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Supplementary Irrigation Manual for Rice Production Using Small Reservoirs

March, 2017

Ministry of Food and Agriculture

Kwame Nkrumah University of Science and Technology

Japan International Research Center for Agricultural Sciences

FOREWORD

Rice has become a primary staple food particularly in Africa. Most growing cities depend on rice as daily diet, with consumption increasing by about 5.5 % per year.

Despite the clear potential to boost regional rice production, most African countries continue to rely heavily on imports for meeting their growing rice consumption needs at an annual cost of USD 5 billion. Thus reliance on rice imports for their consumption continues to pose a serious food security concern for African countries. But records available have indicated that rice consumption is projected to increase by 130% between 2012 and 2035. Notwithstanding the rapid increase in rice production in Africa since 2007, local rice production is unable to keep pace with the increasing demand. It is noted that the demand-supply gap is widening. This requires sustainable intensification of rice production, based on enhancing biological processes of the ecosystem.

The Japan International Research Center for Agricultural Sciences (JIRCAS), Ministry of Food and Agriculture (MoFA), and Kwame Nkrumah University of Science and Technology (KNUST) signed a tripartite agreement to cooperate to carry out the "Study of Improvement of Micro Reservoir Technologies for Rice Production in Africa". The main objective of the study is using micro reservoirs to increase the yield and cropping times of rice production in Africa. The implementation of double cropping in small-scale irrigation paddy fields has been a challenge as a result of seasonality of surface water flow. This has called for the need to develop technologies for micro reservoir construction and sustainable water use in these areas. The study had its main verification sites in the Ashanti and Northern regions of Ghana.

Other research services were also sought from the Savanna Agricultural Research Institute of the Council for Scientific and Industrial Research (CSIR-SARI). It should be noted that the study is in conformity with the target goal of Coalition for African Rice Development (CARD) to double the rice production in Africa from 14 million mt/y in 2008 to 28 million mt/y by 2018.

This manual therefore contains research findings and recommendations to promote more efficient and sustainable rice production systems in Africa through the use of small reservoirs.

SETH OSEI-AKOTO
AG. DIRECTOR OF CROP SERVICES
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Statement by Program Director

In sub-Saharan Africa, rice production falls short of consumption. As a result, the region's imports of rice from Asia or North America have been increasing year by year. In addition, according to "Prospects for Global Food Supply and Demand in 2021" by the Ministry of Agriculture, Forestry and Fisheries of Japan, the global demand for food, such as cereals, will continue to slightly exceed supply in the future, so a modest upward trend in food prices is expected to continue. Therefore, it is urgent not only to take emergency measures but also to increase food production in the medium to long term.

Given such situations, at the Fourth Tokyo International Conference on African Development (TICAD IV), international organizations, such as the Japan International Cooperation Agency (JICA), established the "Coalition for African Rice Development (CARD)," with the goal of doubling rice production in Africa in ten years. Even in Africa's inland wetlands, which have great potential for rice cultivation, the average rice yield is just 2 t/ha, with farmers relying on rainwater for their crops. As a result, the area for rice cultivation is not increasing. In addition, farmers are reluctant to invest in rice cultivation because of social and economic problems associated with land ownership or the distribution of rice.

Moreover, it is expected that, in the long term, in sub-Saharan Africa the amount of precipitation will decrease, and the rainfall pattern will become unstable (Consultative Group on International Agricultural Research). To cope with such situations, it is necessary to develop small-scale irrigation facilities, such as micro reservoirs that can be constructed quickly, maintained easily, and adjusted flexibly to changes in the environment. At present, however, reservoirs are not being developed sufficiently enough because of poor construction techniques or high costs involved. There are also cases in which water management organizations do not function as intended if the constructed facilities are ineffectively used. Therefore, the development of low-cost construction techniques as well as methods for farmers to maintain the facilities and manage water is expected to lead to a substantial increase in agricultural productivity.

Under these circumstances, Ministry of Agriculture, Forestry and Fishery in Japan requested JIRCAS to implement the study to increase (stable) the rice production with using micro reservoirs. JIRCAS decided the study country in Ghana and implemented the study with mutual collaboration with MoFA and KNUST from 2014 to 2017.

This manual is the result of the study. I hope this manual may contribute to rice cultivation especially in the savanna zone.

March 2017

Dr. Kazuo Nakashima

Program Director, JIRCAS

Introduction

In sub-Saharan Africa, rice production falls short of consumption. As a result, the region imports an increasing amount of rice from Asia or North America every year. Given this situation, the Coalition for African Rice Development (CARD) was established in 2008 with the goal of doubling rice production in Africa in 10 years. Even in Africa’s inland wetlands, which have great potential for rice cultivation, the average rice yield is only 2 mt/ha, with farmers relying on rainfall for their crops.

Against this background, it is essential to introduce an irrigation system for rain-fed paddy fields to increase rice production. Considering the sustainability and adapting flexibly to climate change, small-scale irrigation facilities (such as small reservoirs) with short construction period and simple management are necessary.

At present, small dugout reservoirs are mainly constructed for obtaining water for livestock and domestic purposes. Water spilling out from such a dugout reservoir is not utilized effectively. Moreover, in some cases, Water Users Associations (WUAs) of small reservoir do not function well, and the facility may not be utilized effectively after construction.

This manual focuses on improving and ensuring sufficient utilization of spilled water. Water spillage usually occurs at the peak of the rainy season, and irrigation is mainly considered for the late stage of rice cultivation when insufficient water affects productivity severely.

The volume of water required for puddling is the highest among the stages in rice cultivation. Puddling generally starts approximately a month after the beginning of the rainy season. When the sub pond water is used for puddling, a large amount of water is required. The larger the sub pond, the higher the construction cost and the more complicated the maintenance and management tasks.

Hence, the target cultivation method is direct seeding instead of transplanting for which puddling is required. Ploughing is executed even in the case of direct seeding, and rainfall is the source of water. The sub pond water is supplied from the panicle initiation stage to the flowering stage, during which water shortage severely affects production (period of about 40 days depending on the variety of rice).

This manual describes the following with main target users as mentioned:

- Design for Supplementary Irrigation
  User: Engineering Personnel
- Facility Improvement for Supplementary Irrigation
  User: Engineering Personnel
- Rice Cultivation with Supplementary Irrigation
  User: Engineering Personnel, Extension Workers and Farmers
- Water Management
  User: Engineering Personnel, Extension Workers and Farmers

To establish stable rice cultivation through supplementary irrigation, bunds around plots are indispensable. Also, most cultivation techniques suitable for normal irrigation excluding the contents described in this manual that are specially for supplementary irrigation are also suitable for supplementary irrigation. For installing bund around plots, or applying cultivation techniques for irrigation, readers are suggested to refer manuals below;

- Manual for Improving Rice Production in Africa; JIRCAS (2012)

  http://www.jircas.affrc.go.jp/english/manual/ricemanual2012/ricemanual2012_index.html

- Manual of Soil Fertility Improvement Technologies in Lowland Rice Ecologies of Ghana; MoFA-UDS-JIRCAS (2014)

  http://www.jircas.affrc.go.jp/english/manual/soil_fertility_improvemnet_tech_of_Ghana/soil_fertility_Ghana.html

- Extension Guideline, “Model” of Sustainable Development of Rain-fed Lowland Rice Production; JICA (2014)

Table of contents

List of Tables

List of Figures

Abbreviations

CARD	Coalition for African Rice Development
CN	Curve Number
FAO	Food and Agriculture Organization of the United Nations
GHS	Ghana Cedi
GIDA	Ghana Irrigation Development Authority
JICA	Japan International Cooperation Agency
JIRCAS	Japan International Research Center for Agricultural Sciences
KNUST	Kwame Nkrumah University of Science and Technology
MoFA	Ministry of Food & Agriculture
MAFF	Ministry of Agriculture, Forestry and Fishery
SARI	Savanna Agricultural Research Institute
TC	Technical Committee
UDS	University for Development Studies
WUA	Water Users Association

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Chapter 1 Design for supplementary irrigation

Irrigation of paddy fields and use of ponds are subject to constraints when implementing supplementary irrigation using pond water.

In this chapter, the manner of selection of ponds and paddy fields for rice cultivation using pond water through a pair pond system or raised spill way, is discussed.

1.1 How to select a suitable paddy field

1.1.1 Conditions of a suitable paddy field

A suitable paddy field when dugouts are used for supplementary irrigation must satisfy suitable pond and paddy field conditions.

Fig. 1.1 shows a suitable paddy field when dugouts are being used by introducing a pair pond system or raised spill way. This requires that both pond and paddy field conditions are satisfied.

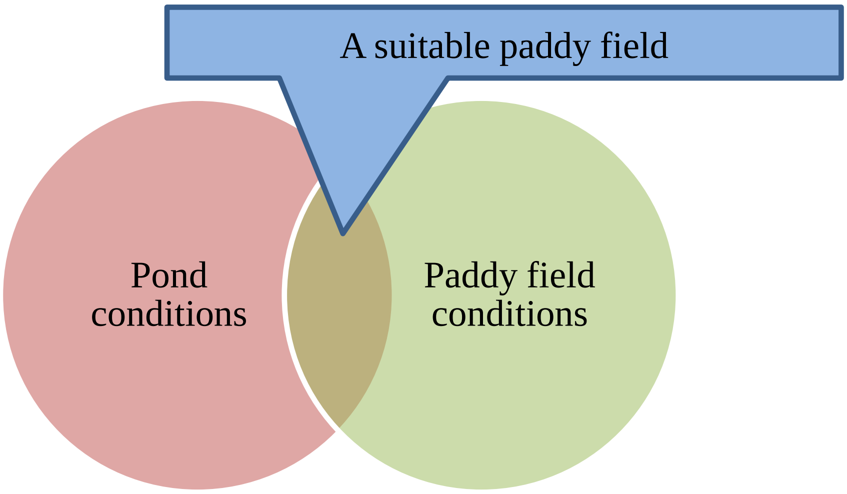


Fig.1.1 Conception of a suitable paddy field

1.1.2 Pond conditions

Pond conditions for selecting a suitable field for dugout reservoirs include water resource condition, socio-cultural considerations and construction material availability.

(1) Water resource conditions

Pond water is not only used for irrigation (rice and other crops), but also for livestock watering and domestic purposes. The order of priority differs depending on the community. Where pond water is insufficient water from wells and taps, where available, can be used to supplement.

- Dugouts in northern regions are mainly used for domestic uses, and livestock watering.
- Water from the dugout will be the only source if tap water and well water are not available.
- Where additional water is required it can be obtained by raising the height of the embankment, desilting the reservoir or by utilizing

(2) Socio-Cultural Considerations

Construction of a small reservoir incurs some cost. Maintenance and management cost are also incurred. Thus, a place where the benefits are not worth the cost is not a suitable place. That is, the suitable place shall be the place where rice is commercially cultivated. Moreover, rice cultivation incurs certain cost. Therefore, a suitable place is one where rice is cultivated commercially. In the case that rice is cultivated for self-consumption, the benefits should exceed the purchasing cost.

(3) Material availability

In places where materials (e.g., soil) cannot be easily acquired (or conveyed), the construction cost increases, and the construction will be economically disadvantageous.

Further, soil cement that is obtained by mixing cement with on-site soil is used to make solid objects. The strength of soil cement depends on the particle distribution of the soil that is mixed with cement (for a given cement volume, the greater the clay content, the less is the strength).

Thus, if sandy soil is not available, the cement volume increases, and the cost of the embankment makes it economically disadvantageous.

Fig. 1.2 illustrates the interaction among the water resources, socio-cultural considerations and construction material availability.

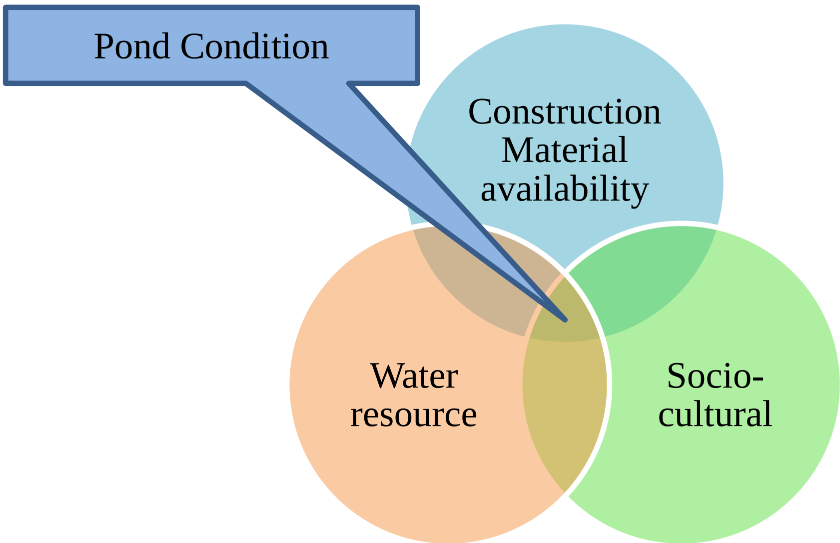


Fig. 1.2 Conception of Pond condition

1.1.3 Paddy field conditions

(1) Fig. 1.3 and Fig. 1.4 show the conceptual framework for the paddy field conditions. The condition for using dugout for paddy fields is that sufficient volume of water cannot be secured under natural conditions given that the site is potentially irrigable.

1) Water environment and rice cultivation

Some fields where the JICA sustainable development project (completed in 2014) was implemented achieved high productivity without supplementary irrigation (according to the final report; productivity increased from 3.0 t/ha to 3.9 t/ha at the trial plot in Tamale, and from 4.0 t/ha to 6.6 t/ha in Kumasi).

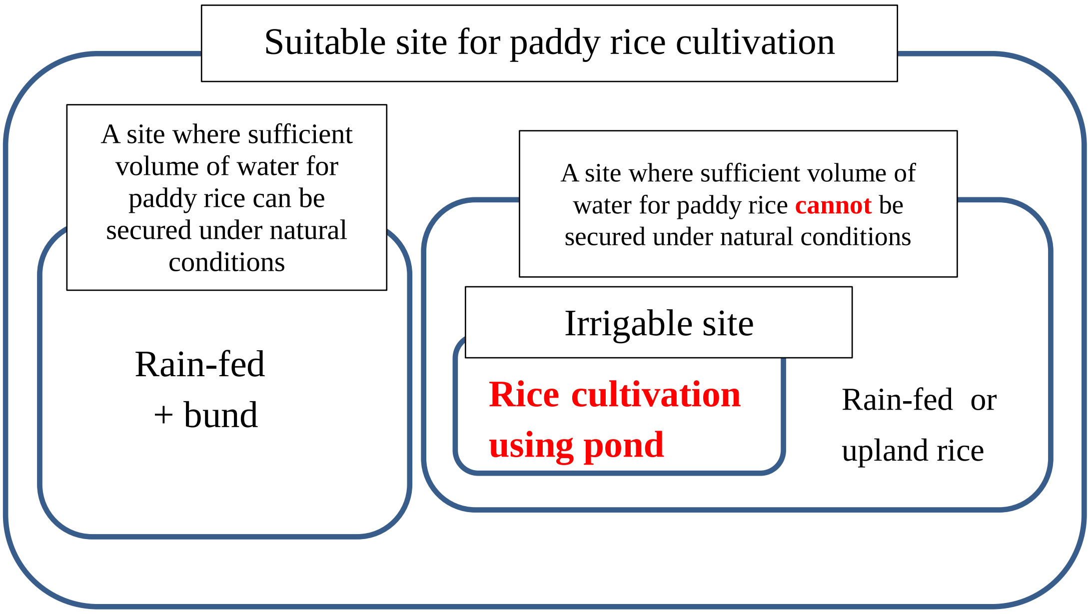


Fig. 1.3 Conception of Paddy field conditions

On the other hand, according to the interim review report, the average productivity in the Northern region in 2007–2009 was 2.1 t/ha and that in Ashanti was 1.1 t/ha. That is, places with good conditions were selected as the trial plots. Thus, the productivity of rain-fed rice varies largely with the conditions. Moreover, the productivity increases up to a certain value with the water volume used by plants.

Thus, given the same volume of rainfall and rain pattern, bund construction improves the productivity at sites where water is easily obtained. On the other hand, irrigation is needed for improving the productivity at places where water is difficult to obtain.

2) Water volume for rice and paddy field conditions

According to this manual, irrigation should be implemented from the panicle formation to flowering stages, when the productivity is heavily influenced. During this period, the paddy field shall be wetted.

According to the Irrigation Water Management training manual (FAO, 1986), the necessary amount of water for the irrigation period is approximately 20 mm/day (for semi-arid regions with strong wind and sandier soil). The water volume at the verification site of this manual is

16.5 mm/d. As the irrigation period is 40 days, the amount of water for irrigation is 660 to 800 mm / 40 days.

Paddy field conditions refers to the conditions in a location where the abovementioned water volume minus the effective rainfall in the irrigation period cannot be secured under the natural conditions. For example, in Tamale (capital of the Northern region), the drought reference year for a 10-year return period is 2000. The total rainfall for the irrigation period of this year (from September 1 to October 10) was 287 mm / 40 days. Thus, the place where approximately 370 to 510 mm / 40 days of water, except rainfall, cannot be secured meets paddy field conditions.

(2) Irrigable area

Collecting water is difficult at a site with elevation higher than the valley bottom. However, many ponds are designed at the valley bottom for collecting water effectively. Hence, when implementing irrigation using pond water by gravity, the canal may be long, or irrigation may have to be realized by pumping. At sites with bad geographical conditions, upland rice cultivation will be more advantageous economically than irrigation (that is, the place is not suitable for irrigation).

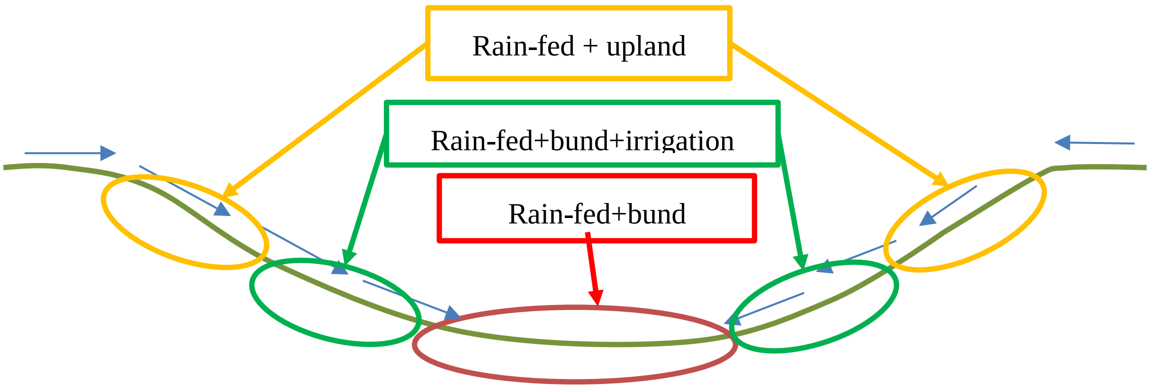


Fig. 1.4 Paddy field conditions (schematic)

(3) Paddy field conditions

The paddy field conditions are summarized as follows (Table 1.1).

i) A place where the water necessary for supplemental irrigation (370 to 510 mm / 40 d) cannot be secured

ii) A place where pond irrigation is not economically disadvantageous

Table 1.1 Paddy field condition

Water availability volume except rainfall	Water conveying cost	Cultivation
More than 370～510mm/40d		Rain-fed + bund
Less than 370～510mm/40d	Low	Rain-fed + bund + supplemental
	High	Rain-fed + upland rice

1.2 Supplementary irrigation design

(1) Reference year for design

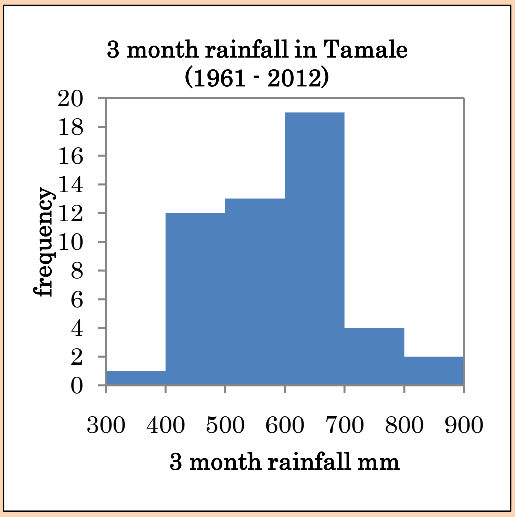
The reference year for design is 10-year drought rainfall of the period that influences on irrigation

The reference year for design is a drought year in the irrigation design. The longer a drought probability year, the larger is the facility. Thus, the smaller the year, the more economical is the facility. The probability year is 1/10 for a paddy field in Japan (MAFF of Japan (2014)). This figure is adopted in this manual. As July seeding is common in the Northern region, the period that affects irrigation is set as July to September.

Method of calculating the reference year for design

The reference year for design for the Northern region where 51-year series data are available, is calculated.

The calculation period is July to September (3-month), when rice is cultivated. The average 3-month rainfall is 584 mm, and the standard deviation is 118 mm. Because of the normal distribution test of rainfall, the P value of both side skewness is 0.35 > 0.01. This means rainfall is not normal distribution. In this case, Gumble method shall be adapted to calculate the reference year.



As a result of Gumble method, 10-year drought rainfall is calculated 440mm. (worth 430.0 mm in 2000)

(2) Irrigation plan

・Irrigation is implemented only from the panicle formation stage to the flowering stage that greatly affect to productivity (40 days).

Although soil moisture in the seeding period is important for germination, if the necessary water for the seeding period is secured, the scale of pond may increase, in turn increasing the construction cost. Hence, in the supplemental irrigation system, seeding is implemented soon after a rainfall. Irrigation is implemented only from the panicle formation to flowering stages that greatly affect productivity (40 days; the number of days may change depending on the species).

