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A Study on the Water Resources Assessment for Irrigation Scheme in Malawi

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Abstract

Generally, in terms of the development of irrigation scheme, the efficient water resource management that supplies the irrigation water in consideration of the required time and accurate quantity to grow the crop should be conducted. The water resource assessment should precede to supply the irrigation water efficiently. The water resources assessment is divided into the water requirement analysis and the water availability assessment. In case of Korea, the major crop is paddy rice unlike crops of Africa, such as sugarcane, maize, and cassava, etc. Because it is not familiar with the method for upland irrigation development in tropical area, it needs to know the water resources assessment for irrigation scheme development about these crops. The Natama Scheme in Chiradzulu District of the Southern Malawi was selected as study area, which has tropical climate. From the collected meteorological data, the evapotranspiration was analyzed by Penman-Monteith Method and the effective rainfall was analyzed by USDA Soil Conservation Service Method. This study displays the results that for study area, the evapotranspiration varies from 2.80 mm/day to 5.51 mm/day and the effective rainfall varied from 2.1mm to 149.0mm. According to the selected crop (Green Maize, Dry Maize), the unit water requirement (UWR) and water demand (WD) considering the irrigation efficiency, irrigation time and irrigation area were estimated to be 0.00122 m³/s/ha and 0.0122 m³/s respectively. For the water availability assessment, the runoff of Natama scheme was calculated by specific yield method. The water availability was evaluated through reviewed differences of discharge between $Q_{80_{intake}}$ and Total WD, and the irrigation water can be supplied sufficiently in the existing 10ha of Natama scheme. As a result of reviewing the extensibility of irrigable area, total WD of scheme is 0.02313 m³/s, and $Q_{80_{intake}}$ is 0.02387 m³/s ($Q_{80_{intake}} > \text{Total WD}$). Therefore, Natama scheme can be extended from 10 ha to 17 ha in the dry season in consideration of the $Q_{80_{intake}}$.

Keywords: Unit water requirement, Water availability assessment, Upland irrigation in tropical climate

1. Introduction

Like most of other African countries, the country's agriculture depends mostly on rain-fed and therefore vulnerable to the effects of climate change. If the irrigation water is enough, double or triple cropping can be expected in consideration of the climate condition and crop characteristics. But, in the dry season, since it is difficult to supply the sufficient irrigation water, the irrigation area shows clear distinction between dry season and rainy season.

For the development of irrigation scheme, the supply and efficient management of irrigation water is very important element. Therefore, the efficient water resource management that supplies the irrigation water

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considering the required time and accurate quantity to grow the crop should be required. The water resource assessment for irrigation scheme development needs a variety of information, such as crop type, climate condition, soil type and irrigation method, etc. Especially the rainfall and evapotranspiration are key factors in order to analyze the crop water requirement and water demand. The water demand is the quantity consumed in the soil under the crop and means the quantity necessary for the growth of the crop. The water demand is calculated by subtracting the effective rainfall actually used in the scheme from the evapotranspiration due to the growth of the crop.

Because the water demand of crop is occurred by region, crop and climate condition, it is weighty element that estimates the reasonable water demand. Various studies related to the water demand considering the effective rainfall and evapotranspiration have continued. But, usually previous study focused just on the yearly water demand regarding the crop type. The unit water requirement and water demand which are essential for the development of the irrigation scheme considering the irrigation efficiency has not been appropriately evaluated. Moreover, the integrated water availability assessment by the water balance analysis is not considered.

