tertiary multiplication sites with partners);**Vegetable (**Five new varieties have been introduced. **Mango**: Six new varieties of mango were introduced. **Banana**: 110 banana accessions are maintained in field. ((ISAR, 2011).

As it was seen, water needed to satisfy the agricultural crops is ranging from **34.77mm** to **463.65mm**, which cannot be available at all months from the precipitation alone in each

season. One obvious reason identified was that Kibaya-Cyunuzi marshland suffered a serious water shortage in seasons due to drought making a big part of it have insufficient water.
The marshland has permanent water source (Kabilizi river), where water abstraction is by gravity. The river doesn't satisfy the needs in water for major identified paddy crop (rice) which made farmers to apply irrigation system. The average value of irrigation water calculated to 5.23 Rwf/m^3 of water.(Urujeni, 2016).

The rice farmers/growers of COOPRIKI-CYUNUZI practice two overlapping seasons (A&B) per year for efficiency use of water through main grown crop of paddy rice and vegetables in season C.(Kopparthi, 2016).

Figure: Kabilizi River supporting the water balance Figure: Proposed water conveyance (pipeline).

Of Kibaya-Cyunuzi Swamp for agriculture for irrigating support of agricultural activities.

The agricultural crops production vis a vis the water balance (storage) of the marshland is varying with respect to the seasonal variation of water (water scarce in dry season) and some crops are growing in the area in either dry or wet/rainy season. This research revealed that the average water productivity is 0.08Kg/m^3(Ngabitsinze, 2016).The table below gives the idea of typical crop production in percent in recent years.(Minagri, 2010).

Table: Output, Yield and Area Change for all major crops, **2007-2010**

	Output Development	Yield Development	Area Development
Sorghum	-3.32%	**25.11%**	-17.83%
Maize	322.08%	**210.69%**	30.81%
Wheat	213.38%	**274.60%**	79.41%
Rice	9.00%	**41.29%**	-13.53%
Cereals	107.59%	**76.70%**	-14.56%
Beans	-1.09%	**12.04%**	-43.49%
Peas	93.31%	**77.99%**	-10.74%
Peanuts	45.16%	**35.70%**	94.44%
Soya	43.37%	**2.92%**	301.75%
Pulses	9.11%	**25.23%**	-31.18%
Banana	1.89%	**13.42%**	-30.56%
Potato	84.99%	**63.36%**	-22.48%
S Potato	-0.60%	**33.22%**	-0.90%
Yam & Taro	22.74%	**31.47%**	24.41%
Cassava	205.97%	**121.45%**	-19.76%
R&T	89.45%	**62.86%**	10.29%
Veg	6.40%	**2.73%**	8.99%

4. CONCLUDING REMARKS

The findings of this research show that the dominant crop of the marshland is rice paddy cultivated at 75% and can be cultivated through four (4) successive seasons(short &long dry seasons and short &long rainy seasons).

The integrated analysis of Kibaya-Cyunuzi water balance from all hydrological components gives the current status of water in Kibaya-Cyunuzi marshland. After a one year (January to December 2018) data analysis, the rainfall in all seasons (**400.7mm for long rainy, 16.9mm for Long dry, 327.54mm for short rainy and 414mm for short dry season**) is less than crop water requirement ranging from **34.77 to 463.65mmm** and all seasonal water storage in Kibaya-Cyunuzi contribute to **annual water balance of -2.85mm (-19,389.43m^3)** .The results show that the irrigation policy is a must for all farmers to boost the agricultural development.

The integrated analysis found that water available at **414mm in short dry season**(December to February) is greater than **400.7mm of Long rainy season**, which can be interpreted as a big change of climate condition and change of seasons in the Kibaya-Cyunuzi marshland as well as in Rwanda.

This knowledge could help Agricultural Engineers, farmers and policy makers, to choose the appropriate period and crops for cultivating according to the availability of water and the amount of water required by crops to grow. This paper results can advice famers and policy makers the crops allocation and irrigation policy plan to increase the agricultural productivity.

5. RECOMMENDATIONS

There are many small Marshlands in the Eastern Province, especially the average sizes of the Non-Developed Marshlands in Ngoma and Kirehe are under 20ha.The findings of this research show that water stored in Kibaya-Cyunuzi marshland is not enough and never meet the agricultural crop water requirement that's why it was recommended to contribute to the amelioration of irrigation system to increase the Rwandan primary sector production and sensitize the key implementers, farmers, agricultural engineers and policy makers on Rwanda seasonal periodic changes to respect the agricultural and good governmental marshland protection plan.

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