Table 1.2 Irrigation policy for each growth stage of rice

Rice growth stage	Days after germination (DAG; in case of Jasmin85)	Mode of Irrigation
Seeding to the maximum tiller number stage	0 to 60 DAG	Rain-fed
Panicle initiation stage to flowering stage	60 to 100 DAG	Irrigation
Maturing to harvest	100 to 120 DAG	Rain-fed

(3) Irrigation volume per day

・Paddy field should be kept wet during the supplemental irrigation period.
・Irrigation volume of the period = (water requirement per day – daily effective rainfall in reference year) / irrigation efficiency * irrigation area

1) Water requirement per day

The water requirement per day is the decrease in the volume of water in one day in a submerged paddy field. The water requirement per day may change depending on rice growth, soil, cultivation history, bund condition, and groundwater. As it affects irrigation volume considerably, a preliminary survey may be implemented. The water requirement per day at the verification site was 15 mm/d.

How to measure the water requirement per day

Strike a stake with a scale in a submerged paddy field, and to read the scale daily to determine the decrease in volume (length) per day

2) Effective rainfall

Irrigation volume per day is calculated by using the water requirement per day minus 80% of the daily rainfall (when the daily rainfall ranges 5 to 80 mm) in Japan. Because a paddy field cannot retain more than 80 mm of water as the water spilled from bund (Maruyama et al., 1979), rainfall of more than 80 mm is also treated as 80 mm.

The limit of the effective rainfall depends on the bund height. Therefore, to create a bund of height more than 20 cm with no outlet, the upper limit (80 mm) should not be considered.

3) Irrigation efficiency

Irrigation efficiency is the ratio of the intake water volume and the irrigation volume for a field. Decrease in the efficiency mainly occurs as water is transported from a sub-pond to a field (conveyance loss).

The conveyance loss ratio differs depending on the mode of transport (for e.g., pipeline, 5%; concrete canal, 10%; and unlined canal, 20%. Conveyance loss is a reference value).

When unlined canals are used, the canal length is maintained as short as possible so that the loss does not increase.

1.3 Calculation method of the volume to overflow in the reference year

1.3.1 General Outline

In order to calculate available water volume for agriculture, it is necessary to consider the current use of water in the target water resources. The overflow from a dugout caused by the influx of rainwater is the water resource of the dugout which does not compete with the water usages at present. Therefore, estimate the overflow by estimating the volume change of the existing dugout, and estimate the "Available water volume for agriculture.

A method of calculating the overflow using the water balance equation by the Curve number method (hereinafter referred to as CN) will be described.

The volume to overflow is calculated by calculating each element of the following water balance. In addition, the data for at least two years are required for calculation and verification.

Water changing in storage = Runoff + Rainfall on the pond surface − water usages − Evaporation − Seepage – Overflow (1-1)

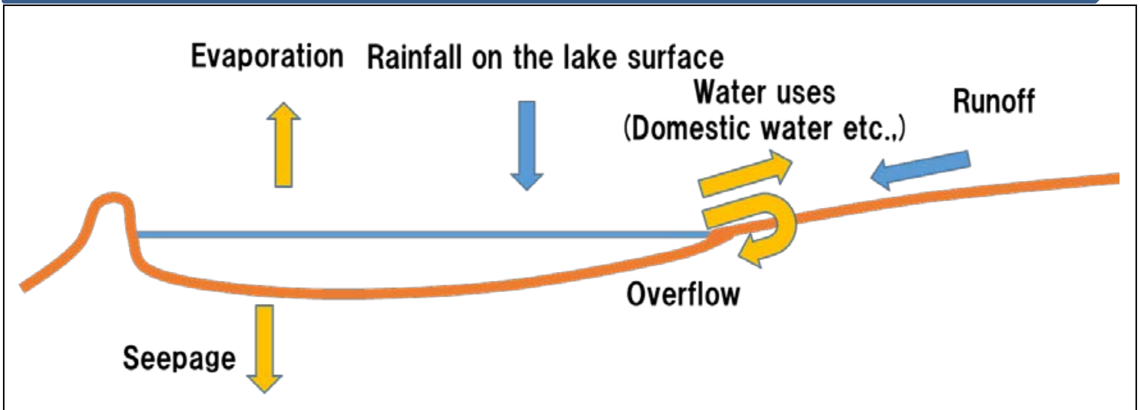


Fig.1.5 Elements of water balance

1.3.2 Data collection

This section describes the purpose and method for calculating each element in the water balance equation around the target reservoir and the target reservoir.

(1) Determination of the catchment area

・The catchment area is used for calculating runoff.
・The catchment area shows the range of the watershed of the reservoir as seen from a topographic map.

A topographic map is required to identify the catchment area. A contour map is plotted using a topographic map, and the catchment area is identified. It is necessary to prepare the map at a scale in consideration of the scale of the reservoir. Further, the recommended scale of the map is more than 1/5,000.

When acquiring a topographic map is difficult, it is necessary to plot a topographic map and a contour map based on a topographic survey.

(2) Rainfall data

・The rainfall data shows the daily rainfall and the rainfall per hour.
・The daily rainfall is used for calculating the runoff using the fixed CN. The rainfall per hour is used for the calculation of the Runoff using the changed CN and regression CN.

To measure rainfall, a rain gauge is installed in the catchment area of the target reservoir.

Fig.1.6 Weather station

(3) Water level

・The water level data shows the changes in the water level for the target dugout.
・The water level is used for verification.

The water level data shows the daily and hourly level changes.

A water level gauge with a logger is used for collecting data per unit time.

(4) Water usage

・Water usage provides information on the total daily use of dugout water as domestic water, drinking water for animals, and so on.

The total usage is calculated by considering the components of actual water usage of the target dugout. For example, the number of containers and the number of users are recorded (Fig. 1.7), and the direct water usage volume from dugout is calculated. Further, through a head count and number of drinking, the volume consumed by domestic animals is measured. As reference, the amount of water consumed per day by animals is listed below.

Table 1.3 Estimated water requirement and voluntary intake of livestock under Sahelian conditions

		Voluntary water intake (liters/day) (27°C)	
Species	**Mean live weight(kg)**	**Wet season**	**Dry hot season**
Cattle	180	10	27
Sheep	25	2	5
Goat	25	2	5
Donkey	105	5	16

Source） Based on MoWR/EARO/IWMI/ILRI, Water resources for livestock in Ethiopia: Implications for research and development, International Workshop held at ILRI, Addis Ababa, Ethiopia 2–4 December 2002, p70, Table 2

Fig.1.7 Drawing water for domestic purposes at Nwogu dugout near Tamale, Ghana

1.3.3 H-V and H-A Relationship

・The H-V(stage-capacity) curve shows the relationship between water level (H) and volume of storage water in a dugout (V).
・The H-A (stage-flooded area) curve shows the relationship between water level (H) and surface area of storage water in a dugout (A).
・The change in volume is calculated by using the water volume or surface area using the H-V or H-A curve and water level.

A detailed topographic survey of the dugout is necessary for plotting the H-V and H-A curves.

A contour map is plotted from the survey of the reservoir area of the dugout. The volume of the dugout is calculated by summing the capacities at all depths along isodepths lines. The area at each depth is measured using a contour map. A_1 is the area of the upper layer in the contour map; A_2 is the area of the lower layer in the contour map; h is the vertical height difference between layers A_1 and A_2. The interlamellar volume (V_{1-2}) between layers A_1 and A_2 is calculated as follows:

$$V_{1-2} = \left(A_1 + A_2 + \sqrt{A_1 \times A_2}\right)\ h/3 \qquad (1\text{-}2)$$

Source） YaTsuka SAIJYO, et al. (2009):The lake survey method, p120 (in Japanese)

All interlamellar volumes are calculated. The capacity of the dugout is determined by summing the volumes of all layers from the bottom to the surface of the dugout.

The H-V curve is drawn from the interlamellar volume and depth, and the H-A curve is drawn from the surface area and depth.

1.3.4 Estimation of the outflow parameter

・The evaporation and seepage that are outflow components in the water balance equation depend on the area, season, and location requirements.

・They are estimated using the observed weather data and the observed water level data.

i. Evaporation

・It is estimated by Penman method using the weather data of the watershed of the target dugout.

・Alternatively, the meteorological observatory or local representative values of evaporation are used.

- Penman method

Evaporation is calculated by the Penman method when the net radiant, temperature, humidity and wind velocity data are available. The albedo is determined by the state of a surface and suitable values for water surface are in the range 0.06–0.12.

- Meteorological observatory or local representative values

According to FAO, the local representative value of evaporation in a semi-arid area is 8–9 mm/d.

When the basin ratio (the ratio of the area of the surface of a pond and that of the catchment area filled with water) is high, the influence of the amount of evaporation on changes in water level is low.

For example, for a basin ratio of 40, an annual rainfall of 1,000 mm and an outflow rate of 20 %, the inflow is high at 8,000 mm/y. On the other hand, the amount of evaporation varies only in 365 mm/y, even if 1 mm/d is different quantity of evaporation. Therefore, the calculation of the volume to overflow is not greatly affected regardless of whether the value of 8 mm or 9 mm is used.

ii. Seepage

Seepage is only estimated when the change in water volume in the no-rain period in the dry season is an outflow element.

Change in the water volume in the no-rain period = Water usage
+ Change in water volume by evaporation + Seepage
(1-3)

1.3.5 Setting CN

・CN is a parameter used to estimate the runoff in the water balance equation.

Generally, the CN is set based on land use, infiltration and vegetation according to Table 1.4. Then, the runoff is estimated by the following equation:

Where R > 0.2 s:

$$Q = (R - 0.2s)^2/(R + 0.8s)$$

$$s = 254\ (100/CN-1)$$

Where R $\leq$ 0.2 s: $Q = 0$

Q: Runoff per day (mm), R: Rainfall per day (mm),

s: Maximum potential retention (mm), and CN: Curve Number

(1-4)

Source） Based on USDA Natural Resources Conservation Service, National Engineering Handbook, Chapter9,2004

Table 1.4 Typical runoff CN

Cover		Hydrologic condition	Hydrological soil group			
Land Use	Treatment		A[1)]	B	C	D
Fallow	Bare soil	-	77	86	91	94
Brush-brush-weed-grass mixture with brush the major element	-	Poor	48	67	77	83
		Fair	35	56	70	77
		Good	30	48	65	73
Wood-grass combination (or orchard or tree farm)	-	Poor	57	73	82	86
		Fair	43	65	76	82
		Good	32	58	72	79

[1)] A: Low runoff potential, B: Moderate infiltration rate, C: Slow infiltration rate, and D: High runoff potential

Source） Based on USDA Natural Resources Conservation Service, National Engineering Handbook, Chapter9,2004

This manual proposes the following calculation method for CN.

i) Fixed CN
One CN is set based on the soil and ground conditions.
ii) Changed CN
Multiple CNs are set based on the rainfall intensity.
iii) Regression CN
CN is set by using the regression equation of rainfall and the dry spell.

i) Fixed CN

This is the standard procedure from the manual "National Engineering Handbook."

The runoff from the catchment area is calculated using a single CN. The CN is revised as an initial CN, and is set by comparing the estimated inflow with the initial CN and the observed inflow.

ii) Changed CN

It is calculated by using multiple CN wherein the runoff of the catchment area is set according to rainfall intensity. The inflow is calculated from the change in the water volume in the dugout, and the CN is determined.

Thereafter, ranks are assigned according to rainfall intensity, and multiple CN is set.

E.g. Daily rainfall ≥36 mm: CN = 72
10 mm ≤ Daily rainfall <36 mm: CN = 81
Daily rainfall <10 mm: CN = 95

iii) Regression CN

The runoff from the catchment area is calculated using the CN by means of the equation of regression of the dry spell and rainfall amount. The inflow is calculated from the change in water volume in the dugout, and CN is identified.

The advantages and disadvantages of the CN methods are as follows.

Table 1.5 Advantages and disadvantages of the CN methods

Method type	Simplicity	Accuracy
Fixed CN	+++	+
Changed CN	++	++
Regression CN	+	+++

1.3.6 Verification of CN

・The precision of the calculated runoff with the selected method is determined by comparison with the actual survey data of changes in water volume.

The calculated value shows the calculated runoff obtained using the selected CN. The observed value shows the runoff obtained from observation of changes in the water volume and the water balance equation.

The verification is performed using the following two quantities:

i) Relative error

ii) Nash–Sutcliffe Efficiency (NSE)

The verification results are evaluated depending on the capacity of the dugout, the catchment area and precision.

i) Relative error

Relative error is calculated using the following equation.

$$\text{Relative error (\%)} = (V_{cal} - V_{obs}) / V_{obs} \times 100$$

V_{obs}: Observed data, V_{cal}: Calculated data

(1-5)

ii) NSE

NSE is calculated using the following equation.

$$\text{NSE Value} = 1 - \frac{\Sigma\ (V_{obs}-V_{cal})^2}{\Sigma\ (V_{obs}-V_{ave})^2}$$

V_{obs}: Observed data, V_{cal}: Calculated data, V_{ave}:The average of observed data

(1-6)

Source) Based on River flow forecasting through conceptual models part I

According to Sakaguchi (2013), NSE is used for verification as follows:

NSE ≤ 0.50	Unsatisfactory
$0.5 <$ NSE $\leq$ 0.65	Satisfactory
$0.65 <$ NSE ≤ 0.75	Good
$0.75 <$ NSE	Very good

1.3.7 Calculation of the volume of available water for irrigation (overflow) in the reference year

The volume of outflow in reference year is estimated by water balance equation using verified CN.

Overflow is caused by rainfall event eliminating the dugout's remaining capacity. In order to grasp the remaining capacity, the store volume (Q_{store}) is calculated from the water balance equation using the verified CN. Overflow is estimated using the water balance equation according to the relationship between the remaining capacity ($Q_{residual}$) and the total inflow volume ($Q_{total\text{-}inflow}$).

i. In Cases where there is no overflow i.e. the total inflow volume does not exceed the remaining capacity

The Fig. 1.8 shows the concept of water balance and water balance equation when no overflow occurs.

$$\Delta Q_{store} = Q_{total\text{-}inflow}\ (\text{Runoff} + \text{Rainfall on the pond surface} - \text{Water usage} - \text{Evaporation} - \text{Seepage}) \quad (1\text{-}7)$$

$Q_{residual}$ (Remaining capacity) $> Q_{total\text{-}inflow}$: $Q_{overflow} = 0$

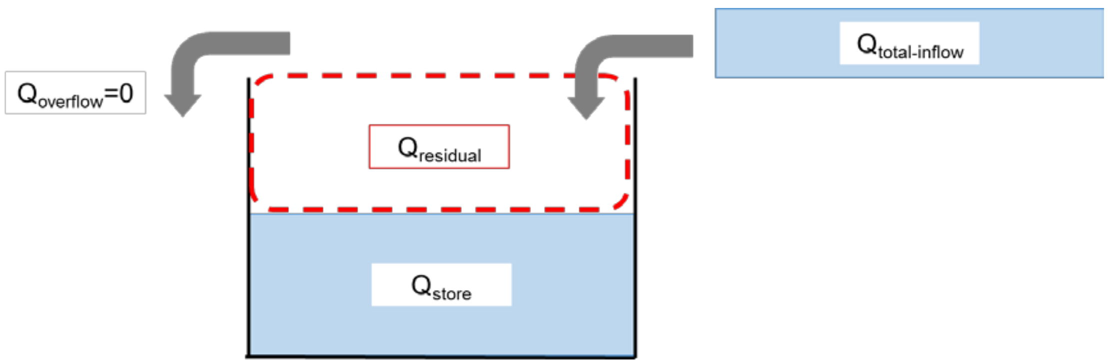


Fig.1.8 Water balance when overflow does not occur

Note that the remaining capacity is the amount obtained by subtracting the total store volume from the dugout capacity.

ii. In the case where the overflow occurs due to the total inflow exceeding the remaining capacity

The overflow occurs when an inflow exceeding the remaining capacity is generated. The Fig.1.9 shows the concept of water balance and water balance equationfor calculating the overflow.

$$Q_{overflow} = Q_{total\text{-}inflow} - Q_{residual}$$

Where $Q_{total\text{-}inflow}$=(Runoff + Rainfall on the pond surface

Water usage - Evaporation - Seepage) (1-8)

0 < $Q_{residual}$ (Remaining capacity) < $Q_{total\text{-}inflow}$

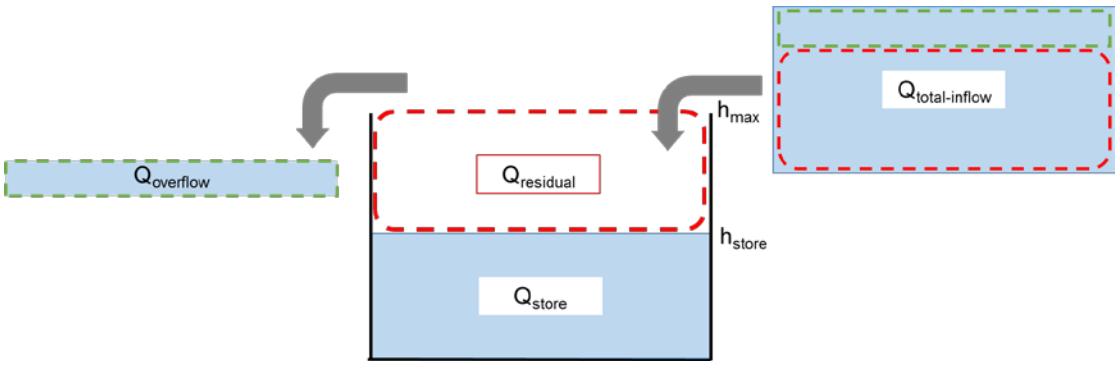


Fig.1.9 Water balance when the overflow occurs due to the total inflow exceeding it even though there is the remaining capacity

iii. When overflow occurs due to rainfall when there is no remaining capacity (full water)

When rainfall occurs during full water at the dugout, the remaining capacity is zero, so the total inflow and the overflow are equal. The Fig.1.10 shows the concept of water balance and water balance equation for calculating the overflow.

$$Q_{overflow} = Q_{total\text{-}inflow}\,(\text{Runoff + Rainfall on the pond surface} \quad \text{Water usage - Evaporation - Seepage}) \qquad (1\text{-}9)$$

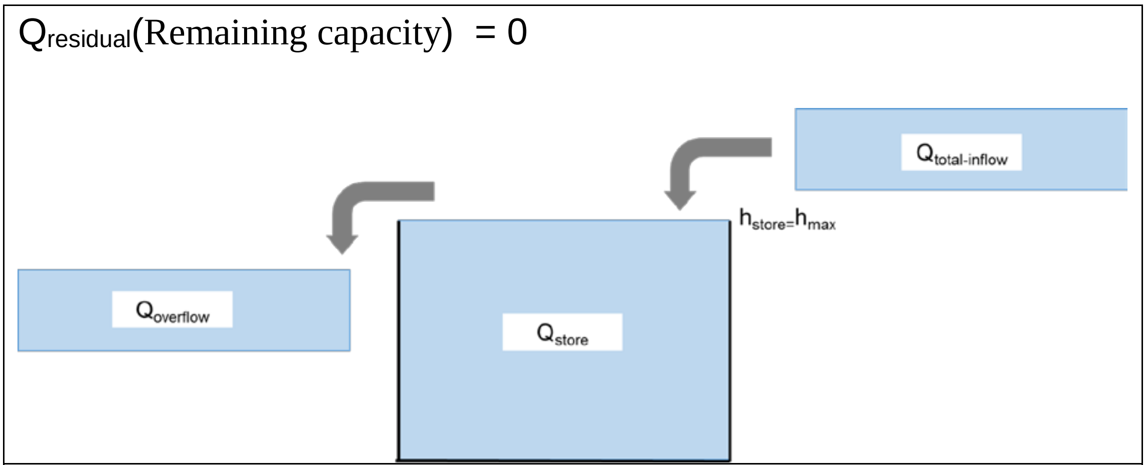


Fig.1.10 Water balance when there is rainfall at full water and overflow occurs

1.3.8 Sample calculation

i. Determination of the catchment area

Total Station survey equipment was used, and the topography was surveyed within 30-50 m interval in this project. The area of the catchment was calculated as 44 ha

ii. Rainfall data

A weather station (Fig. 1.6) installed on the embankment was used to gather hourly rainfall data in this project.

iii. Water level

Water gauge and water level logger were used for collecting data on changes in the water level in this project.

iv. Water usage

The water of the dugout in this project is mainly used for domestic uses, for example, as drinking water and for livestock watering.

The daily volume of domestic water used was set as 32.65 m^3 by recording the number of users and the capacity of container for supplying water.

The main livestock of the target site was cattle and sheep. The head count per day was set as 100 cattle and 200 sheep via a herding survey in the village and a counting survey at the dugout.

The drinking water consumed per day was calculated as 10 l/d per head of cattle according to Table 1.3.

v. H-V and H-A curves for Nwogu Dugout

Generally, the depth from the surface to the bottom of a dugout is surveyed (bathymetric survey) for calculating the capacity. This is done using a staff (sounding scale) from a boat on the dugout. With regard to bathymetric surveying, the depth along lines at three crossing on the dugout is measured at 5 m intervals. The measured positions are plotted, and the corresponding depth values noted. Using the plotted position and depth, an isodepth contour is drawn, and a bathymetric map is plotted.

Table 1.6 lists the calculated dugout capacity, and the H-V and H-A curves shown in Fig.1.11 and Fig.1.12. The dugout capacity is approximately 11,490 m^3, and the surface area of the pond is 9,110 m^2, and the maximum depth of water is 2.2 m.