Jyotsna et al. analyzed the water requirement of the sugarcane, maize and wheat in arid regions, Pune District, India using CROPWAT 8.0 program [1]. Abdelhadi et al. evaluated the water demand of acala cotton in irrigation scheme of Sudan using FAO Penman–Monteith in arid regions [2]. But, both study did not evaluate whether the water requirement for the irrigation scheme can be secured. Sunil K. reviewed the irrigation water demand of the rice, maize, wheat, etc. in Bihar State of northern India [3]. The water demand was calculated from the relationship between the effective rainfall and reference evapotranspiration. But, in this case, because the loss of canal and scheme did not considered, the suitable water demand estimation was failed in order to develop or rehabilitate the irrigation scheme. In terms of the water demand of irrigation scheme development, the irrigation efficiency, such as application efficiency and conveyance efficiency, should be applied to the unit water requirement analysis phase. Yoo et al. analyzed the design water requirement of the paddy rice considering the climate change scenario in Korea [4]. The nation was divided into 19 zones and the yearly water requirement of each zone was estimated in accordance with the variation of effective rainfall and evapotranspiration in the paddy area of each zone. Silva et al. predicted the water requirement of paddy irrigation regarding the climate change in Sri Lanka [5]. In these studies, it is evaluated properly to grasp the demand for agricultural water at the national level in comparison with the climate change. But, the detailed calculation method of irrigation water and evaluate the water availability has not been presented.

In case of Korea, the major crop is paddy rice unlike the case of Africa, such as sugarcane, maize, and cassava, etc. Because it is not familiar with the method for upland irrigation development in tropical area, it needs to know the water resources assessment for irrigation scheme development about these crops. Therefore, this study wants to present the method that analyzes the reasonable unit water requirement and decides the irrigable area of scheme in Malawi considering the water availability assessment. This method will be the most applicable method in other African countries extensively as well as in Malawi, and this study presents a guideline and procedure of water resources assessment to develop or rehabilitate the irrigation scheme.

2. Methodology

Generally, for the irrigation scheme development, the water resource assessment consists of the water requirement analysis (unit water requirement, water demand of scheme) and water availability assessment. According to the water resources assessment, the current utilization level, net irrigation area and extensibility of irrigable area are evaluated.

The water requirement is estimated by adding the efficiencies to the water requirement in the field. The unit water requirement (UWR) by crops depends not only on climate, field and farming practice but also on the type of irrigation canal and stages of crop growth. The water availability assessment is the capacity of water supply, how much water can be supplied in accordance with the calculated water demand of scheme. To check the water availability, 80% exceedance probability discharge (Q80) and environmental flow requirement (EFR)

at the intake point have to be considered.

In terms of water resource assessment, this study presented the method and application standard, and the procedure of the water resource assessment such as water requirement analysis and water availability assessment which is presented in Figure 1.

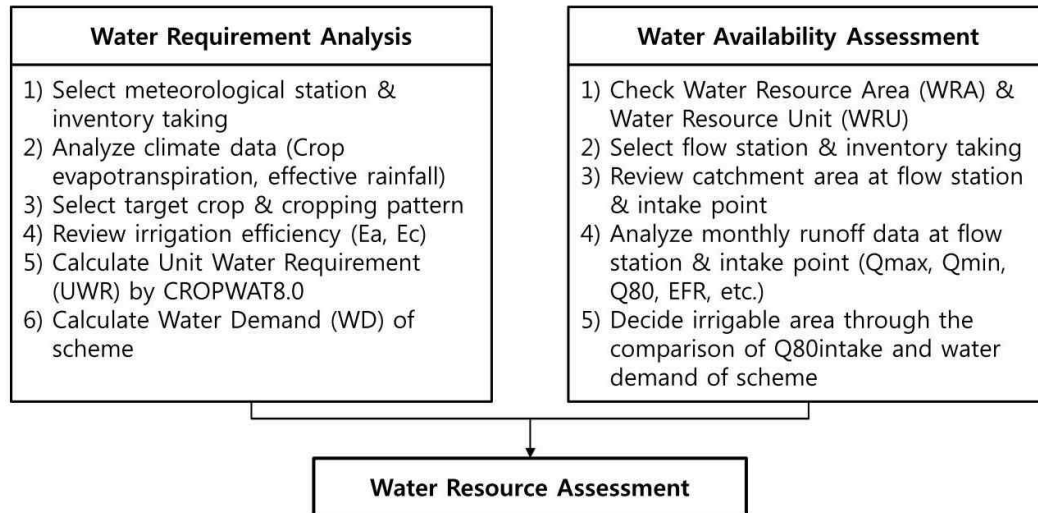


Figure 1. Methodology procedure for water resource assessment

3. Results and Discussion

3.1 Selection of the Scheme

Among the scheme with existing irrigation facilities, this study selected the Natama irrigation scheme in the southern Malawi as the study area. Natama scheme was constructed by World Vision in 2007, and is located in Chiradzulu district. Natama scheme has about 10 ha of irrigation area that is gravity fed from the Malimba River. This study reviewed the water resource assessment of Natama scheme in accordance with the above mentioned methodology. The scheme layout is shown in Figure 2.

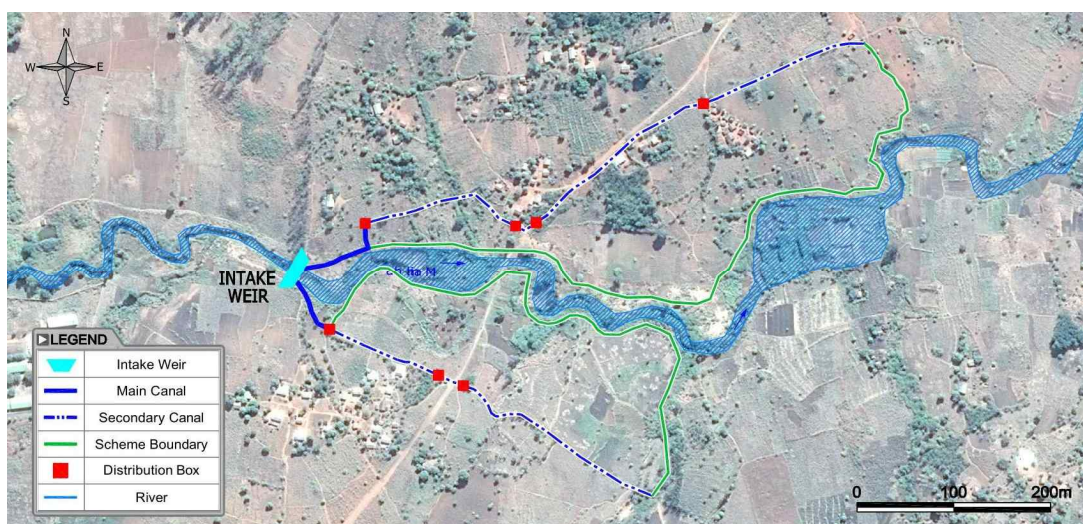


Figure 2. Layout of Natama irrigation scheme

3.2 Water Requirement Analysis

3.2.1 Climate Station and Data Analysis

For the analysis of water requirement, climate data were collected from the climate station which is closer to the Natama scheme and has recorded data of at least 20 years managed by Department of Climate Change and Meteorological Services. The Makoka climate station was selected in consideration of the reliability and continuity of data. The climate status of selected station is presented in Figure 3.

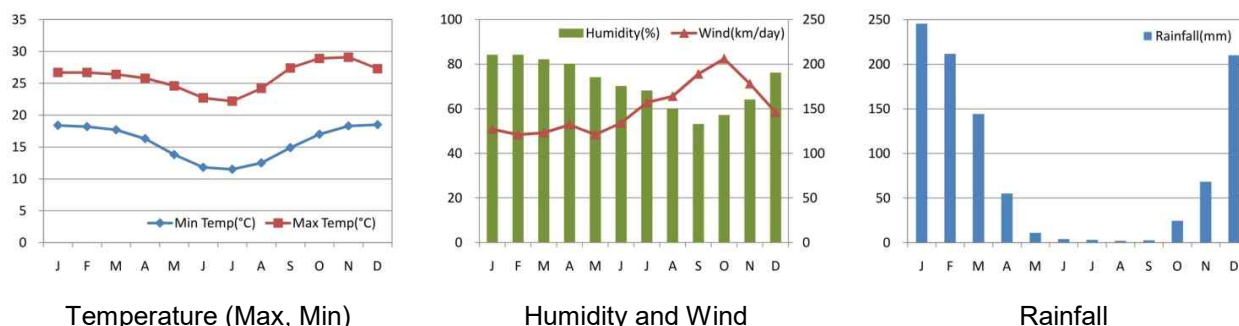


Figure 3. Climate status of Makoka climate station

The crop evapotranspiration (ETo) represents the potential evaporation of a well-watered grass crop. The water needs of crops are directly linked to this climatic parameter. This study selected the Penman-Monteith Method recommended by FAO [6] as the appropriate combination method to determine ETo from climatic data such as temperature, humidity, sunshine and wind speed. Effective rainfall is the remaining water quantity from rainfall, subject to rainfall, rainfall intensity, topography, soil and contained water, utilized for farming by the irrigation system. To account for the losses due to runoff or percolation, the effective rainfall calculated by USDA Soil Conservation Service Method. In this study, ETo and effective rainfall was analyzed using a CROPWAT8.0 program by FAO, and monthly results are shown in Table 1.