Table 1.6 Calculation sample for the dugout

No.	Depth(m)	Area (m^2)	Capacity by depth (m^3)	Capacity (m^3)
1	0	0	0	0
2	0.2	200	7	7
3	0.3	411	127	134
4	0.5	1,773	325	458
5	0.7	3,257	538	996
6	0.9	4,231	805	1,801
7	1.1	4,797	1,032	2,832
8	1.3	6,338	1,207	4,040
9	1.5	6,753	1,383	5,423
10	1.7	7,678	1,552	6,975
11	1.9	8,819	1,709	8,685
12	2.2	9,109	2,779	11,463

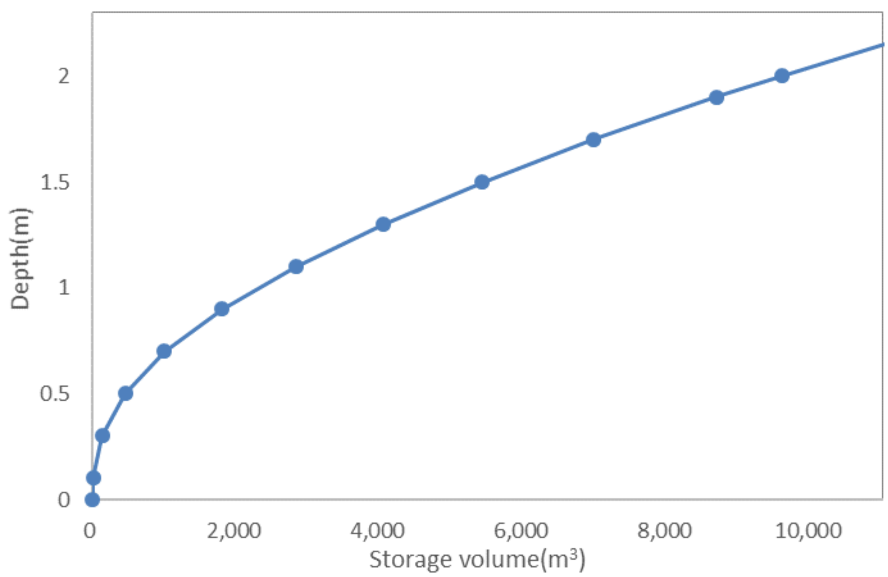


Fig.1.11 H-V Curve

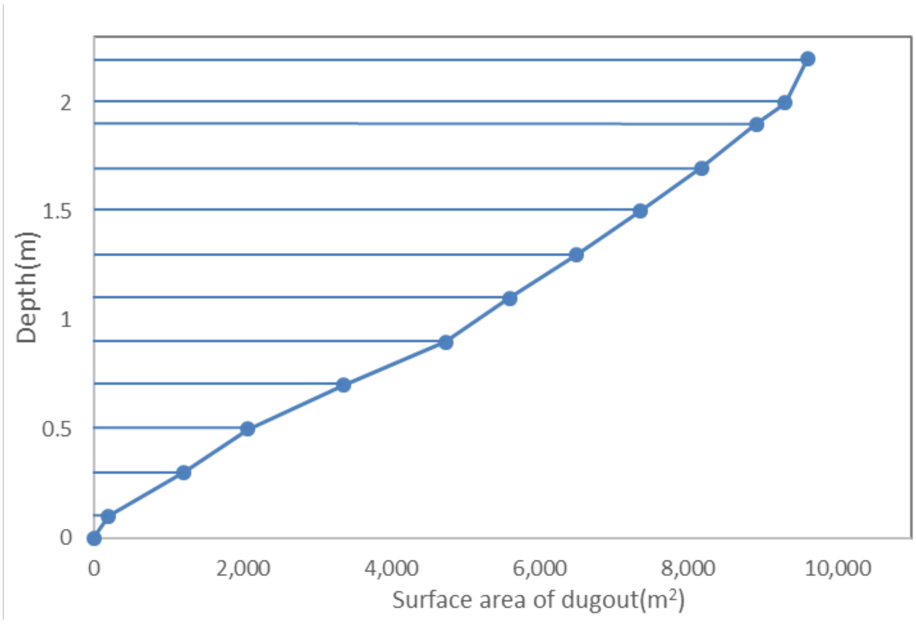


Fig.1.12 H-A Curve

vi. Evaporation

The weather station (Fig. 1.6) installed on the embankment recorded temperature, moisture, and wind speed data in this project. Evaporation was estimated by using the latitude and longitude of the site, the recorded data, and the net radiant calculated based on daylight hours.

vii. Seepage

Based on the water gage data of changes in the water level per day, the period from Dec 12, 2013, to Mar 12, 2014, was considered a no-rain period. The seepage was calculated assuming that the water balance of the dugout in this season comprised only the outflow element.

The average seepage was estimated as 1.28 mm/d by using the data of evaporation, total water usage, and changes in water volume as calculated by using the H-V curve.

1.4 Surveying and preparation of topographic map by using UAV (Drone)

By using a commercially available drone, a topographic map can be easily plotted by consuming less time and incurring less cost as compared to other existing methods.
The Accuracy for height is 10 cm / 100 m and pond capacity of ±20% for a diameter of 100 m.

i. Drone type, software, and PC

The drone used in this project was Phantom3 Advance. In addition, the software for plotting the topographic map was Agisoft Photoscan Professional ver. 1.2 (Photoscan). For measuring the area enclosed by contours, QGIS Desktop 2.14.1 (QGIS: free software; http://www.qgis.org/en/site/) was used.

ii. Procedure for plotting a topographic map using a drone

The procedure to plot a topographic map is as follows. However, techniques to maintain, operate (fly), and capture pictures are not explained in this manual. For these details, please refer to the production manual.

To take photos one scene wider against target features (e.g. pond, watershed and paddy field)

- Capture photos one scene wider against target features (e.g. pond, watershed, and paddy field)
- Capture photos with at least overlapping 2/3 portions
- High-resolution format is desirable for saving data. For Phantom3, RAW and JPEG (5 MB) are available.
- Photographing altitude changes with the size of the feature and the necessary accuracy. The approximate altitude for a watershed is 100 m and for a pond is 50 m.

Analyze the images by Photoscan and create DEM data and contour data

When calculating pond capacity, open the contour data using QGIS and measure each elevation area enclosed by a contour

iii. Calibration

Photoscan is used to plot a topographic map using aerial photographs. Before plotting a topographic map, camera lens distortion should be considered (calibration). Calibration can be performed in two ways.

a) Capture a photograph of a chess board design and modify the distortion from the photo (Agisoft Lens in Photoscan can be used to identify the distortion)
b) Self-calibration using aerial photographs

The accuracy of method “a” is better; therefore, if time is available, calibration should be performed by method “a”.

iv. Area calculation

Photoscan can be used to create digital elevation model (DEM) data and draw contours. However, the area enclosed by contours cannot be measured. For estimating the water capacity of a pond, the area per unit elevation enclosed by a contour should be known.

Therefore, contour data created by Photoscan is exported as a shape file, and the data (shape file) is opened using QGIS to analyze the enclosed area (polygon). The procedure is as follows.

- Export contour data (both polygon and polyline) which is created by Photoscan as a shape file
- Open the files using QGIS
- Modify the figures as some polygons (contours) created by Photoscan are not closed (partly open)
- Measure the area of each polygon

Refer to the following site for modifying figures.
http://docs.qgis.org/2.6/en/docs/training_manual/create_vector_data/topo_editing.html

v. Case study

- Topographic survey of a paddy field

The topographic survey of a paddy field in Nwogu village, Northern region, Ghana, was carried out. Photos were captured in dry season (hence, the vegetation is poor). If vegetation is present, the height of the plants is also reflected, and hence, the actual height cannot be determined.

Photos were taken with 2/3 overlapping. The points at which photographs were captured are shown in Fig.1.13; these points were at 50 m intervals.

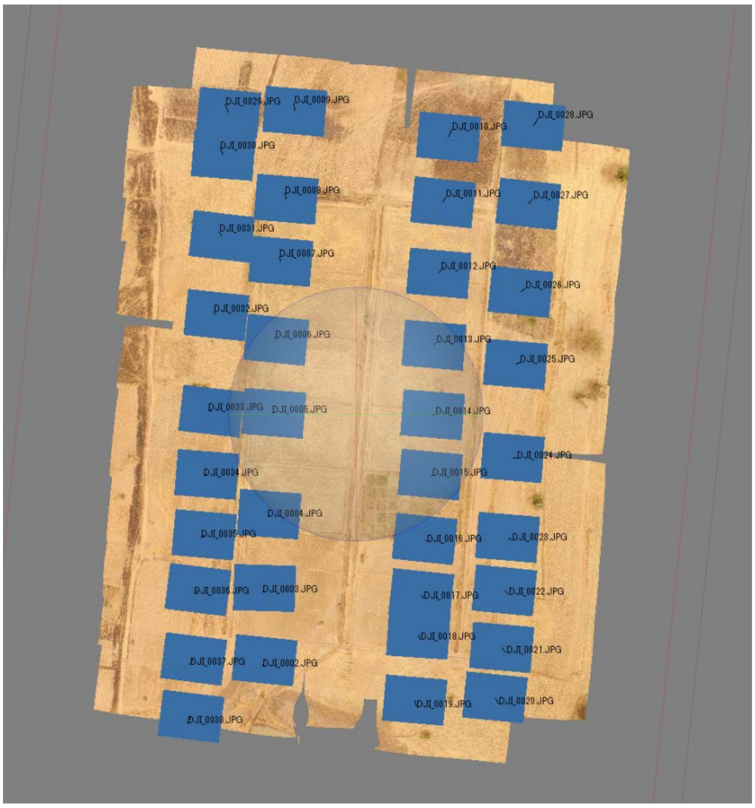


Fig.1.13 Photographic points for the field at Nwogu village

The topographic map plotted by using Photoscan is shown in Fig.1.14. The height accuracy is 10 to 15 cm.

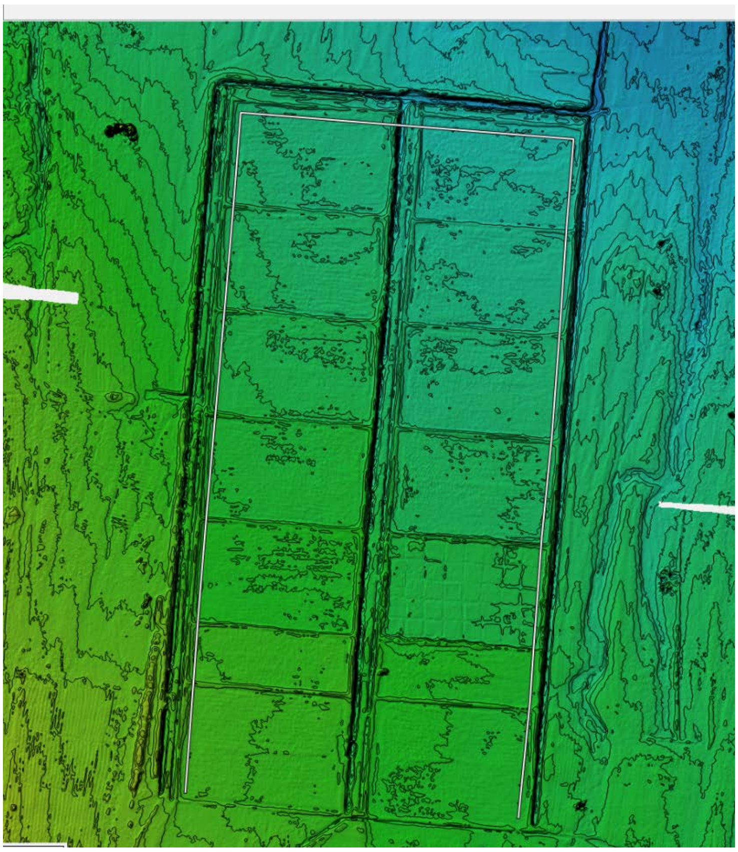


Fig.1.14 The topographic map of the field at Nwogu village

- Topographic survey of a dugout

An example of a topographic survey is shown below. The photographic points for a dugout is indicated in Fig. 1.15. A dugout can be surveyed if it does not contain water; else, if the dugout contains water, its depth should be surveyed.

The diameter of the sample dugout is about 100 m. Surveying this dugout using the survey instrument takes 4 hour. On the other hand, the drone can scan this area in 30 min.

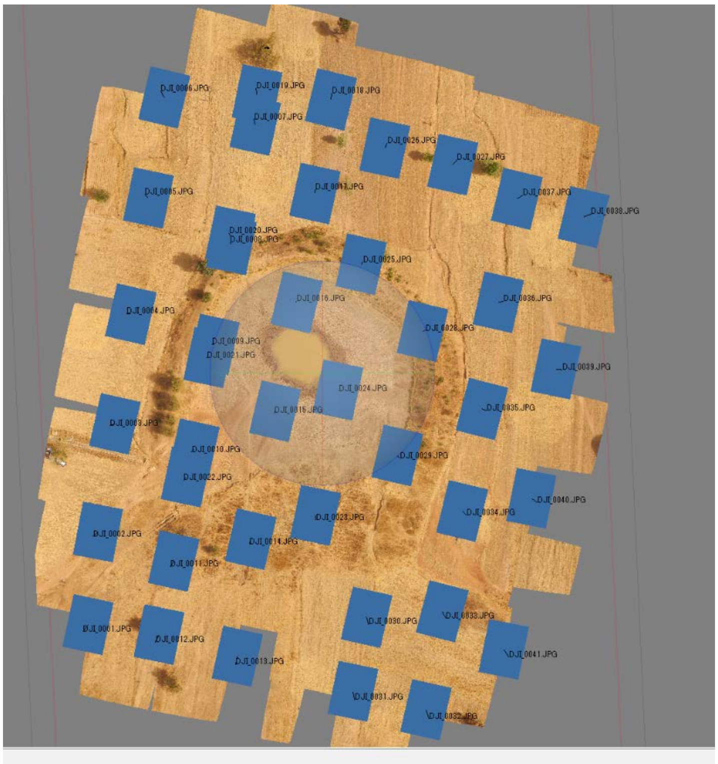


Fig.1.15 Photographic points for the Nwogudugout

A topographic map plotted by Photoscan is shown in Fig. 1.16. The accuracy of the capacity is ±20 %.

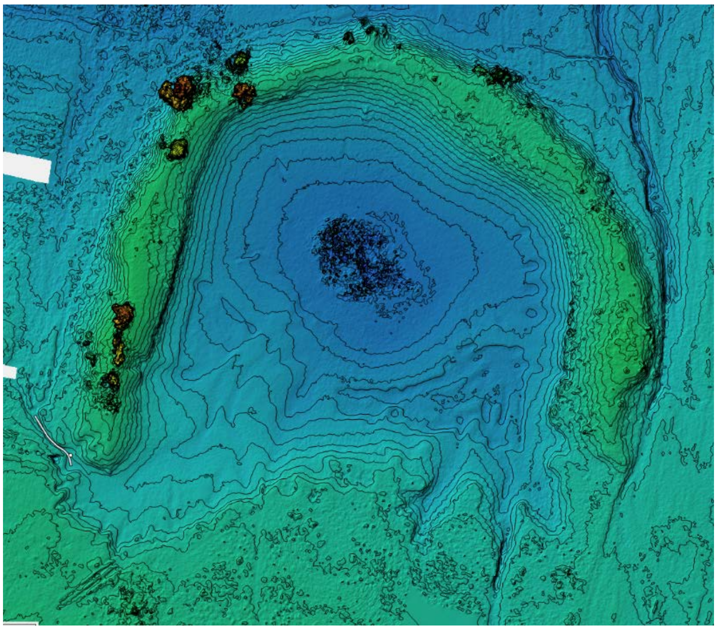


Fig.1.16 Topographic map of the Nwogu dugout

- Topographic survey of the watershed of a dugout

The result of the watershed survey is shown in Fig. 1.17. Because a watershed is much wider than a dugout, surveying a watershed takes more time. In this case, the time needed to survey the watershed was 6 person-day. In contrast, only one hour (1 h) is sufficient for the drone to scan the watershed, and the accuracy is ±10 %.

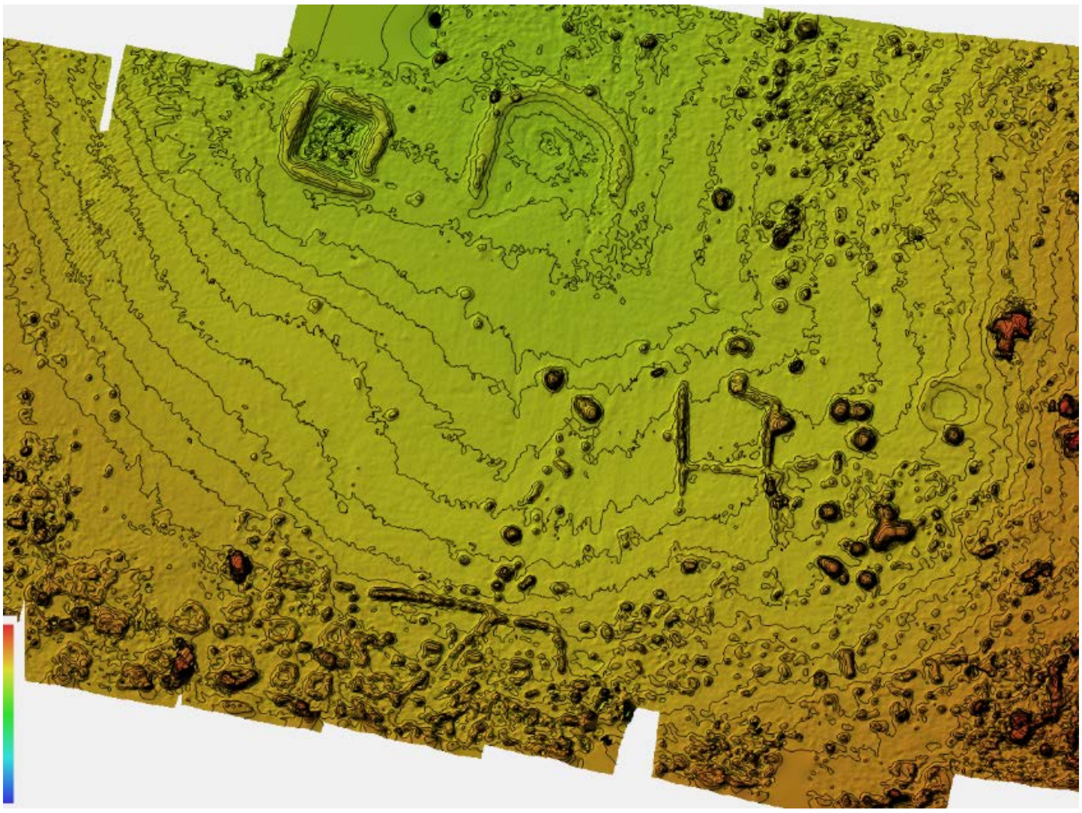


Fig.1.17 Topographic map for part of the Nwogu water

Chapter 2 Facility improvement for supplementary irrigation

2.1 Introduction

This manual proposes a facility improvement plan for generating additional water storage for irrigation. In the project, two methods were developed with focus on unutilized spillage water. The methods provide techniques to obtain new storage capacity. The outline of techniques is presented in Table 2.1.

Table 2.1 Outline and merits of the developed techniques

Facility	Outline and merit of technics
Pair Pond System (PPS)	PPS is the system to construct sub pond to store spilled water from dugout (main pond) and use the stored water for supplementary irrigation, where the water of dugout is mainly for domestic use and livestock watering. In terms of usage of the water, the system can avoid the conflict.
Increasing the volume of water in a reservoir by raising spillway level.	The facility is constructed with a sandbag filled with soil-cement mixture. Sandbag is used to form a dyke or an embankment. By using soil-cement mixture, the durability of the dyke is improved. It can be constructed by manpower with available local material in rural area.

2.2 Pair Pond System (PPS)

2.2.1 Outline of the PPS

PPS is the system to construct sub-ponds to store water spilled from the dugout (main pond) and to use the stored water for supplementary irrigation so that the water from the dugout is mainly for domestic use and livestock watering.

Water spilling from dugouts in the Northern region in Ghana flows downstream without being optimally utilized in the rainy season when the dugout fills with water.

Dugout water in northern Ghana has competing uses. However, using the spilled water for irrigation can help avoid this conflict. Thus, the sub-pond, which stores the water spilled from the dugout (main pond), is planned (Fig. 2.1).