Table 1. Monthly crop evapotranspiration (mm/day) and effective rainfall (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo	3.87	3.86	3.73	3.48	3.13	2.80	2.91	3.72	4.97	5.51	5.18	4.20
Eff. Rain.	149.0	140.0	111.0	50.3	10.9	4.1	3.2	2.1	2.6	23.5	60.9	139.5

3.2.2 Cropping Pattern and Crop Coefficient

Major crop of Natama scheme is Green Maize in the dry season and Dry Maize in the wet season. In Malawi, the development days of Green Maize and Dry Maize are 90 days and 145 days respectively. Therefore, in case of Maize, it can cultivate 3 times a year; Green Maize 2 times and Dry Maize 1 time. The cropping pattern is shown in Figure 4.

Crop	1			2			3			4			5			6			7			8			9			10			11			12		
	10	20	30	10	20	30	10	20	30	10	20	30	10	20	30	10	20	30	10	20	30	10	20	30	10	20	30	10	20	30	10	20	30			
Green Maize (90 days)	2 weeks																																			
Dry Maize (145 days)	10 days																																			

Figure 4. Cropping pattern of Maize

The crop coefficient (K_c) incorporates crop characteristics and averaged effects of evaporation from the soil. Changes in vegetation and ground cover mean that the K_c varies during the growing period. The K_c required to describe and construct the crop coefficient curve; the initial stage $K_{c(ini)}$, the mid-season stage $K_{c(mid)}$, and the end of late season $K_{c(end)}$. As the Irrigation and Drainage Paper No.56 [6], the K_c and maximum height of Maize is presented in Table 2.

Table 2. Crop coefficient (K_c) and maximum height for Maize

Crop	$K_{c(ini)}$	$K_{c(mid)}$	$K_{c(end)}$	Maximum Height
Maize(Green)	0.30	1.15	1.05	1.5 m
Maize(Dry)	0.30	1.15	0.60	1.5 m

3.2.3 Irrigation Efficiency

The main factors that affect irrigation efficiency are application, conveyance and distribution losses. In case of small scale schemes, because the distribution losses are limited, this study did not consider the distribution losses. The application efficiency is the ratio of water stored in a particular soil layer to the amount of water arrived at paving from source for cropping. The application efficiency mainly depends on the irrigation method and the level of farmer discipline. Since the irrigation method of Natama scheme is furrow irrigation, the application efficiency is decided to 60%. The FAO standard of application efficiency by irrigation type [7] is shown in Table 3.

Table 3. Standard of application efficiency by irrigation type (E_a)

Irrigation Method	Application Efficiency
Surface Irrigation (Furrow, Border, Basin)	60%
Sprinkle Irrigation	75%
Drip Irrigation	95%

The conveyance efficiency represents the efficiency of water transport in canals, and is the ratio of water arrived from the water source to the field. The conveyance efficiency mainly depends on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals. The following table provides some indicative values of the conveyance efficiency, considering the length of the canals and the soil type. In case of Natama scheme, the main canal that supplies irrigation water from intake to field is lined canal, and then conveyance efficiency decided 90%.

Table 4. Standard of conveyance efficiency (E_c)

Length	Earth Canal			Lined Canal
	Sand	Loam	Clay	
Long (>2,000m)	60%	70%	80%	90~95%
Medium (200~2,000m)	70%	75%	85%	90~95%
Short (<200m)	80%	85%	90%	90~95%

Irrigation efficiency is calculated by multiplying the application efficiency by the conveyance efficiency. The irrigation efficiency is 54% (E_a 60% x E_c 90%), but this study decided the overall irrigation efficiency of 50% considering the safety factor in order to secure the stability of irrigation water supply. The irrigation efficiency is generally good (50~60%), reasonable (40%), and poor (20~30%).

3.2.4 Irrigation Time

The daily time for irrigation depends on the irrigation methods. For pivot irrigation system, irrigation time can be 24 hours, the whole day. For furrow irrigation, the water application is normally 12 hours, during the daytime. The irrigation method of Natama scheme is furrow irrigation by manpower. Also, the furrow irrigation during the night time is inefficient in its water utilization and inconvenient to farmers. Therefore, in case of furrow irrigation, the selected irrigation time is 12 hours in consideration of water availability and experience of farmers.

3.2.5 Unit Water Requirement and Water Demand of Scheme

The unit water requirement of scheme calculated by CROPWAT8.0 in consideration of basic factors. The basic factor of Natama scheme for the water requirement analysis is indicated in Table 5.

Table5. Basic factors for water requirement analysis

Scheme	Area	Climate Station	Major Crop	Irri. Efficiency	Irri. Time
Natama	10 ha	Makoka	Maize(Green), Maize(Dry)	50 %	12 hours

For Natama scheme, the peak unit water requirement was estimated to be 0.00061 m³/s/ha (0.61 l/s/ha) in October, but it is determined on the basis of 24 hours irrigation time and daily basis. Therefore, the unit water requirement (UWR) and water demand (WD) for the Natama scheme estimated to be 0.00122 m³/s/ha and 0.0122 m³/s respectively, in consideration with 10 ha of total scheme area and 12 hours of irrigation time. The results of the water requirement analysis for Natama scheme are presented in Table 6.

Table 6. Monthly water requirement analysis (m³/s) of Natama scheme

Q	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UWR(24hr)	0.00000	0.00000	0.00006	0.00006	0.00008	0.00030	0.00036	0.00007	0.00036	0.00061	0.00021	0.00000
UWR(12hr)	0.00000	0.00000	0.00012	0.00012	0.00016	0.00060	0.00072	0.00014	0.00072	0.00122	0.00042	0.00000
WD	0.00000	0.00000	0.00120	0.00120	0.00160	0.00600	0.00720	0.00140	0.00720	0.01220	0.00420	0.00000

3.3 Water Availability Assessment

The water availability assessment is estimated by a specific yield method between the catchment area at representative flow station and catchment area at intake point. According to the water availability assessment, the extensibility of irrigable area is reviewed by comparing water demand of scheme and Q80 at the intake in consideration with the environmental flow requirement (EFR).

3.3.1 Flow Station and Data Analysis

The runoff data were collected from the flow station which is closer to the study area firstly and then belonged to the same Water Resource Units (WRUs). The 2B6 flow station which is located in Namadzi road bridge and has catchment area of 26.7 km² is selected as a representative flow station, and daily recording data (1980~2009) were collected from the HYDSTRA database of Surface Water Division of Ministry of Agriculture, Irrigation and Water Development. For the assessment of water availability, this study calculated Qmax, Qmin, Q80, and EFR using the recording data during 30 years. The EFR is used to describe the component of flows in a watercourse that are required to sustain some level of ecological functioning such as flora and fauna, purification, sediment transport etc., so that water resources are developed in a sustainable way. In Malawi, EFR is generally 10% of Q80, and the results of runoff analysis are presented in Table 7.

According to Table 8, Natama scheme can be supplied enough irrigation water consistently throughout the year. To estimate the extensibility of irrigable area, 80% exceedance probability discharge at the intake point determined the appropriate scheme area to cover Total WD. Therefore, Natama scheme can be extended from 10 ha to 17 ha in the dry season in consideration of the $Q_{80_{\text{intake}}}$. In this case, $Q_{80_{\text{intake}}}$ ($0.02387 \text{ m}^3/\text{s}$) can cover total water demand ($0.02313 \text{ m}^3/\text{s}$) of the scheme. The results of extensibility of irrigable area and trends in available discharge and irrigable area for Natama scheme are presented in Table 9 and Figure 6.