The dugout (main pond) is classified as an on-stream reservoir, while

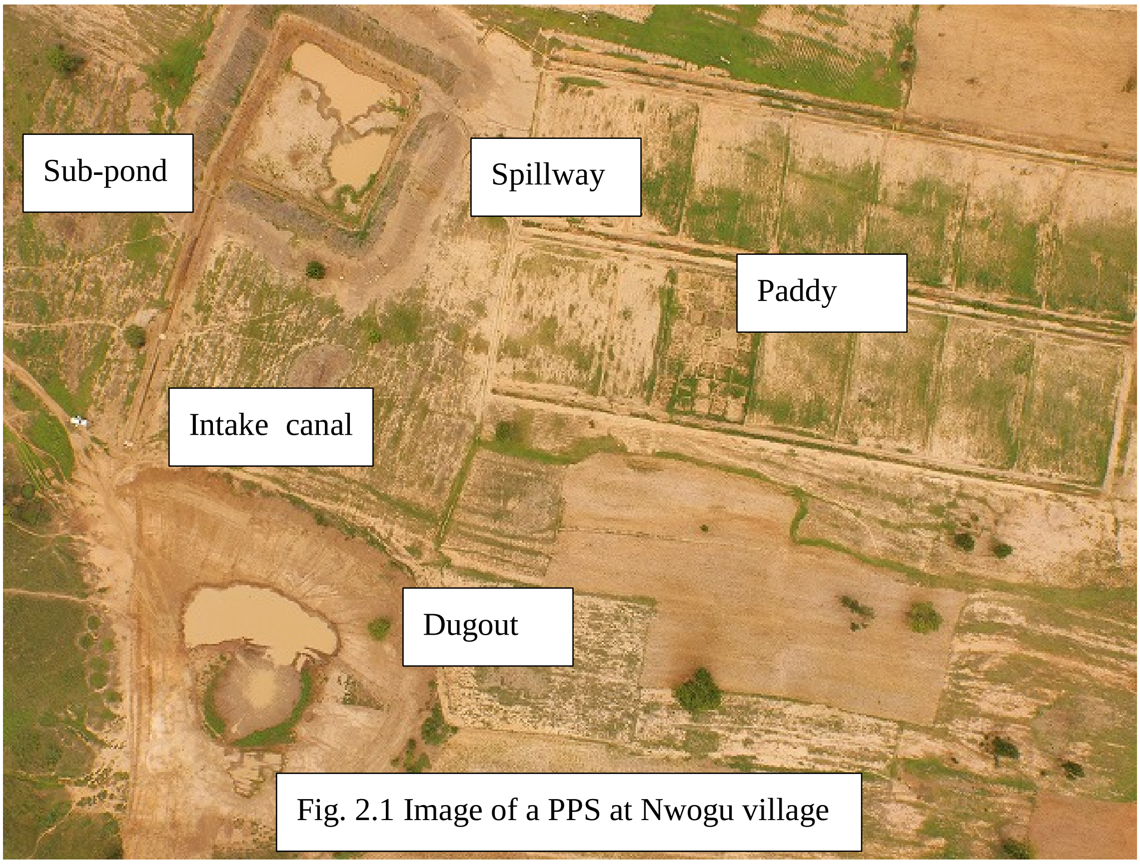


Fig. 2.1 Image of a PPS at Nwogu village

a sub-pond is classified as an off-stream storage.

Water from a sub-pond can be delivered to a paddy field by means of gravity or a pump, depending on the relative height.

2.2.2 Definition of dugout

The typical ground plan and cross section of the dugout are shown in Fig. 2.2. A dugout is defined as a structure that does not have an intake facility (Regassa et. al, 2011), and a canal is a simple structure dug into the ground by piling the soil downstream.

This manual explains how to use water spilled from a dugout efficiently for rice cultivation.

Difference between a dug pond (Fig. 2.3) and a dugout is explained as follows.

Dugout: Water spills from **the edge** of its embankment (spillway function is upstream).

Dug pond: Water spills **downstream** of its embankment.

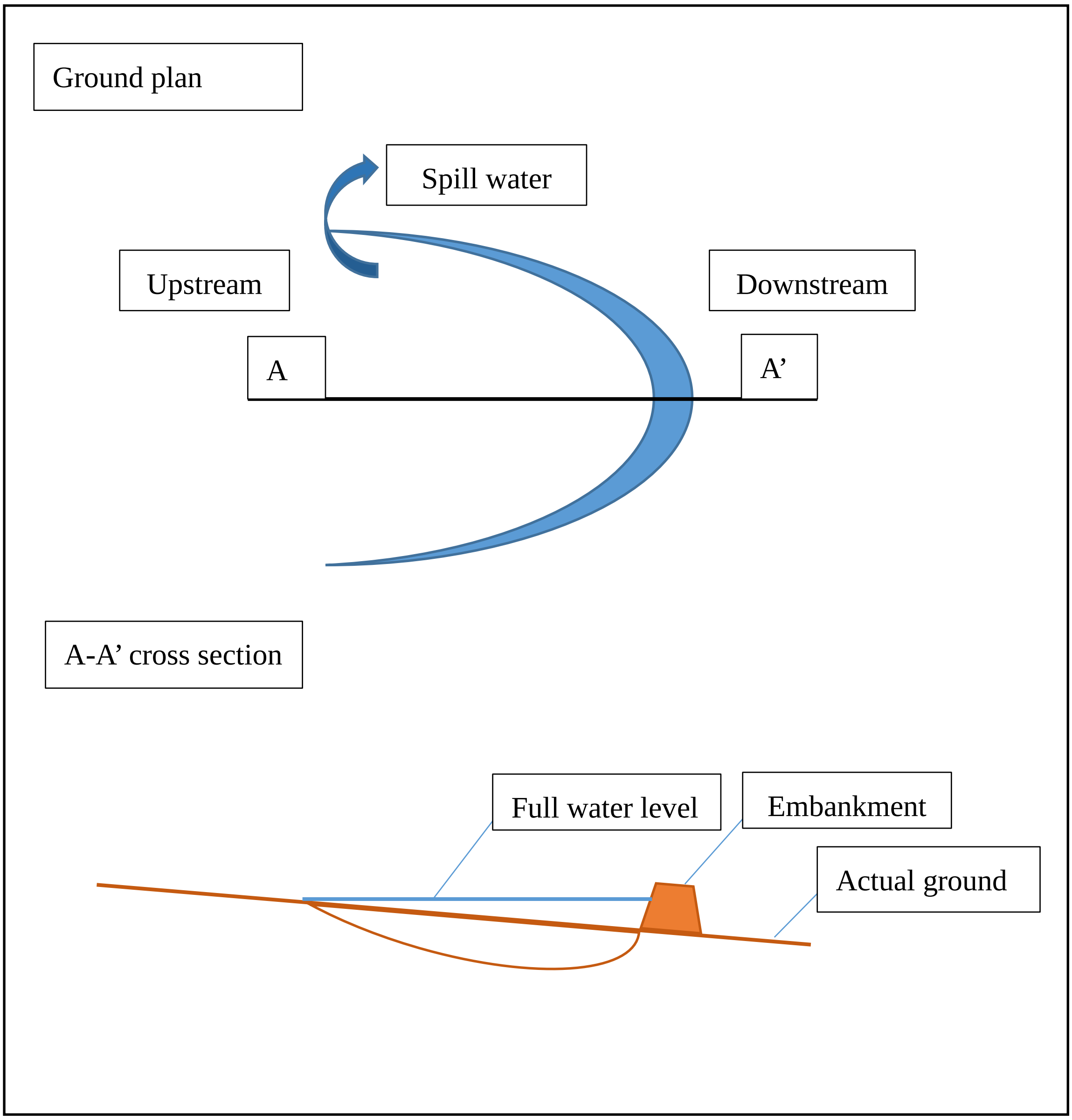


Fig. 2.2 Plan and cross section of a typical dugout

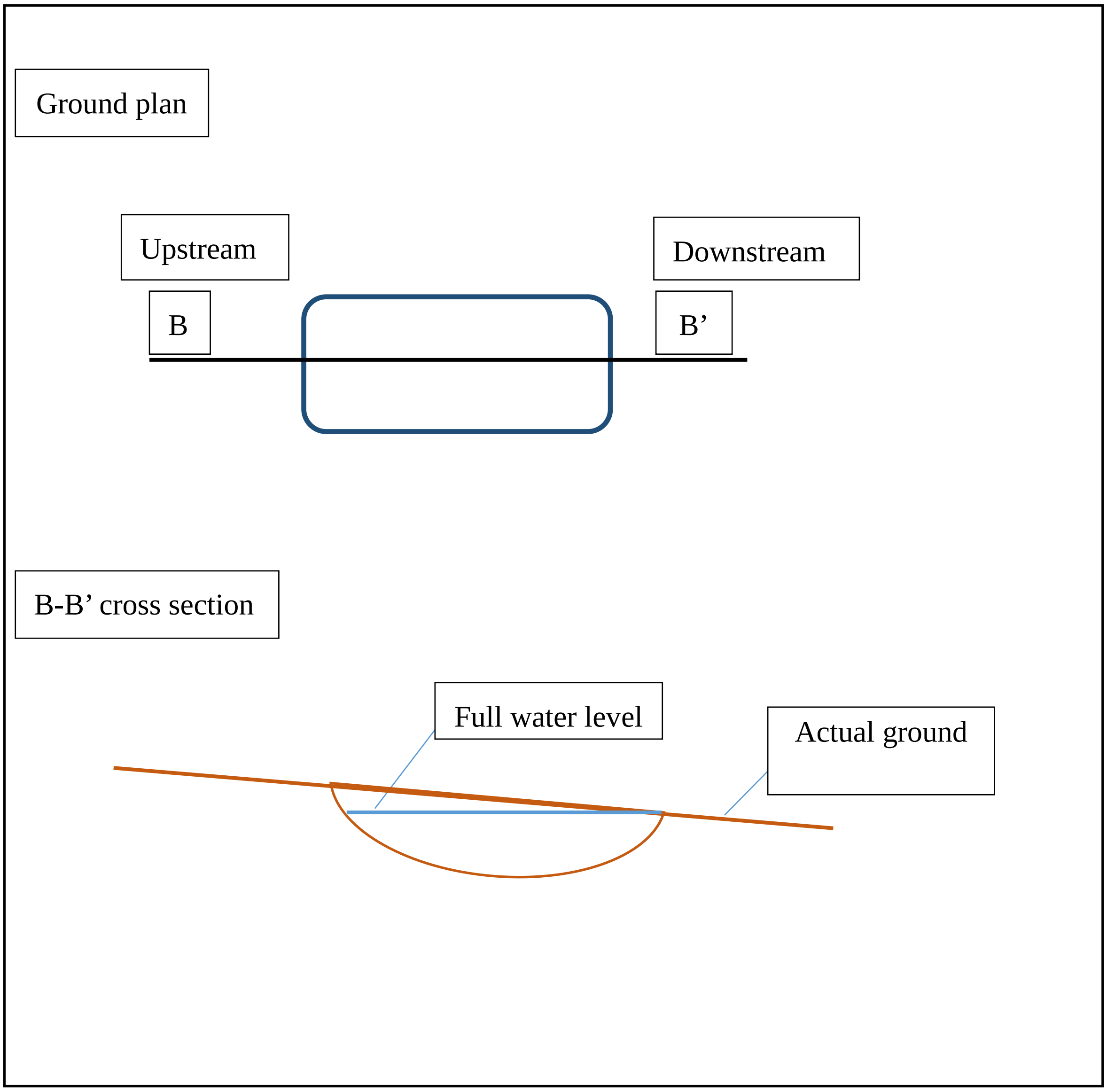


Fig. 2.3 Plan and cross section of a typical dug pond

2.2.3 Design of a sub-pond

i. Design flow

The capacity of a sub-pond can be determined by the following procedure:

- Determination of the reference year for design
- Calculation of water spilled from the dugout
- Determination of sub-pond capacity

The first and second bullets are described in Chapter 2 “Supplementary Irrigation.”

ii. Determination of sub-pond capacity and irrigable area

> The capacity of a sub-pond shall be determined considering the water remaining for the calculated daily irrigation volume using the water requirement per day, daily rainfall, and irrigable area.

The capacity of the sub-pond shall be calculated by the following procedure:

- Calculate the irrigation water per day using unit irrigation water volume, daily rainfall in irrigation period, and irrigable area per day
- Calculate next day’s water volume of the sub-pond by deducting the irrigation water from the sub-pond water volume of the day
- In the event of rainfall, add the direct rainfall amount in the sub-pond and the water spilled from the dugout to the sub-pond water volume
- Obtain the sub-pond capacity considering the water remaining during irrigation period, for example, by using a solver (MS Excel)

Sample Calculation

The volume of a sub-pond that satisfies the requirements for supplementary irrigation for 40 days and 2 ha from 1st September is considered.

The conditions are as follows:

Water requirement per day: 16.5 mm/d (15 mm/d × 1.1: actual measured value + 10 % margin), irrigation efficiency: 95 %, evaporation from pond surface: 6 mm/d, seepage: 8.6 × water depth (m) mm/d, irrigation interval: 7 days, and watershed of main pond: 44 ha.

The calculation starts under the following conditions:

- The main pond and sub-pond are filled with water on 1st September.
- The inflow to the main pond (by CN method) in the reference year (2000) by rainfall flows to the sub-pond. The capacity of the sub-pond that is sufficient for irrigating 2 ha is calculated. (Table 2.2 is an example of a sub-pond capacity of 5,000 m^3). Then, the capacity of 5,000 m^3 is sufficient for 2 ha (Fig. 2.4). The depth of the sub-pond is determined as 2.3 m (spillway depth: 20 cm, thickness of the seepage prevention work (refer to section 2.2.5): 10 cm).

Table 2.2 Daily irrigation water volume and sub-pond water volume during the supplementary irrigation period

	Water volume Sub-pond	rainfall	Water flow volume	Pond surface rainfall	decrease	Spill water	irrigation
	m^3	mm/day	m^3	m^3	m^3		m^3
August 25th		5.3					0
August 26th		0					0
August 27th		0.4					0
August 28th		0					0
August 29th		0					0
August 30th		13.2					0
August 31st		0					0
September 1st	5,000	0	0	0	628	0	571
September 2nd	4,372	0	0	0	650	0	597
September 3rd	3,723	0	0	0	645	0	597
September 4th	3,078	0	0	0	642	0	599
September 5th	2,437	10.6	0	27	35	0	0
September 6th	2,428	9.6	594	24	35	0	0
September 7th	3,011	27.8	1,286	70	40	0	0
September 8th	4,327	0	0	0	617	0	564
September 9th	3,711	0	0	0	473	0	425
September 10th	3,238	0.5	0	1	468	0	425
September 11th	2,772	9.4	558	24	465	0	425
September 12th	2,889	0	0	0	40	0	0
September 13th	2,849	0	0	0	40	0	0
September 14th	2,809	14.8	30	37	40	0	0
September 15th	2,836	32.5	2,087	81	656	0	616
September 16th	4,349	21.8	506	55	594	0	542
September 17th	4,315	14.4	20	36	432	0	379
September 18th	3,939	14.2	15	36	323	0	273
September 19th	3,668	19.1	260	48	48	0	0
September 20th	3,928	0.5	0	1	50	0	0
September 21st	3,879	0	0	0	48	0	0
September 22nd	3,831	6.5	146	16	200	0	153
September 23rd	3,793	0	0	0	363	0	315
September 24th	3,431	5.4	53	14	437	0	392
September 25th	3,061	1.1	0	3	506	0	464
September 26th	2,558	0	0	0	38	0	0
September 27th	2,520	26.9	1,151	67	38	0	0
September 28th	3,701	10.4	0	26	48	0	0
September 29th	3,680	5.7	74	14	513	0	466
September 30th	3,255	25	885	63	489	0	446
October 1st	3,714	0.2	0	1	465	0	418
October 2nd	3,250	0	0	0	362	0	320
October 3rd	2,888	0	0	0	40	0	0
October 4th	2,848	0	0	0	40	0	0
October 5th	2,808	0	0	0	40	0	0
October 6th	2,768	5.3	47	13	551	0	511
October 7th	2,277	0.5	0	1	574	0	539
October 8th	1,705	0	0	0	668	0	638
October 9th	1,037	0.2	0	1	661	0	636
October 10th	377	24.3	795	61	18	0	0

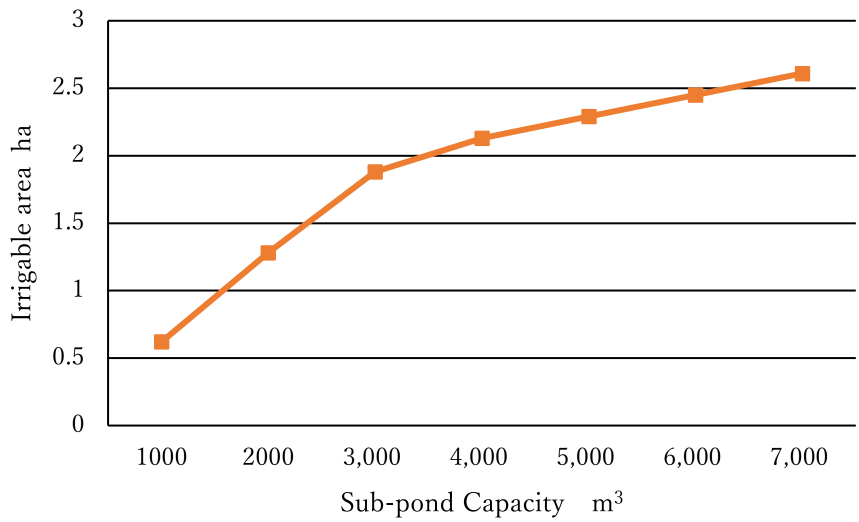


Fig. 2.4 Relationship between the irrigable area and sub-pond capacity

iii. Location of the ponds

- Location of the main pond (dugout)

The PPS needs an existing main pond (dugout). Many dugouts are located at the bottom of a gradual valley topography. Thus, the dugout is lowest in the right angle cross section in the direction of the valley (Fig. 2.5).

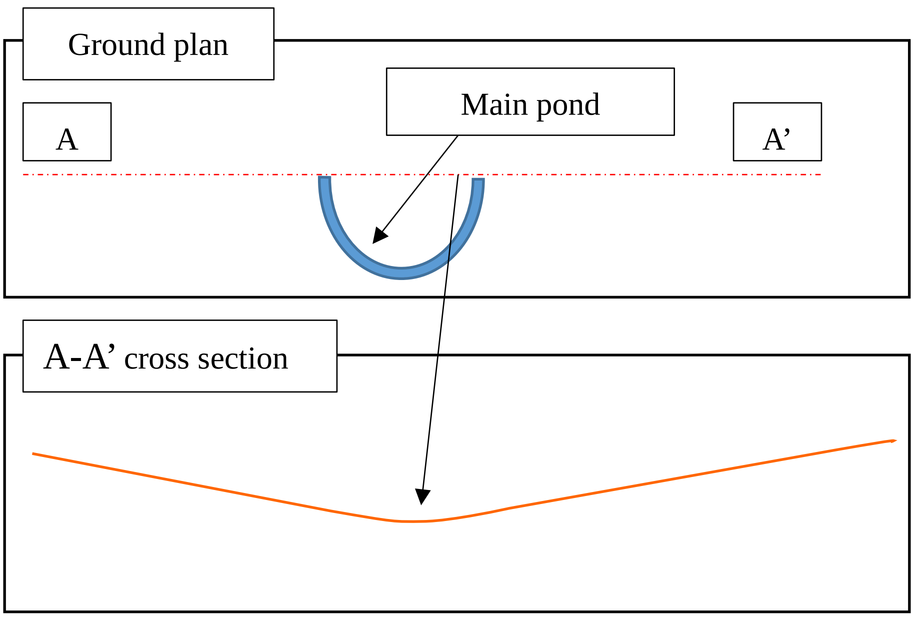


Fig. 2.5 Cross section of the area surrounding the main pond

- Location of the sub-pond
  The sub-pond shall be designed for an economically advantageous site, considering the location of main pond and the following points.
- The sub-pond collects water spilled from the main pond by gravity.
  Therefore, the full water elevation of the sub-pond shall be lower than the spillway elevation of the main pond.
- The main canal is longer when the sub-pond is in the downstream direction (Fig. 2.6).
- The excavated volume increases when a sub-pond is located downstream (Fig. 2.6).

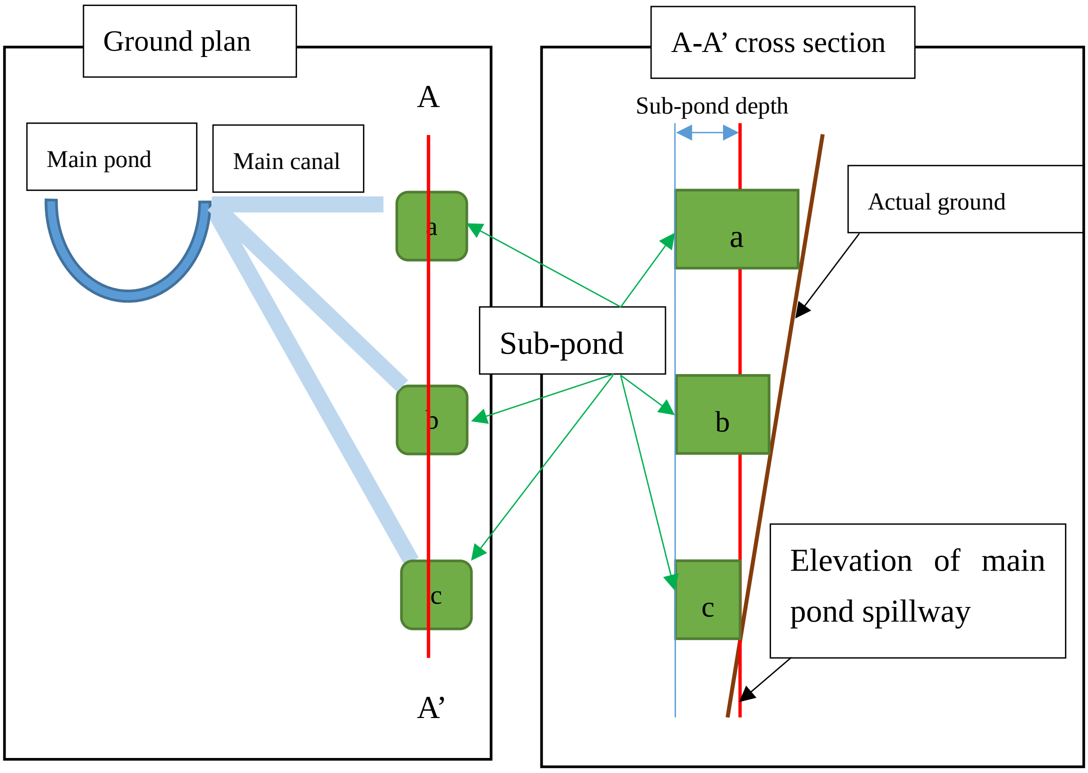


Fig. 2.6 Relative positions of the main pond and sub-pond

iv. Full water elevation of sub-pond

Ideally, the full-water elevation of a sub-pond shall be lower than the spillway elevation of the main pond.