Table 9. Review of the extensibility of irrigable area for Natama scheme

Q (m^3/s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$Q_{80_{\text{intake}}}$	0.05581	0.09223	0.07496	0.05545	0.03994	0.03623	0.02631	0.02631	0.02197	0.02387	0.02387	0.04142
EFR_{intake}	0.00558	0.00922	0.00750	0.00554	0.00399	0.00362	0.00263	0.00263	0.00220	0.00239	0.00239	0.00414
WD	0.00000	0.00000	0.00204	0.00204	0.00272	0.01020	0.01224	0.00238	0.01224	0.02074	0.00714	0.00000
Total WD	0.00558	0.00922	0.00954	0.00758	0.00671	0.01382	0.01487	0.00501	0.01444	0.02313	0.00953	0.00414
Assess.	O.K	O.K	O.K	O.K	O.K	O.K	O.K	O.K	O.K	O.K	O.K	O.K

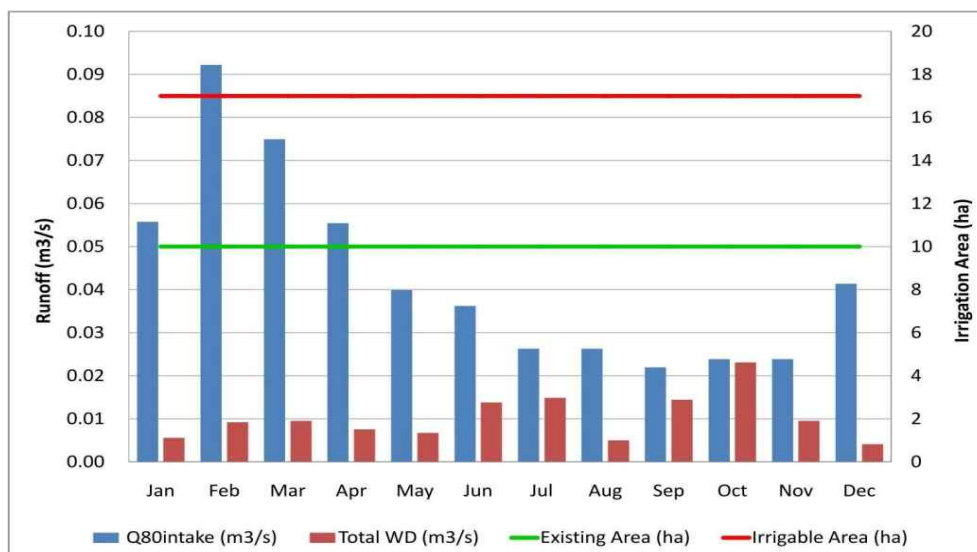


Figure 6. Trends in available discharge and irrigable area for Natama scheme

4. Conclusions

This study proposed the procedure and methodology of water resource assessment to develop and rehabilitate the irrigation scheme for Malawi in Africa, which has tropical climate. According to the presented methodology, the study area was selected, and it was estimated the water resource assessment, such as unit water requirement, water demand of scheme, and water availability. This method will be the most applicable method in other African countries extensively as well as in Malawi, and this study presented a guideline and procedure of water resources assessment to develop or rehabilitate the irrigation scheme.

The basic data that are required to analyze were collected from the HYDSTRA database of Surface Water Division of Ministry of Agriculture, Irrigation and Water Development, Government of Malawi. Also, through the field investigation, the target crops and cropping pattern suitable for local condition were determined. In terms of irrigation time, unlike in the case of Korea, irrigation time of 12 hours was selected in consideration of farmers' working conditions and irrigation method. On the basis of these factors, unit water requirement and water demand of scheme were calculated, and the result is $0.00122 \text{ m}^3/\text{s}/\text{ha}$ and $0.0122 \text{ m}^3/\text{s}$ respectively.

Also, the availability to supply the irrigation water was evaluated, accordingly water availability assessment that estimated the optimum irrigable area was analyzed. In case of Natama scheme, the irrigation water can supply enough to the existing scheme area of 10 ha in consideration of $Q_{80_{\text{intake}}}$. Therefore, the extensibility of irrigable area was studied in accordance with the dry season, and then Natama scheme was reviewed to be able to extend the irrigation area from 10 ha to 17 ha.

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