Moreover, it is desirable that the full water level of a sub-pond is lower than the lowest point of the main canal bottom, so that sediment does not accumulate in the main canal (Fig. 2.7).

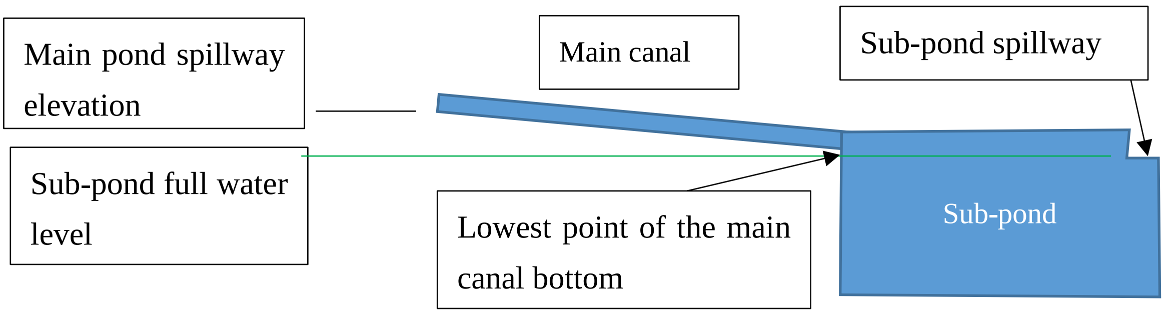


Fig. 2.7 Schematic diagram of sub-pond elevation

v. Spillway

The cross-sectional area of the spillway should be sufficiently large to enable the spilled water to flow down during maximum rainfall. The lower (deeper) the elevation of the spillway, the less will be the water storage volume. Therefore, the cross section of a spillway should be wide and shallow.

Example:

The maximum rainfall in an hour in 2014 was 81 mm. When CN is 72, the inflow is calculated as approximately 2.86 m^3/s. When the height (depth) of the spill way is 20 cm, the gradient is 2 %, and roughness coefficient is 0.015, a canal width of 4.6 m is for the water volume to flow.

2.2.4 Design of the main canal

i. Design of the main canal

The cross-sectional area shall be sufficiently large for preventing spilled water from the main pond from overflowing.
The gradient shall be determined by considering the relative heights of the main pond, sub-pond, and paddy field.

- Cross section

The cross-sectional area of the main canal shall be the area across which the maximum water spilled from the main pond can flow.

Water flow volume is calculated by the Manning formula (2-1).

$$Q = n^{-1} I^{1/2} R^{2/3} \times A \qquad (2\text{-}1)$$

where

Q is the water flow volume (m^3/s)

n is the roughness coefficient

I is the hydraulic gradient

R is the hydraulic mean depth

Water flow volume is determined by the gradient and water flow area.

A trapezoidal section is preferable for the canal cross section as it gives a lower earthwork volume during construction.

The canal gradient is determined based on the locations of the main pond, sub-pond, and paddy field. The larger the gradient, the smaller is the water flow area for the same water flow volume. However, if the gradient between the main pond and sub-pond is large, the relative height difference between the sub-pond and paddy field is small.

The roughness coefficient, hydraulic gradient, and hydraulic mean depth can be determined as explained below.

- Roughness coefficient

The roughness coefficient can be selected from following conditions depending on the canal structure as indicated in Table 2.3.

Table 2.3 Roughness coefficients depending on the canal conditions

	Roughness coefficient		
	Minimum	Standard	Maximum
Unlined canal, straight	0.016	0.018	0.020
Concrete	0.012	0.015	0.016
Mortar	0.011	0.013	0.015

Source: Canal work; Japanese Standard of Agricultural Civil Engineering (MAFF Japan, 2013)

- Hydraulic gradient

The hydraulic gradient is the same as the water surface gradient, and usually the water surface gradient is considered the same as the canal bed gradient.

- Hydraulic mean depth

The hydraulic mean depth is calculated using the trapezoidal cross section shown in Fig. 2.8. Hydraulic mean depth is calculated by (2-2).

Hydraulic mean depth = A / S (2-2)

where

A is cross-sectional area of flow and is calculated by (2-3).

$A = (BT+BB) \times h/2$ (i.e. in the case of a trapezoid) (2-3)

S is Wetted perimeter and is the cross-sectional perimeter when water is in contact with the canal and is calculated by (2-4).

$S = L1 + L2 + BB$ (2-4)

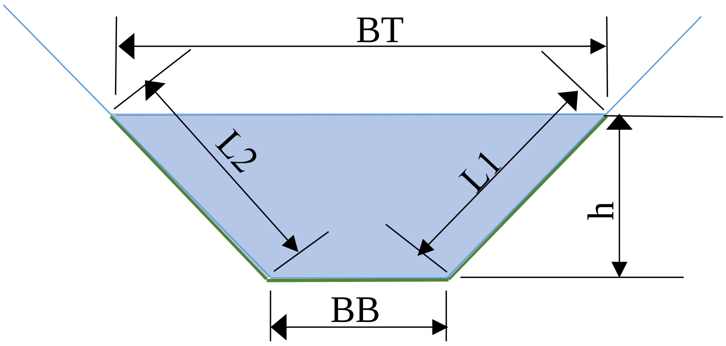


Fig. 2.8 Cross section of a trapezoidal canal

Sample Calculation for a canal with bottom width 1 m, depth 1 m, upper width 2 m, free board 0.2 m, roughness coefficient 0.02, and canal gradient 1 %, the maximum water flow can be calculated as follows:

Table 2.4 Maximum capacity of the main canal

item		value	unit
Canal upper width		2.0	m
Canal surface water length	*BT*	1.8	m
Canal bottom width	*BB*	1.0	m
Canal depth	*h*	1.0	m
Free board	*f*	0.2	m
Depth	*d*	0.8	m
Gradient	*i*	0.01	
Roughness coefficient	*n*	0.02	$m^{-1/3}s$
Area of flow	*A*	1.12	m^2
Wetted perimeter	*s*	2.39	m
Hydraulic mean depth	*R*	0.47	m
Average velocity	*U*	3.02	m/s
Maximum water flow	*q*	3.38.0	m^3/s

When the area of the watershed is 44 ha, and all the inflow to the main pond flow into the main canal, the water flow is $3.38m^3/s$ and this is the same as 87 mm/h rainfall.

Reference: the maximum per hour rainfall in 2014 was 81 mm.

The main canal direction is designed to secure 1 % canal gradient.

ii. Structure of the main canal

Canal slope: stable slope or concrete lining
Canal shoulder: mortar lining + sandbag
Canal back: drainage pipe from back to forward

- Slope protection

Water enters the main canal rapidly during heavy rain. Hence, the canal slope should be protected by using mortar or concrete so that the canal is not eroded by water flow. If concrete lining is used, the back of the structure shall be refilled and compacted well so that surface water does not erode the back.

- Concrete mix proportion

The design strength of a gravity-type retaining wall (18 N/cm^2) is applied for the concrete lining. The water cement ratio (W/C) is 60 %; the specific gravity of the fine aggregate (sand) is 2.6; that of coarse aggregate (gravel) is 2.6, that of normal Portland cement is 3.15. Mixed proportions per 1 m^3 are as follows (Table 2.5):

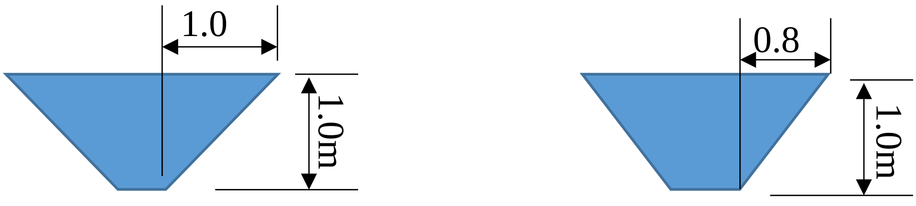
Table 2.5 Concrete mix proportions

Water (kg)	Cement (kg)	Sand (kg)	Gravel (kg)
170	283	792	1,140
30	50 (1 bag)	140	201

iii. Canal slope gradient

A Slope should be stable. Thus, slope gradient shall be determined considering the earth pressure acting on the slope. If slope stability is not calculated, the canal slope gradient is 1:1 to 1:0.8 (see Fig. 2.9; Japanese road construction standard, Fig. 2.15 for good example).

If the slope is steep (Fig. 2.14), the canal may collapse (Fig. 2.12).



Slope gradient 1:1 (depth 1 m)	Slope gradient 1:0.8 (depth 1 m)

Fig. 2.9 Canal slope gradient and canal cross section

iv. Protection of the top of the canal

In the event of heavy (high intensity) rain, surface water may directly enter the canal. In such a case, the top of the canal may be breached, and water may invade the back of concrete lining; consequently, the slope may collapse (Fig. 2.12).

Hence, sandbags should be piled, and the top of the slope should be protected using mortar so that the water cannot directly enter the canal (width: >50 cm, thickness: >5 cm; Fig. 2.10 and 2.11).

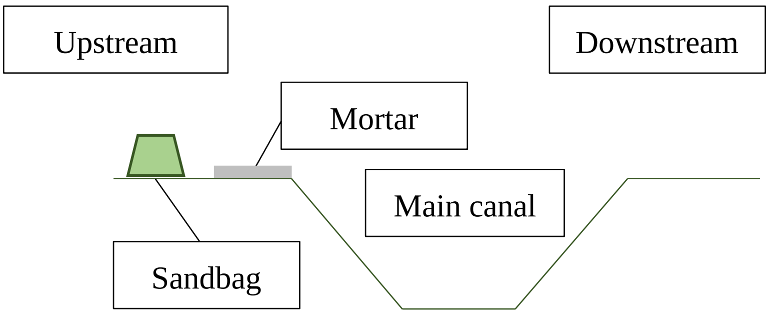


Fig. 2.10 Standard cross section of protection of the top of the canal

Fig. 2.11 Construction example

Fig. 2.12 Example of canal collapse

Fig. 2.13 Main canal construction

Fig. 2.14 Completed main canal
（the canal slope is too steep）

Fig. 2.15 Good example
(the canal slope is gentle)

v. Drainpipe

If the water level of the canal back is high, the slope of the canal may collapse. For preventing this, a water drainpipe (PVC pipe) should be installed when the slope is lined.

Drainpipes shall be installed at area of every 3 m^2, and they should have an inner diameter >7.5 cm, (the drainage pipe of the retaining wall; the standard of MLIT Japan). The pipe shall be installed simultaneously with slope lining.

The pipe shall be installed at a lower level than the canal slope, because the pipe should drain the ground water (Fig. 2.16).

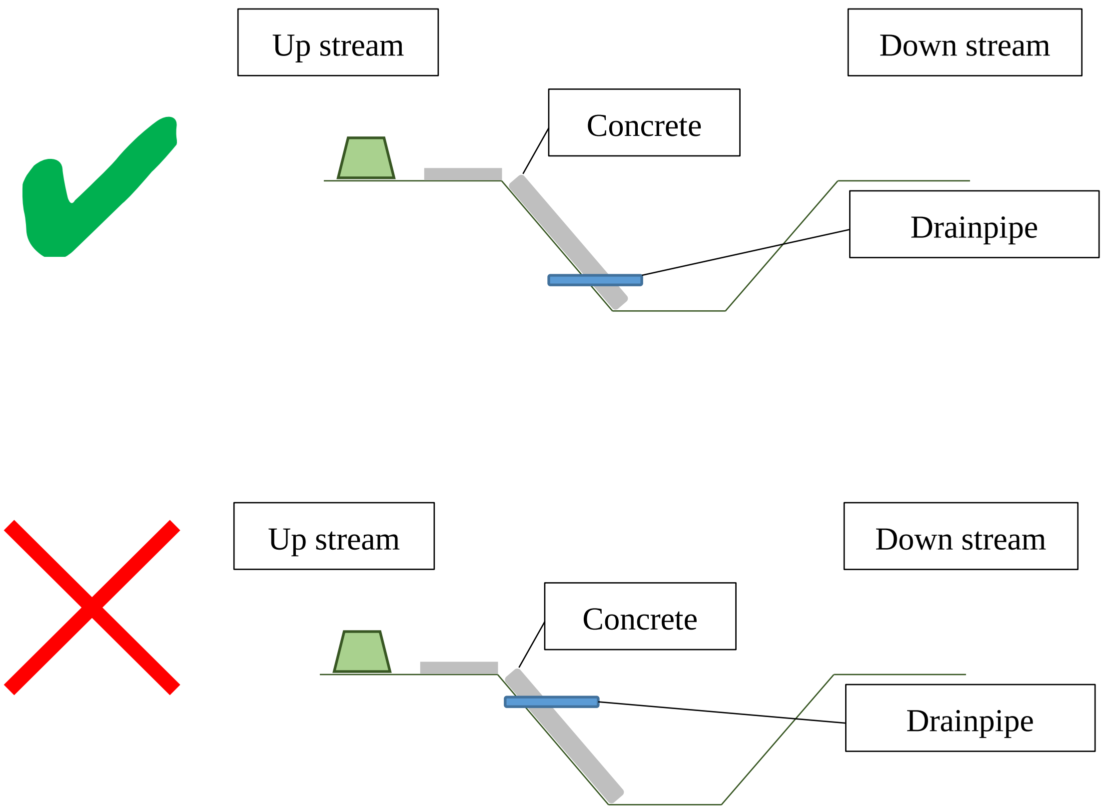


Fig. 2.16 Standard cross section of the drainpipe work

2.2.5 Construction case of a sub-pond

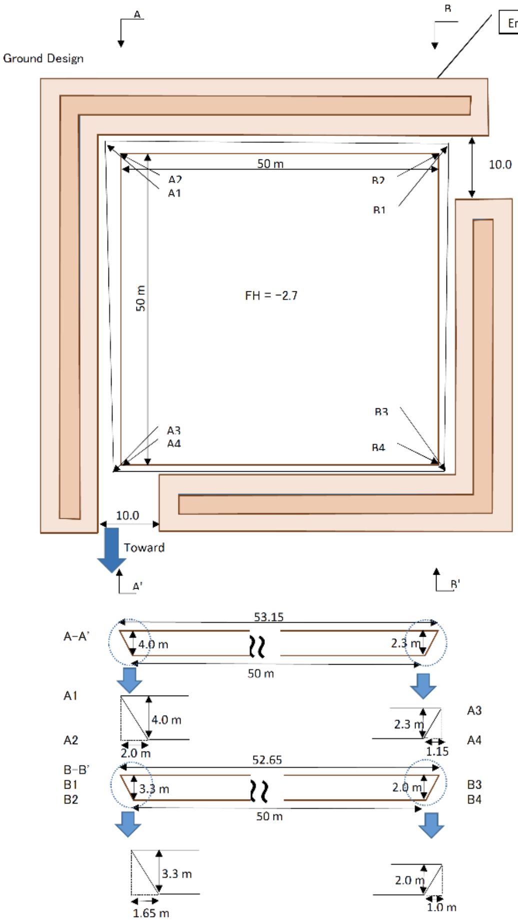
Fig. 2.17 Sub-pond construction

Fig. 2.18 Completed sub-pond

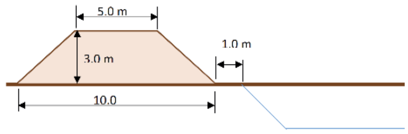
Case of sub-pond construction

Field survey (ordinate, abscissa, and elevation) was conducted at a sub-pond construction site. Based on the survey results, a sub-pond design was made. The maximum height differential in the current ground level at the site is 1 m, and 3m excavation is needed to secure a depth of 2 m for the sub-pond. Further, the volume of soil excavated is 7,500 m^3.

Based on this design, the estimated cost of approximately US$ 20,000 was provided by the local contractor. Construction was implemented in the dry season (Fig.2.17, 18, 19).

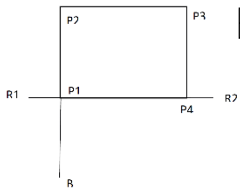


Detail of the Embankment



Point	FH	Point	FH
A1	1.06	B1	-0.27
A2	-2.7	B2	-2.7
A3	0.48	B3	-0.69
A4	-2.7	B4	-2.7

Pegs Information



Distance

P1 - R1	10.00	m
P4 - R2	10.19	m

	GL	Peg Head	GL	GL	Peg Head
BM	0				
P1	0.476	0.896	R1	0.361	0.811
P2	1.064	1.514			
P3	-0.269	0.241			
P4	-0.69	-0.28	R2	-0.981	-0.571

Fig. 2.19 Sub-pond standard scheme

2.2.6 Sub-pond incidental facilities

i. Seepage prevention

As water may seep from the bottom of the sub-pond in the initial period, seepage prevention work should be implemented using mud of the main

- Outline

Generally, the ground permeability of the designed sub-pond location is good because water generally does not gather in the sub-pond in the rainy season.

Therefore, the seepage of the sub-pond may be high, and some measures against seepage are necessary.

The mud in the main pond (dugout) was conveyed from the watershed by rain and accumulated in the sub-pond (Fig. 2.21). The mud particles were very fine, and the coefficient of permeability was low. Therefore, laying this low-permeability mud on the bottom of a sub-pond can prevent seepage from the bottom of the sub-pond. Moreover, the capacity of the main pond increases if mud is collected from the main pond.

The coefficient of permeability is calculated by using formula (2-5) (the permeability is determined by the falling head permeability test)

$$k = 2.303 \frac{L}{86400} \log_{10} \frac{h_1}{h_2} \quad (2\text{-}5)$$

Where

h_1 [cm] is water depth

L [cm] is pond bottom mud thickness

k [cm/s] is permeability coefficient of the main pond mud

h_2[cm] is water depth of next after

When the coefficient of permeability is constant, the seepage volume (h_2 - h_1) is a function of water depth, h_1 and thickness L.

When the permeability of the mud at the bottom of the pond is assumed to be good, and the water that infiltrates through the mud is assumed to infiltrate downward immediately, the relation between water depth and seepage volume is presented in Table 2.6 (when the coefficient of permeability of the main pond mud is assumed as 1×10^{-6} cm/s). For example, the seepage volume is 17 mm/d for a thickness of 10 cm (34 mm/d at 5 cm).

Table 2.6 Volume of seepage (mm/d) depending on water depth, and the coefficient of permeability is set as 1×10^{-6} cm/s

Water depth (cm)	Mud Layer thickness (cm)				
	5	10	20	50	100
20	3.4	1.7	0.9	0.3	0.2
40	6.9	3.4	1.7	0.7	0.3
60	10.3	5.2	2.6	1.0	0.5
80	13.7	6.9	3.4	1.4	0.7
100	17.1	8.6	4.3	1.7	0.9
120	20.6	10.3	5.2	2.1	1.0
140	24.0	12.0	6.0	2.4	1.2
160	27.4	13.8	6.9	2.8	1.4
180	30.8	15.5	7.8	3.1	1.6
200	34.3	17.2	8.6	3.5	1.7

Fig.2.20 Sub-pond condition

Fig.2.21 Mud laying in the sub-pond

- Determination of thickness of the mud layer

The greater the thickness, the less the seepage. However, the capacity also decreases and the construction cost increases as the thickness increases.

Thus, thickness should be decided by considering the balance among seepage volume, irrigable area, and construction cost.

Sample Calculation

A calculation example for the reference year (2000) is as follows.

Dimension of the sub-pond: 50 m ×50 m × 2 m

Irrigation efficiency, 95 %; water requirement per day, 16.5 mm/d; irrigation interval, 7 days

Effective storage capacity of the sub-pond

= 50 m × 50 m × (2 m - free board (20 cm) - thickness)

Table 2.7 Irrigable area depending on thickness

Thickness	5 cm	10 cm	20 cm	30 cm
Irrigable area	2.01 ha	2.16 ha	2.22 ha	2.19 ha

Table 2.7 indicates there are few differences in irrigable area for mud layers 5 to 30 cm thick (0.21 ha; differential of 5 cm and 20 cm). Further, 125 m^3 of sediments (the construction cost is 1,250 GHS = US$ 330) is needed for realizing a thickness of 5 cm; however, the cost is quadrupled if 20 cm thickness is to be realized.

Incremental benefit (with and without irrigation) per hectare is 2,000 GHS (US$ 530). Although a thickness of 5 cm has an economical advantage, a layer of this thickness maybe uneven (especially, if farmers are involved in the work), and seepage may occur from the defects in the construction. Hence, the thickness should be more than 10 cm.

ii. Countermeasure against erosion of the top of the slope

Top of the slope of the sub-pond should be protected by Vetiver grass (*Chrysopogon nigratana*).

The top of the cut slope of the sub-pond can easily collapse by rainfall erosion. Thus, slope protection is indispensable. Protection measures for the top of the slope can be done by selecting materials available as follows:

- Plant grasses (e.g. vetiver)
- Construct catch drains along the top of the slope and prevent surface water intrusion
- Lay thatch materials on the top of the slope

Construction example (Vetiver grass planting)

Vetiver grass (Fig. 2.22; *Chrysopogon nigratana*), which is used as a measure against erosion, is introduced for slope protection. Planting is implemented at 50-cm intervals. Water is sprinkled until the grass takes root.

The price of the grass is 60 GHS (US$ 15) / bag (60 kg). One bag provides sufficient grass for planting between 60 m to 80 m length (50-cm interval; Fig. 2.23).

Fig. 2.22 The planted Vetiver bundle

Fig. 2.23 Vetiver planting intervals

- Disposal of excavated soil and fill-slope protection

a) Disposal of excavated soil

If the excavated soil has no use, it is piled in the area surrounding the sub-pond.

Soil is excavated when a sub-pond is constructed. If the excavated soil can be used for filling depressions, road embankment, etc. it can be effectively used. However, if this is not possible, to minimize the transportation cost of the soil, the soil is piled in the area surrounding a sub-pond.

If the soil has any other use, some of it is piled upstream of the sub-pond, so that surface water cannot directly flow in (height: approx. 50 cm).

If the soil is piled, every 50 cm layer has to be compacted, for example, by using a bulldozer after sprinkling water so that fill subsidence is minimized.

b) Fill slope protection

A fill slope has to be protected (covered) by thatch material, etc.

Because the sub-pond is constructed during the dry season, there is very little water for compaction. In addition, rainfall that occurs after piling may severely erode the fill slope. Thus, for preventing the fill slope from being eroded by rainfall or water flow, the slope should be physically covered.

Concrete slope protection measures are as follows:
a) Protect using thatch materials
b) Lay stones on a slope
c) Apply mortar on a slope
d) Broadcast grass seed on a slope

When selecting the grass seed, note that the slope will be eroded by rainfall if the soil moisture is inadequate, and grass cannot cover a slope before the rainy season begins.

Case Study (protection by thatch materials)

Grass (e.g. thatch (*Andropogan spp*) materials) which are utilized for roofing houses in the Northern region in Ghana can be introduced for covering the slope. Some inhabitants of Northern region usually use roof material 1.5 m wide and 16 m long. Because the slope is approximately 5 m long, a roof with half the length of the standard roof is prepared (4.5 GHS/sheet = US$ 1.2; Feb 2015). Fig. 2.24 illustrates how the thatch material was laid on the slope of the sub pond.

Fig. 2.24 Slope protection by thatch material

Effect of slope protection by thatch materials

Difference in the covering ratio with and without thatch materials is shown in Table 2.8 (analyzed by ImageJ*). As a result, the covering ratio with the thatch material is double as shown in Fig. 2.25 and 2,26.

* http://imagej.net/Welcome

Table 2.8 Covering ratio depending on slope treatment

Place	Covering ratio	Place	Covering ratio
Inner slope with thatch material South and east sides	50.8%	Outer slope with thatch material South and east sides	19.4%
Inner slope with thatch material North and West side	58.9%	Outer slope with thatch material North and West side	29.2%
Arithmetic average	54.9%	Arithmetic average	24.3%

Inner slope covered with thatch material

Outer slope not covered with thatch material

Fig. 2.25 Comparison of the effect achieved with and without thatch material

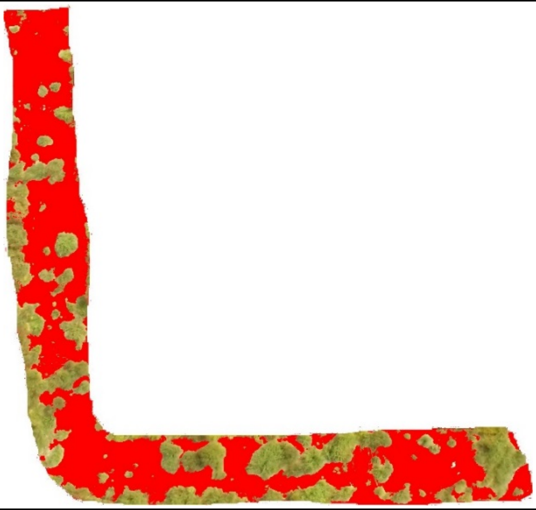
	
Inner slope: South and east sides	Result of ImageJ analysis
	
Outer slope: South and east sides	Result of ImageJ analysis

Fig. 2.26 Comparison of the effects achieved with and without thatch material (analyzed by ImageJ)

Reference

Regassa, E.N., Leaf, H., Ben, N., Boubacar, B. : Irrigation Development in Ghana: Past experiences, emerging opportunities, ans future directions, GSSP Working Paper No.0026, 17p.(2011)

Canal work; Japanese Standard of Agricultural Civil Engineering, MAFF Japan, 2013

The drainage pipes of the retaining wall; the standard of MLIT, 2012

Japanese road construction standard, MILT, 2014

2.3 Raising the level of spillway with sandbag containing soil-cement mixture

To increase storage capacity of dugout, desilting, extending of embankment and raising the level of spillway are the choices. Desilting and extension of the embankment are implemented with construction machinery generally. On the other hand, raising the level of the spillway concrete structure is generally constructed manually and it requires certain level of skill such as setting up the form for concrete.

In this chapter, level raising construction technics by using sandbag containing soil-cement mixture is described as easier implementation by farmers.

	
Concrete structure （Jamoni village in Saboba district）	Sandbag containg soil-cement mixture structure （Sanga village in Sagnerigu district）

Fig. 2.27 Spillway control structures (in Northern region)

In Northern Ghana, sandbags are utilized frequently as material for repairing bunds and small structures in the field in rural areas. However, sandbag are not durable. As the countermeasure to improve the durability of sandbag, soil-cement mixture is useful.

This chapter explains the method of raising the level of spillway structures using sandbags containing soil-cement mixture as illustrated in F

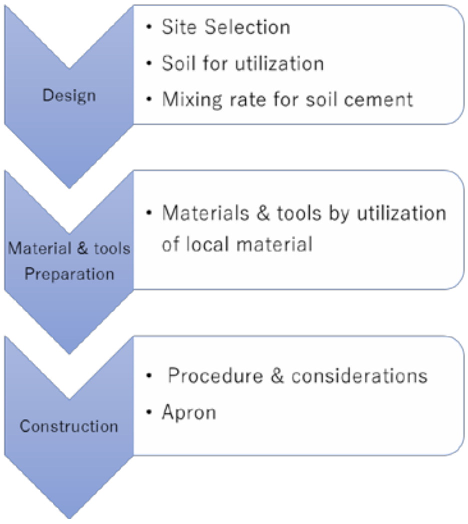


Fig. 2.28 Implementation flow

2.3.1 Spillway Design

i. Selection of construction point

Construction point shall have enough cross-sectional flow area and minimized volume of stacking sandbag

Using the case of Sanga dugout, the procedure for spillway design is described here.

Sanga dugout has about 887 ha catchment area. In case of CN is 72 and R is 36.8 mm/day, Q is 2.51 mm (refer 1.3.5 setting CN) and discharge volume is 22,248 m^3. Spillway should have the capacity to flow down such volume.

A spillway and its downstream pass of existing dugout, ground height and width shall be surveyed to calculate cross-sectional flow area. Then a point that has minimum volume of sandbag stacking and excavation shall be found. Generally, such points exist at the highest ground level of downstream of spillway.

Construction point selection

Dugouts have spillway at both edges or one edge of the embankment. In the case of Sanga village dugout, ground height (GH) of point A at the right bank, B, C & D at the left bank were measured (Fig. 2.29, Table 2.9). The results show that the left bank ground level is lower than that of the right bank and point D is the highest ground level on the flow pass of the spillway. Consequently, D is selected as construction point.

Fig. 2.29 Measured points at Sanga village dugout

Table 2.9 Relative GH

Point	Relative GH (m)
A	0
B	-1.72
C	-1.20
D	-1.16

At point D ground height difference between the left bank and bottom of the flow is 70 cm. Considering this situation, sandbag stacking height and the overflow depth are planned in 3 layers of 30 cm with a free board of 40 cm. Cross sectional area of flow is changed from 4.29 m^2 to 5.52 m^2 by excavating both sides embankment to avoid its reduction by sandbag stacking.

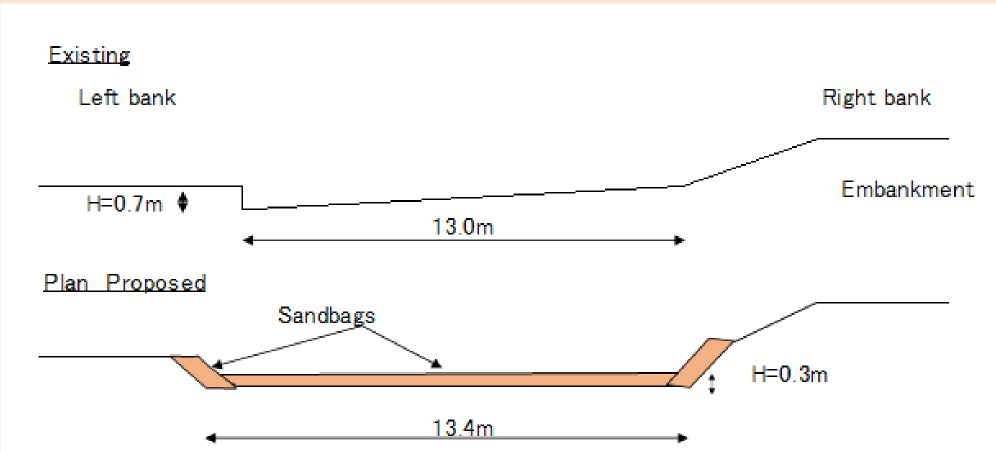


Fig. 2.30 Cross section of construction point

ii. Stacking sandbags

Example of sandbag stacking is shown in Fig. 2.31. Bottom of sandbags are set upstream where water flows directly. For downstream side, inclined stacking is introduced to improve resistance of the sandbags downstream against the force of the water. The space between upstream and downstream sandbags is filled with soil-cement mixture to stop seepage and to ensure resistance to erosion. At upstream side a trench is set with impermeable material to prevent seepage destruction also. After setting one layer of sandbag, soil-cement mixture is filled into spaces between the upstream and downstream and compacted.

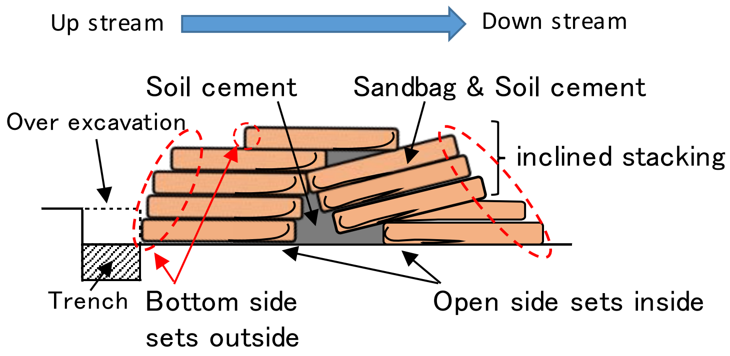


Fig. 2.31 Cross section of stacking sandbags

iii. Ratio for soil-cement mixture

The mixture ratio of soil, cement and water for the soil-cement, is defined by target strength.

- Target strength

> The target strength of 3 N/mm^2 is recommended.

Soil-cement mixture shall be resistant to water erosion. Uniaxial compression strength (UCS) is set at a minimum level of 3 N/mm^2 . (Sabo & Landslide Technical Center, 2011).

- Soil

> The soil for soil-cement requires less than 10 % of clay and silt, and also less than 55 % of sand, silt and clay.

What constitutes the clay and silt in the soil-cement must have particle sizes less than 0.0075 mm and the sand less than 2 mm.

Table 2.10 Composition of soil in soil cement

Material	Size of Material (mm)	% Soil
Sand, silt & clay		< 55
Silt & clay	< 0.0075	< 10
Sand	< 2	
Gravel	< 10	≥ 45

(Source: Public Works Research Institute, Sabo & Landslide Technical Center, 2006)

To decide whether soil is suitable for soil cement, particle size analysis results are needed. If there is any difficulty in undertaking the analysis you may use existing information.

Soil for soil cement shall be sieved using a mesh of 1cm size. The reason for sieving is to remove organic material, and as well exclude aggregate sizes which may break the sandbag and limit compaction.

- Cement

Portland cement is recommended

Uncaked Portland cement should be used.

- Mixing rate

7 % of cement to soil weight, 8 % of water to total weight of soil and cement are recommended.

The recommended mixing rate for soil cement is as follows:.

$$Wc = Ws \times Mc \quad (2\text{-}6)$$
$$Ww = (Ws + Wc) \times Mw \quad (2\text{-}7)$$

where,

Wc : Cement weight (kg)
Ws : Soil weight (kg)
Ww : Water weight (kg)
Mc : Cement mixing rate, Wc/Ws, (%)
Mw : Water mixing rate, Ww/(Ws＋Wc), (%)

Mc of 7 % is recommended but for the part where human traffic is high it is advisable to increase the Mc to 10 %. Also Mw should be increased from 8 to 10 % if the construction is in the dry season. In the rainy season the Mw should be reduced to a level that will not make the mixture sticky.

- Curing

Water curing is required daily after construction work

Hydration reaction of soil-cement start just after mixing water. For smooth continuation of the reaction, water curing has to be done absolutely. During construction period, water curing is necessary before break time such as lunch break and end of the day work. And after the completion of construction, water curing has to continue for five days (Ministry of Infrastructure, Transport and Tourism, Japan, 2015).

Deciding mixing rate. Case Study

Sieve of size of 9.5 mm was used in the Sanga village as shown in (Fig. 2.32).

Fig. 2.32 Borrow pit in Sanga village (left) and close view of soil (right)

Soil cement is made with this soil and UCS test is done. The results show that combination of Mc is 10 %, Mw is 10 % or 12 % can give UCS more than 3 N/mm^2 (Fig. 2.33)

Table 2.11 Particle size distribution

Particle size	%
Gravel (>2.0mm)	59.5
Sand (0.075-2.0mm)	37.3
Clay, Silt (<0.075mm)	3.2

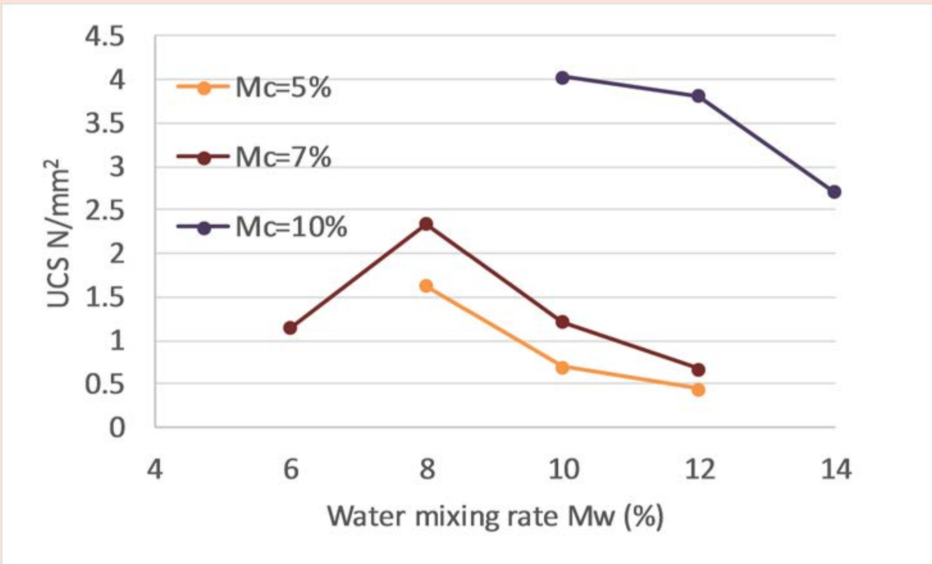


Fig. 2.33 Relationship of Mc, Mw and UCS

The test results (Fig. 2.33) and Felt (1955) indicate the necessity to consider careful water content management that has a big influence on UCS. And there is possibility Mc is 8 % or 9 % reach 3N/mm^2 with Mw is 8 % or 10 %.

Focusing on the curing condition of soil-cement, curing is done under the sealing condition using sandbag. And increasing of UCS is expected because water curing is planned at site construction. Based on such condition, Mc shall be 7 % instead of 10 % for reducing the construction cost and Mw is pegged at 8 % with water curing. And Mw is adjusted plus 2 % (= 10 %) by considering the loss on mixing.

To confirm UCS, soil sample was taken on March 2016 (dry season) and test pieces were made with Mc 7 % and Mw 10 % and set under air and water curing. UCS values of 2.97 N/mm^2 and 3.24 N/mm^2 were obtained respectively. The result indicated that water curing increase UCS to 9 %. In the case of Mw 8 % with air curing, UCS will reach 2.83 N/mm^2 with water curing.

Concerning UCS of test pieces made by sample of soil-cement from the construction, it is 2.67 N/mm^2. That means 2.91 N/mm^2 at the site under water curing condition and UCS at the site is expected to reach the target strength.

2.3.2 Construction of spillway

i. Materials and tools

Materials and tools for the construction are listed in Table 2.12 and 2.13. These are available in the rural areas and can be used to reduce cost.

Table 2.12 Main materials and tools

Item	Sandbag	Cement
Descripti	Used Polypropylene textile of size 110cm×70cm.	Portland cement, 50kg/bag
Photo		
Item	Crushed stone	Compaction tool
Description	Mixing with soil 1:1. For back filling to sandbags at bank protection and trench.	Can is fixed by nails to pestle and stuffed with mortar. Its total weight is about 7kg.
Photo		
Item	Sieve (metal mesh, wood frame)	Leveling tool
Description	Metal mesh 1 cm opening, 5 cm square wood bar, nails for fixing mesh.	To check ground level using levelling instrument Alternatively use pet bottle containing water (Fig. 2.34).

Photo

How to make leveling tool with plastic bottle

a) Fill a plastic bottle approximately half way with water. Lay the bottle horizontally.

b) Mark level of water on both sides of the bottle.

c) Place the bottle in a reverse position at the same place.

d) Mark the water level as c) (A2 and B2)

e) Get the center of each side and mark as A3 & B3.

f) Draw a line from A3 to B3 with a marker.

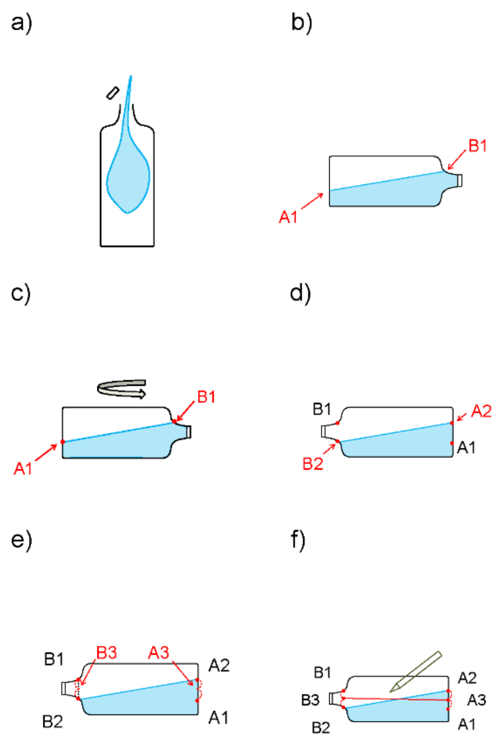


Fig. 2.34 How to make simple level tool for construction

(JIRCAS 2012)

Table 2.13 Other materials and tools

Item	Description
Pickaxe Shovel	For digging. Wooden handle is suitable to avoid heating up . Spare handle is required.
Bucket	For measuring soil, cement and water
Wheel barrow	For transporting soil, cement, etc.
Water tank	To store water for construction.
Jute sacks	For water curing. Used ones are acceptable.
Watering can	For water curing. Bucket is alternative.
Weighing Scale	For measuring weight of materials.

Treat sandbags to avoid insect attacks.

ii. Procedure for construction

- Preparation

Soil is transported from borrow pit to the construction point. Excavation of the spillway, measuring materials required, setting out and leveling the soil-cement are done. Details of the work are summarized in Table 2.14.

Table 2.14 Work procedure (from sieving to excavation & leveling)

<table>
<tr><th>Photo</th><th>Description</th></tr>
<tr><td></td><td>Sieving
At the borrow pit, excavate and sieve soil to remove all debris.</td></tr>
<tr><td></td><td>Filling Sandbags
Sandbags are filled with sieved soil and transported to the site. Check the sandbags for defects and rectify.</td></tr>
<tr><td></td><td rowspan="2">Measuring material
Materials to be mixed are measured using a known measuring can. Alternatively, a locally calibrated container can be used.

Leveling soil-cement (Mc=10 %, Mw=10 %)
Soil : 1 bucket (about 40 kg)
Cement : 7 cm in tomato can (4 kg)
Water : 2 tomato cans (4.4 kg)

Soil-cement for sand bag (Mc=7 %, Mw=10 %)
Soil : 1 bucket (about 40 kg)
Cement : 5 cm in tomato can (2.8 kg)
Water : 2 tomato cans (4.4 kg)</td></tr>
<tr><td></td></tr>
</table>

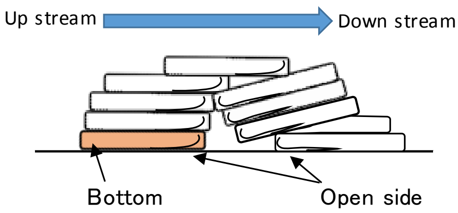
	Excavation At the sandbag setting point, excavation and leveling are done. Obstacles are removed from the excavation point.
	Watering Watering is done to improve setting of the mixture.
	Mixing and transportation Watering should be done before mixing to avoid absorption of water from soil-cement. After placing soil, cement shall be added proportionately at appropriate intervals. Then water is added and mixed rapidly well. Mixed soil-cement in sandbag is transported to construction point.
	Excavation and levelling Soil-cement mixture at Mc 10 % is placed at a thickness of 2 cm and levelled.

<table>
<tr><td></td><td>Water curing
Jute sacks are used to cover the surface and watering is done.</td></tr>
</table>

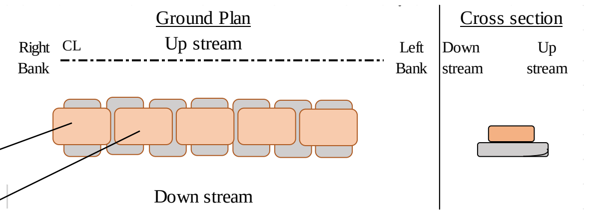
- Mixing materials, setting sandbags and water curing

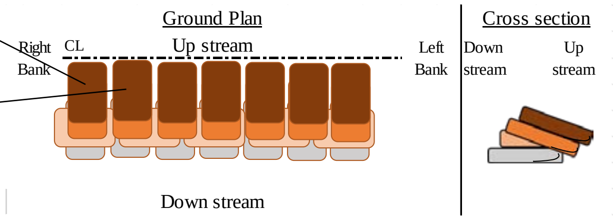
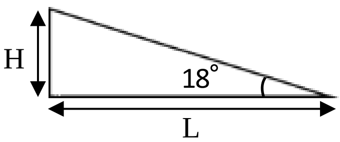
Mixing of materials, setting sandbags and compaction should be done as soon as possible.(Table 2.15)

Table 2.15 Work procedure (from mixing materials to water curing)

<table>
<tr><th>Photo</th><th>Description</th></tr>
<tr><td></td><td>Mixing, filling and transportation
At mixing point, sufficiently wet the ground and place the mixture dividedly. Mix to attain a uniform consistency. Fill sandbag and transport to setting point.</td></tr>
<tr><td>
</td><td rowspan="2">Setting


The bottom of sandbag has to face upstream on the upstream side and downstream on the downstream side. After placement, adjust to reduce spaces between sandbags while maintain the height. After adjustment, the open part of the bag is folded and pushed under. the bag.</td></tr>
<tr><td>
</td></tr>
</table>

<table>
<tr>
<td></td>
<td>Compaction
Sandbag is compacted using compaction tool from 20 cm drop height and ten times. There are 15 points per bag (3 points on short side and 5 points on long side). The compaction point should overlap. Bottom and edge should be compacted carefully.</td>
</tr>
<tr>
<td></td>
<td>Filling soil cement between bags
Put soil cement into the spaces between upstream and downstream bags before compacting.</td>
</tr>
<tr>
<td></td>
<td rowspan="2">Inclined stacking


Open side of the bag is set across the first set of bags, perpendicular to the axis of the spillway.

</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>H=0.32L because
tan (18°)=0.32

</td>
<td>Put next layer bag on existing bags with bottom part face to downstream. It should be noted that the angle has to be more than 18 degrees (Matsushima et al, 2014).</td>
</tr>
</table>

e.g. In case of L is 30 cm, H is about 10 cm	
	Backfilling and compaction Backfill with a mixture of soil and crushed stone with the ratio of 1:1 and compact adequately.
	Compaction The sandbags have to be compacted well, especially at the edges.
	Water curing Cover sandbags with jute sacks and sprinkle water very well over a period of 5 days.

iii. Bank protection and apron

At the spillway abutment, the banks are protected with additional sandbags to cover the entire free board. Apron shall be set at downstream of the spillway to avoid scouring. The material for apron shall be boulders with diameter more than 30 cm.

	
Bank protection (this side) and apron	Bank protection (back) and apron (flag stones this right side)

Fig. 2.35 Bank protection and apron

iv. Maintenance and repair

Institute a regular inspection regime on the embankment to look out for signs of erosion. Repair works would have to be done at the beginning stage of the damage, especially, where stronger water flow pressure has occurred such as the crest, and connecting parts of the embankment. In cases of severe damage increase the amount of cement in the mixture, in relatively minor cases it is recommended that repair works are done utilizing stone or sandbag with sediments.

Appendix

Concerning a facility utilized sandbag and soil-cement, Institute for Rural Engineering (NIRE) in Japan developed a construction method for earth dams allowing overtopping (Mohri, Y., Matsushima, K. et al. 2009) and the case study on utilizing the method “The pilot test of countermeasure against wave erosion for road embankment in Bangladesh” (Matsushima, K. et al. 2014) are reported with its effectiveness. Based on those study results, test construction in Sanga village is implemented.

References

1. Sabo & landslide technical center (2011): Sabo soil cement design and construction handbook, p43 (in Japanese)

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7. Matsushima, K., Mohri, Y., Hori, T., Ariyoshi, M., Nakazawa, K. (2014): Development of enforcement technology for embankment with labor based technology to mitigate earthquake and temporary flood, case study in Bangladesh, Agricultural and Rural Development Information, No.113, p8-15 (in Japanese)

2.4 Investigation of bunds erosion in the northern regions of Ghana

2.4.1 Introduction

Rice cultivation and consumption has become a very common practice in Ghana and the sub region. Most valleys are being developed into rice fields. Some of the rice varieties prefer water conditions and some grow in relatively dry conditions, many rice varieties however grow in shallow water. So, a field where rice is grown has to fulfil the following conditions Yamaji (1995):

- The field is enclosed by bunds to conserve water
- Provision of inlet for irrigation.,
- Provision of outlet for drainage.

These above mentioned conditions are the minimal that any rice field should have to meet. Other conditions which are preferable for good rice growing are:

- Percolation should be controlled to keep water
- Field surface should be levelled to a uniform depth to ensure homogeneous growth and water control,
- Field surface should be levelled to ensure uniform depth of water and for ease of farm machinery operational activities.
- Soil is to be sufficiently fertile.

Bund construction is among the various soil conservation techniques also practiced by some farmers in Ghana. It is with the aim of controlling soil erosion, reducing runoff and also to increase infiltration. These bunds are usually made with soils or stones normally from the farmland and also with locally made tools. The soil properties and compaction have great effects on the strength of bunds especially during the rainfall period and on lands with steep slope. These farm bunds should therefore withstand the adverse effects of rainfall and runoff to the end of the production season.

2.4.2 Main project activity

Bunds are small earth embankments, which contain irrigation water within basins. The irrigation depth and the freeboard determine the height of bunds. The freeboard is the height above the irrigation depth to be sure that water will not overtop the bund. The width of bunds should be such that seepage will not occur, and that they are stable

The main project activity is to investigate field bunds with different soil types. Specifically, this research is addressing the following:

- Construct field bunds with clay and sandy soil from the locality
- Monitor the resistance of the bunds to erosion.

Methodology

Study area

This research activity has been carried out in the Nwogu of the Kumbungu district in the Northern Region. The community has access to basic electricity, mechanized borehole and basic education to the primary school level. The members of the community are engaged in both subsistence and commercial farming. Motorbikes, bicycles and tricycle are the common means of transport.

Materials

The following tools were mainly used for the construction the bunds; pick axe, wheel barrow, mall hammer, wooden pegs, spade, rope and head pan. All the listed tools were obtained from the local market. Core sampler was used to take soil sample from the constructed bund for laboratory analysis.

Setting out the field

A 20 m x 10 m rectangular plot was divided into four. The base widths of all the bunds were marked as in Fig. 2.36 before digging started. Due to the sloping nature of the field, which will not allow water to pond uniformly, internal bunds were constructed to keep the sub-field (basins) level.

- For sloping fields, basins must be small for the ease of levelling so that field water depths can be uniform.

Bund construction

The bunds constructed have approximate base width of 60-80 cm and a height of 60-90 cm. It is supposed that the settled height of the constructed bunds will be 40-50 cm (See Fig.2.37) as recommended by Brouwer, *et al*, (1988). This settlement (consolidation of the bund) will take several months. The bunds were constructed in varying ratios of clay material from the Nwogu main reservoir (which was desilted) to local available materials as stated in Table 2.16.

Fig. 2.36 Setting out field

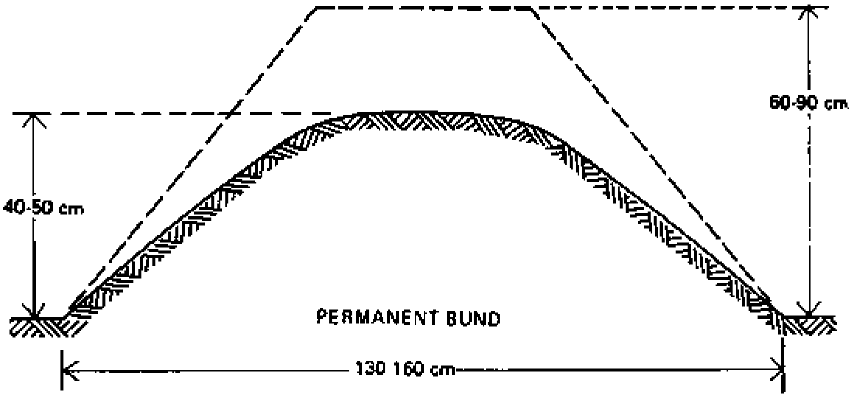


Fig. 2.37 Shape and dimensions of permanent bunds

Table 2.16Bund types constructed

Bund tag	Material composition	Ratio (clay:local sand)
A	Clay only	-
B	Sand only	-
C	Clay and sand	1:1
D	Clay and sand	1:2
E	Clay and sand	1:3

An 8 cm deep trench has been dug along the bund track (see Fig. 2.38), and then filled with the bund material to the required height. The bund material were placed in layers of 0.1-0.3 m and compacted to average height of 0.7-0.9 m (See Fig. 2.39). Since the construction was done in the dry period, water was added to the dry soil (bund material) in order to attain that high level of compaction (Fig. 2.39). After the construction, rainfall values from on-site weather station were analyzed to determine the amount of erosion.

Fig. 2.38 Digging of trenches

Fig.2.39 Bund compaction

Fig. 2.40 shows the completed constructed bunds. For the purpose of the study all bunds were constructed as permanent bunds.

Bund Construction

- The basin layout is set out and positions marked with pegs.
- Shallow trenches are dug to a depth of a few centimeters along the marked positions.
- Bund material is placed in the shallow trenches in of about 0.1-0.3 m and then compacted.
- The process of laying the material and compaction continuous until the desirable height of the bund is attained.

Fig. 2.40 Constructed bunds

Plot levelling

Internal bunds were introduced to minimize the amount of levelling required after which the plots were levelled and prepared for cropping (see Fig. 2.41). This was done to prevent water from stagnating at low points of the field.

Fig. 2.41 Levelling of field inner perimeter

Data collection

The heights of the bunds were measured and continued at 2 weeks intervals for the research duration of 6 months.

Soil samples of the bund were taken at three different locations using the core sampler (Fig. 2.42) for laboratory determination of the bulk density. Sampling has also been done at the matured stage of the rice.

Fig. 2.42 Taking soil sample

2.4.3 Results

Sustainability of cropping of rice in the Northern Region will depend on the availability of water. Hence water management practices become very important. For water to be stored on the field, an effective bunding system must be in place. At the JIRCAS experimental site at Nwogu in the Kumbungu District of the Northern Region, a research work carried out by the KNUST team on bunds stability.

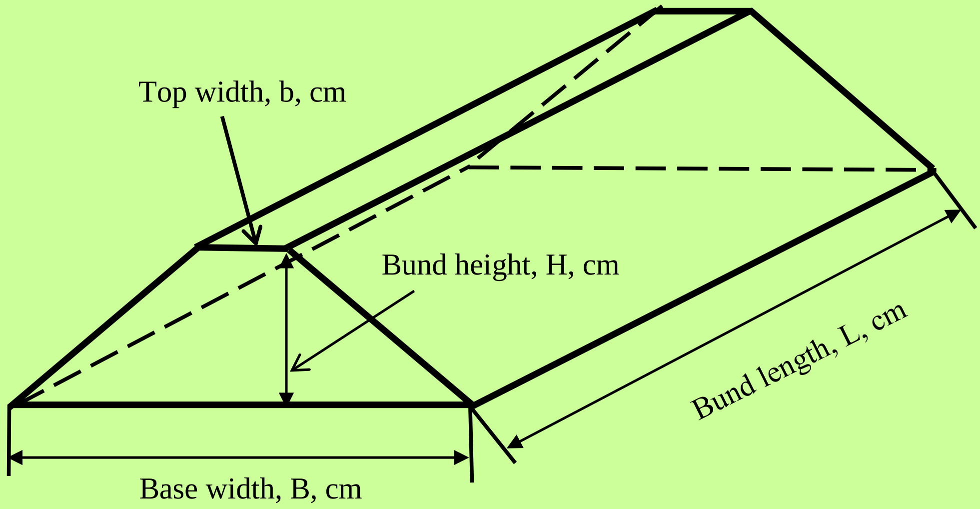
Heights and volume of bund material

The heights of the bunds at various locations were measured and their respective cross sectional areas were determined over the period. This was done in order to determine the volume of bund material. The measurement dates were ordered from 1 to 12 as in the table as follows:

Date of measurement

Order	Date of measurement
1	28-Jul
2	31-Jul
3	10-Aug
4	16-Aug
5	16-Aug
6	6-Sep
7	11-Sep
8	14-Sep
9	14-Sep
10	20-Sep
11	28-Sep
12	6-Oct

For the purpose of this study, the cross section of the all bunds was approximated to a trapezoidal section. Each bund type was divided into three sections.



Typical trapezoidal bund section

- Height of the bund is H, cm
- Base width of bund is B, cm
- Top width of bund is b, cm
- Length of bund is L, cm

Cross sectional area (A) of the Trapezoidal, bund is given as:

$$A = (\frac{B + b}{2}) \times H, cm^2$$

Volume of bund material (V) is given as

$$V = A \times L, cm^3$$

The mean bund height measured with time (Fig. 2.43) showed a trend of decrease in height. This may partly be attributed to some amount of erosion and consolidation of the bunds. The slope of decrease height curves of bund type A (Clay) is more gentle than the other bund types. Similar observations were made for the materials used for the volumes.

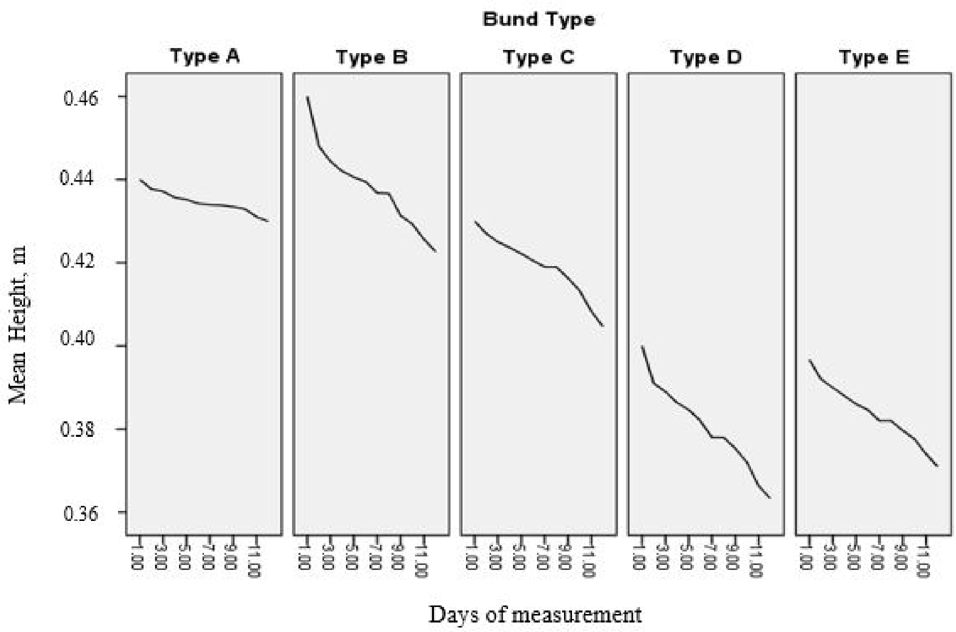


Fig. 2.43: Mean bund height variations with time

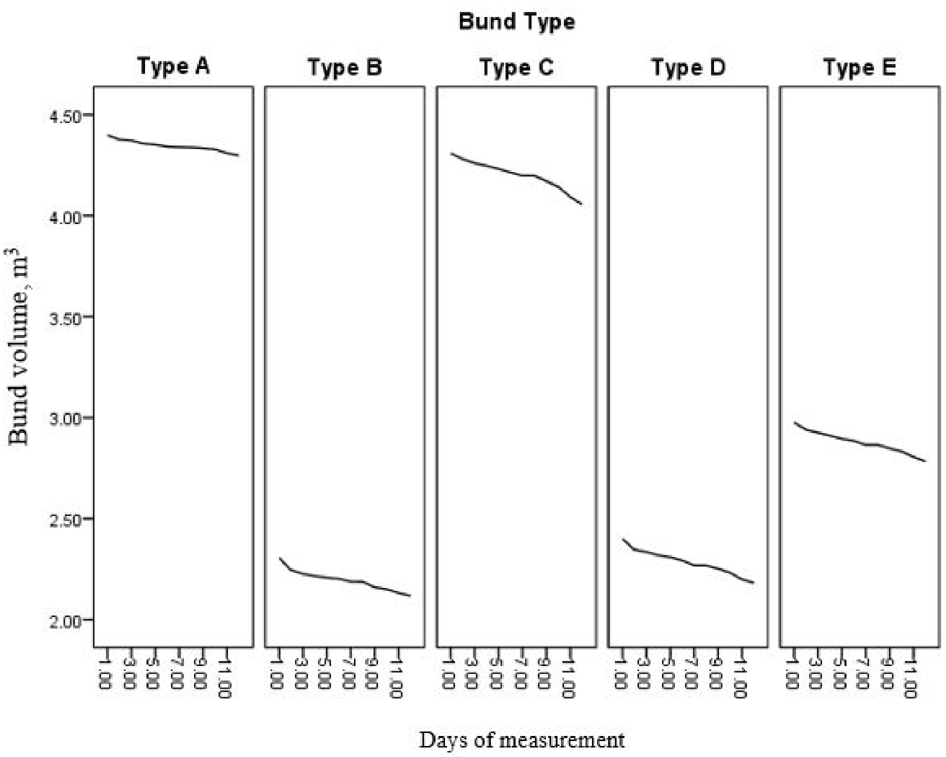


Fig. 2.44: Mean bund volume variations with time

Bulk density

To determine the erosion rate, the bulk density of the bund material must be known. The bulk density of all bund types was determined for the bund materials at the beginning and end of the research.

The procedure for the determination of the bulk density is as follows:

Bulk density determination using the core-cutter method

- Determine the volume of the core-cutter (V_c), cm^3
- Determine the weight of the core-cutter (W_c), g
- Determine the weight of the core-cutter plus the wet soil (W_s), g
- Weight of wet sample is given as ($W_c - W_s$), g

Bulk density is then computed as follows:

$$\gamma_b = \frac{W_s - W_c}{V_c},, \text{g/cm}^3$$

Erosion rate

The erosion rate is determined as the weight of bund material eroded per unit amount of rainfall over the period. Its computation was done as stated as follows:

$$Erosion\ rate = \frac{Weight\ of\ eroded\ bund\ material\ in\ a\ period,\ [M]}{Total\ rainfall\ in\ the\ same\ period, [L]}$$

If

- Cross sectional area of bund at the beginning of a period is A_1, cm^2
- Cross sectional area of bund at the end of the period is A_2, cm^2
- Length of bund is L, cm

Volume (V) of bund is given as:

$$V = \text{Cross sectional area} \times \text{Length} = A \times L$$

- Volume of bund material at the beginning of a period is $V_1=A_1\times L$, cm^3
- Volume of bund material at the end of the period is $V_2=A_2\times L$, cm^3
- Volume of bund material eroded,

$$V_{erod} = V_1 - V_2,\ cm^3$$

- The bulk density of bund material is γ_b, g/cm^3
- Weight of eroded bund material at the end of the period is M, g

$$M = \gamma_b \times V_{erod}$$

- Total rainfall within the period, I mm

Plot of the mean erosion rate with time is as in Fig. 2.38. The erosion from all the bunds are similar in nature. The amount of erosion is least for bund type A (Clay) and highest for bund type B (Sand). The mean erosion rate for bund types A, B, C, D and E is below:

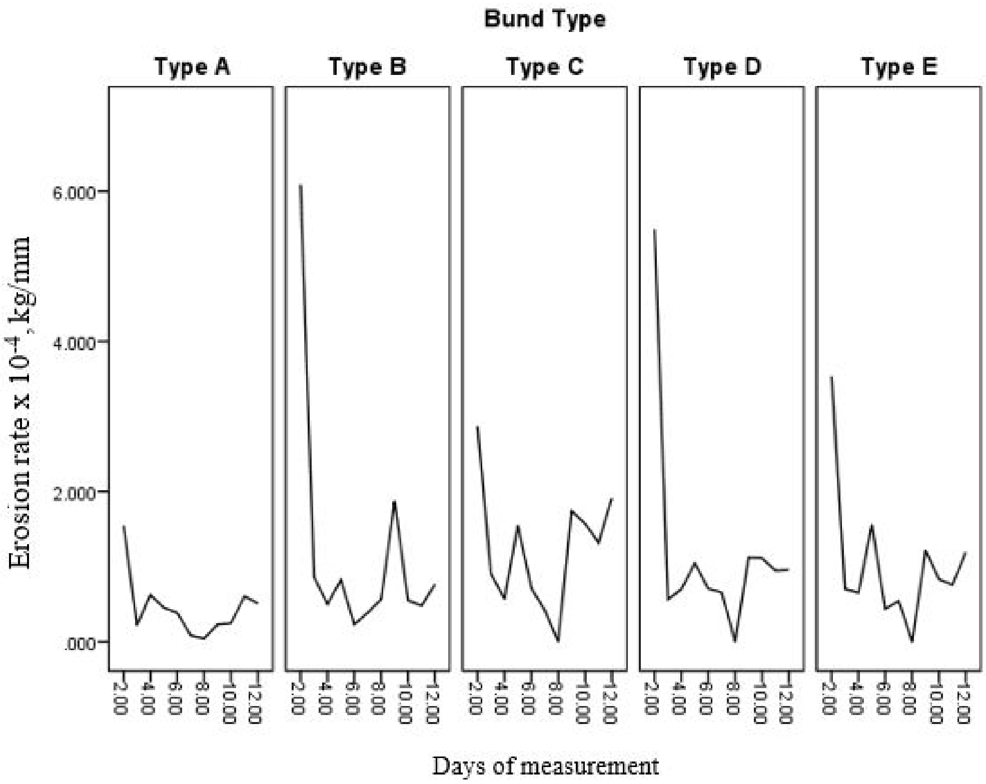


Fig. 2.45: Mean bund erosion rate variations with time

Cross sections of the constructed bunds were drawn with respect to time of measurement. Fig. 2.46 shows the cross of the experimental constructed bunds.

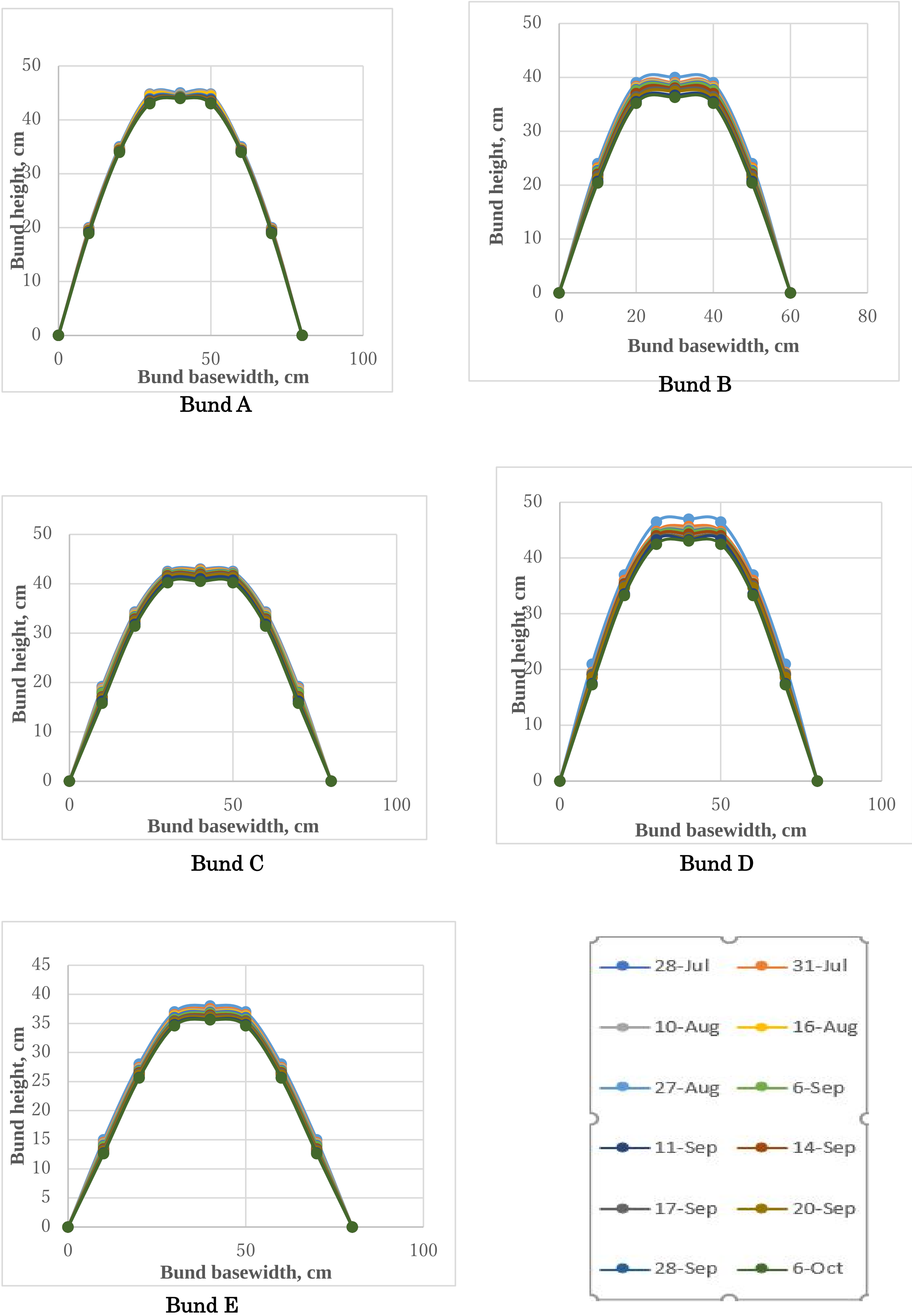


Fig. 2.46 Cross sections of bunds

Yield from the experimental plot

Yields obtained averaged at 30 bags of paddy per acre or 75 bags per hectare. This yield is above the expected break even yield of 18 bags/acre.

Reference

Brouwer C, Prins K, Kay M, and Heibloem M. (1988) Irrigation water management: irrigation methods. Irrigation and drainage paper 5, FAO, Rome.

Yamaji E. (1995) Paddy structures and its improvements. J. JSIDRE. (Paddy fields in the world): 269-280.

Chapter 3 Rice Cultivation with supplementary irrigation

An effective and efficient crop management is required for rice cultivation with the supplementary irrigation using water from a small reservoir. The verification study showed attainable rice yield of 7 mt/ha and that was 42 % higher than yields from a solely rainfed condition in the experimental field.

In this chapter, the details of crop management system for supplementary irrigation rice cropping is introduced. The system is designed based on the environmental conditions in the Northern Region of Ghana, which is typically Guinea Savannah agro-ecological zone. The rainy season stretches from June until September and the soils are typically sandy loam. The results for this research should be used with caution when applied to other agro-ecologies.

3.1 Choice of variety

Use medium maturing varieties

Rice varieties recommended for irrigated or rain-fed lowland condition in Northern region are classified into three groups by their growth duration (Table 3.1).

Table 3.1 Rice group depending on growth duration

Group	Growth duration	Varieties
Early	80 to 110 days	IR64, NERICA 1, NERICA 2, Digan etc.
Medium	115 to 125 days	Sikamo, Gbewaa, AGRA rice, Amankwatia etc.
Late	130 to 160 days	Katanga: Tox 3107, FARO 15 etc.

Early maturing varieties do not enjoy advantages of supplementary irrigation because of their low yield potential and short growth period. Late types have the disadvantage of requirement of rather large amounts of irrigation water. This manual is based on work done using the medium maturing variety, Gbewaa (Jasmine85) (Fig. 3.1).

Fig. 3.1 Gbewaa (Jasmine85) at maturity stage at Nwogu site

3.2 Cultural practice

Sowing date should be decided following the irrigation plan

Supplementary irrigation is designed to ensure rice is irrigated for 40 days, from panicle initiation to the end of flowering. The water resource for the supplementary irrigation is derived from collected or harvested rainwater and impounded in a small reservoir in the rainy season.

Cropping starts at the beginning of July which corresponds to the start of rice cropping season in northern Ghana. Sometimes that is later than the start of rainfed rice cropping; however, there are no risks of terminal drought during the maturing stage because of supplementary irrigation. In addition, the late cropping has a merit of less weeds.

3.3 How to irrigate the field

For 40 days from panicle initiation to the end of flowering period. Irrigate by flooding the entire paddy field when the soil surface is dry.

3.3.1 Period of supplementary irrigation

The period of supplementary irrigation is 40 days from the beginning of panicle formation stage. The beginning of panicle initiation (Fig. 3.2 and Fig. 3.3) is different for different varieties, and is affected by weather condition. The important point is to avoid a strong drought stress to rice plants. Irrigation period could be extended if water were available in the reservoir. In addition, irrigation before sowing and after fertilizer application is effective to ensure good germination and nutrient uptake of rice when the paddy field is dry. It is also necessary to irrigate when there is no rain after flowering period.

Fig. 3.2 Rice plants just before panicle initiation (Gbewaa: 49 days after germination)

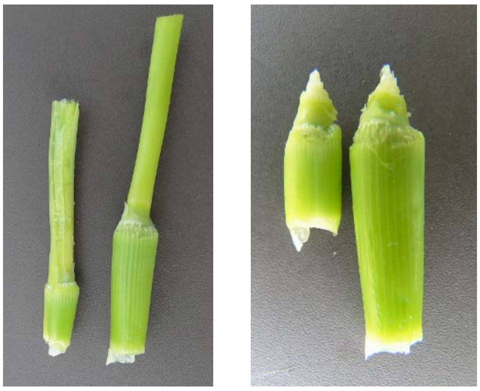


Fig. 3.3 Basal part of stem Left: internode elongation is observed. Right: panicle has not been developed yet (Gbewaa: 49 days after germination)

3.3.2 Criterion of irrigation

Irrigate until all the paddy field is flooded when the soil surface is dry (Fig. 3.4, Fig. 3.5). Generally, it is impossible to keep water in a paddy field with sandy loam soil. It does not appear extremely critical if the water rapidly disappears. No relation has been established between the flooding period and the rice yields. You could get high yield if you avoid drought.

Fig.3.4 The soil condition needs irrigation

Fig. 3.5 After irrigation

3.4 Cultural practice schedule

Cultural practice schedule is shown in Fig. 3.6.

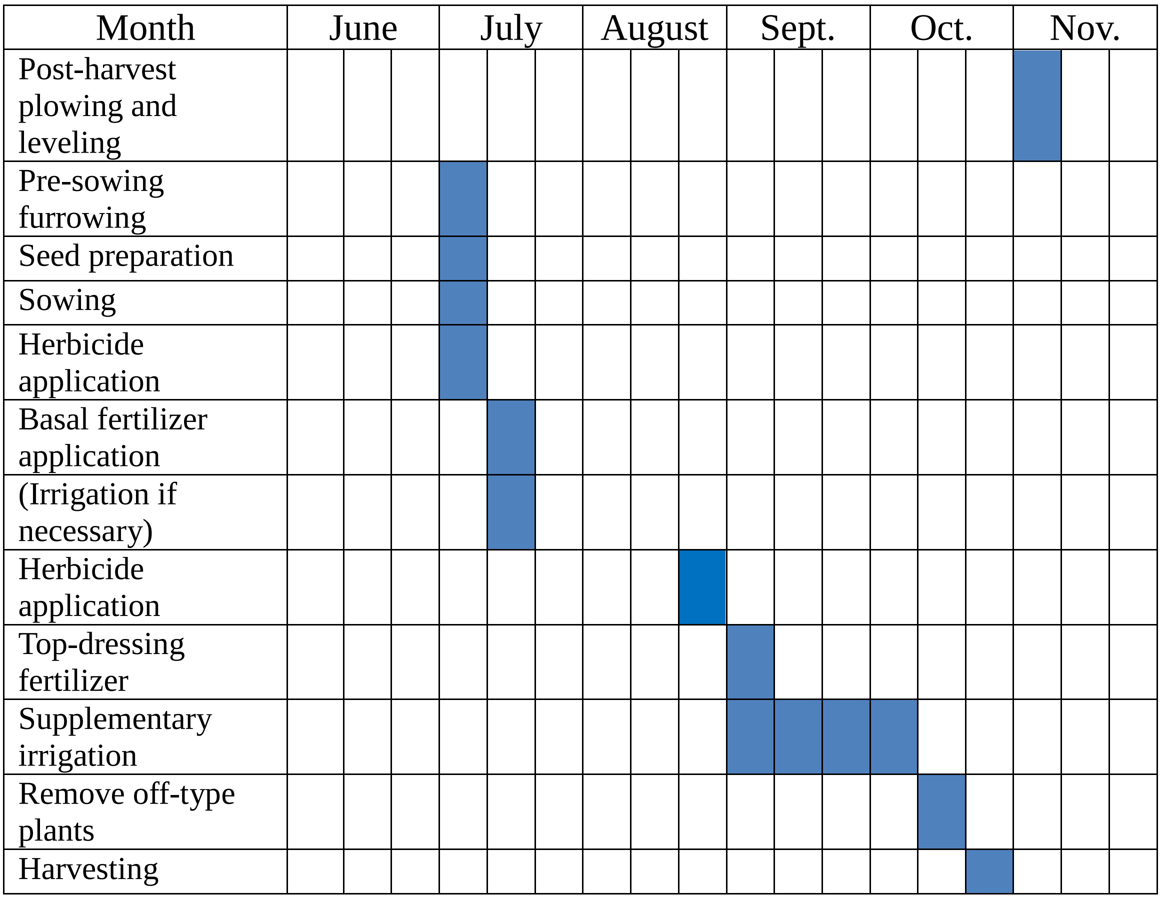


Fig. 3.6 Expected work schedule (For Gbewaa rice in Northern Ghana)

3.4.1 Land preparation

Undertake ploughing and leveling immediately after harvesting

Plough, level and repair bunds just after harvesting because there is still residual soil moisture. Ploughing back at this time hastens decomposition of rice residue and soil aggregation formation. This improves the water holding capacity of the soil with the early rains, minimizing surface run off. Harrow before seeding to control weeds.

Fig. 3.7 Plough back after harvest

Fig. 3.8 Field leveling

3.4.2 Seeding

Seed at 25×20 cm space, 3 to 5 seeds per hill at 3 cm depth

Use pure seeds with good germination ability for sowing. If seed stock contains many immature seeds, select good seeds by use of salty water solution with a specific gravity of 1.075, then soak into fresh water for 24 hours and dry. The standard of seeding is 25×20 cm in spacing, 3 to 5 seeds per hill, at 3 cm depth of sowing. Spot sowing (dibbling: Fig. 3.9, Fig. 3.10) in lines is labor intensive than broadcasting; however, it results in high germination, easy management such as weed control, and finally, higher yields.

Fig.3.9 Field depicting dibbling with wooden sticks

Fig.3.10 Field depicting dibbling by use of specialized tool (*multiple dibbler*)

3.4.3 Weed management

Spray a mix of soil and foliar treating herbicides

Many weed species in wet lowlands of Northern Ghana have low dormancy, and they germinate at once in the beginning of the rainy season.

Therefore, effective weed control entails killing these weeds by ploughing or harrowing. In addition, it is also recommended to spray a mixture of soil (Pendimethalin formulation) and foliar (glyphosate formulation) treating herbicides just after seeding. Selective herbicides (2,4-Diamine salt plus propanil formulation e.g. *Orizo plus*) before top-dressing is useful for the first weed control.

Remove off-types such as different color or shape/growth habit rice plants whenever they are found for improving product quality.

Fig.3.11 Spraying herbicide

Fig.3.12 Off- types in a Gbewaa field

3.4.4 Termite control

Apply pesticide (termicide) selectively or irrigate when termites are found

Apply pesticide or irrigate when termites are found (Fig. 3.13). Irrigation is also effective if there was enough amount of water.

Fig.3.13 Rice plants damaged by termite attack

3.4.5 Fertilizer application

Apply 250 kg/ ha of NPK(15-15-15) at 2 weeks after germination. Apply mix of 36 kg of Urea and 80 kg of Ammonium sulphate per ha at 6 weeks after germination.

Following the recommendation to rainfed condition, apply 250 kg/ ha of NPK (15-15-15) at 2 weeks after germination. Supplementary irrigation is effective when severe drought is observed and if you have enough water in the storage pond. Irrigation helps dissolve fertilizers, enhancing mineral uptake by rice plants and prevents fertilizer burns on the plants.

Apply a mixture of 36 kg of Urea and 80 kg of Ammonium sulphate per ha at 6 weeks after germination (panicle initiation). Urea is cheaper than ammonium sulphate. Ammonium sulphate helps to amend sulphur deficiency in the soil.

3.4.6 Harvesting

Harvest when the moisture of paddy is 20 to 25 % (85 to 90 % of paddy has become yellow).

Harvest when the moisture of paddy at 20 to 25 %. That is the time when 85 to 90 % seeds of panicle (head) have become yellow (Fig. 3.14, Fig. 3.15).

Fig.3.14 The best timing for harvesting

Fig.3.15 Too late

Chapter 4 Water management

4.1 Outline of the manual for water management

4.1.1 Context

To utilize dugout water for rice farming, it is necessary for farmers to perform some activities:

- operating irrigation system maintaining irrigation facilities
- managing funds for operation and maintenance.

Rice irrigation is a collective activity in most cases and this irrigation may trigger competition with other water users. Rice farmers require functions of group decision making on:

- irrigation for rice
- coordination with other water users.

To implement these activities with other water users in a sustainable manner, it is advisable to have an organizational framework to plan, implement and monitor these activities and functions.

This manual describes the methods to introduce the above mentioned activities, functions and an organizational structure of a community[1] where people want to utilize dugout water for rice farming. This is based on some principles, an experimental case study and lessons learned from the study. The principles can be applied widely, but cases and lessons need modification depending on the social situation in the target area, because they resulted from an experimental study specifically applied in the Northern Region of Ghana.

4.1.2 Outline of the experimental study

The experiments were conducted from 2013 to 2016. In this study, a paired-pond system composed of an existing dugout, a newly constructed sub-pond that collect spilled water from the dugout through an intake canal

[1] Unit that correspond to a ‘village’ in northern Ghana. This manual describes how community/ village people manage and utilize dugout water.

to sub-pond were used. Other components included leveled farming plots surrounded by bunds, a water pump and pipelines to distribute water (Fig. 4.1, Fig. 4.2). Additionally, hoses were supplied to deliver water from valves at the end of pipe lines into the plots (Fig. 4.3, Fig. 4.4).

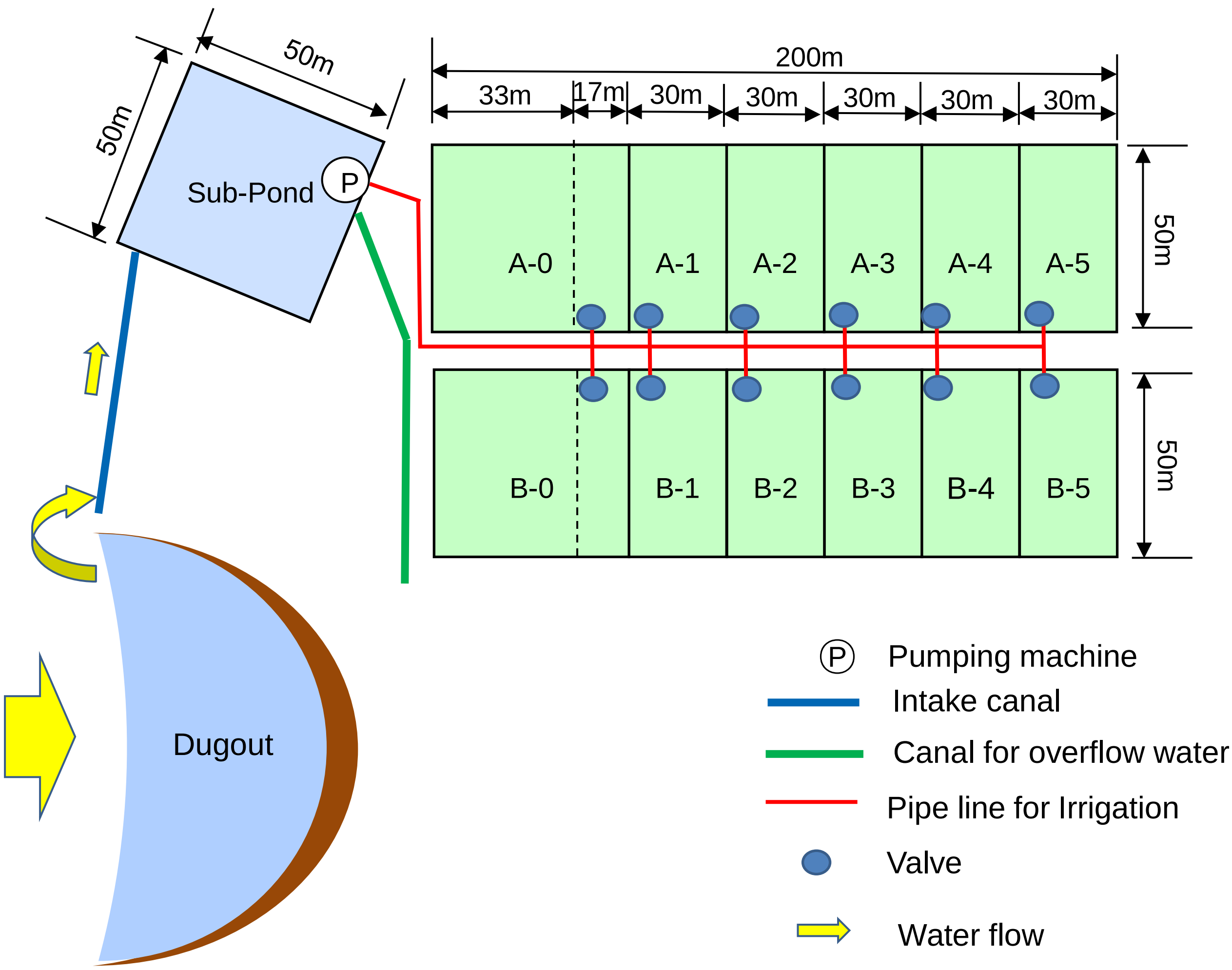


Fig. 4.1 Outline of irrigation system in the experimental study

Fig. 4.2 Water pump

Fig. 4.3 A valve at the end of a pipe line

Fig. 4.4 Hose to deliver water

Plot numbers A-0 and B-0 were used as cultural test plots, in some part rain-fed and the other part supplementary irrigated. Plot numbers A-1 to A-5 and B-1 to B-5 were used by 10 farmers who participated in the experimental study to farm rice using water from the sub-pond.

4.2 Water management framework to utilize a small reservoir for supplementary irrigation of rice

4.2.1 Principle

A small reservoir is used for multiple purposes such as domestic use and livestock watering.

To use the water of a small reservoir for rice irrigation, a community should have functions of coordination for water use and allocation of maintenance duties among competing water users.

To activate these functions sustainably, it is desirable to establish a water management framework in a community (see Fig. 4.5).

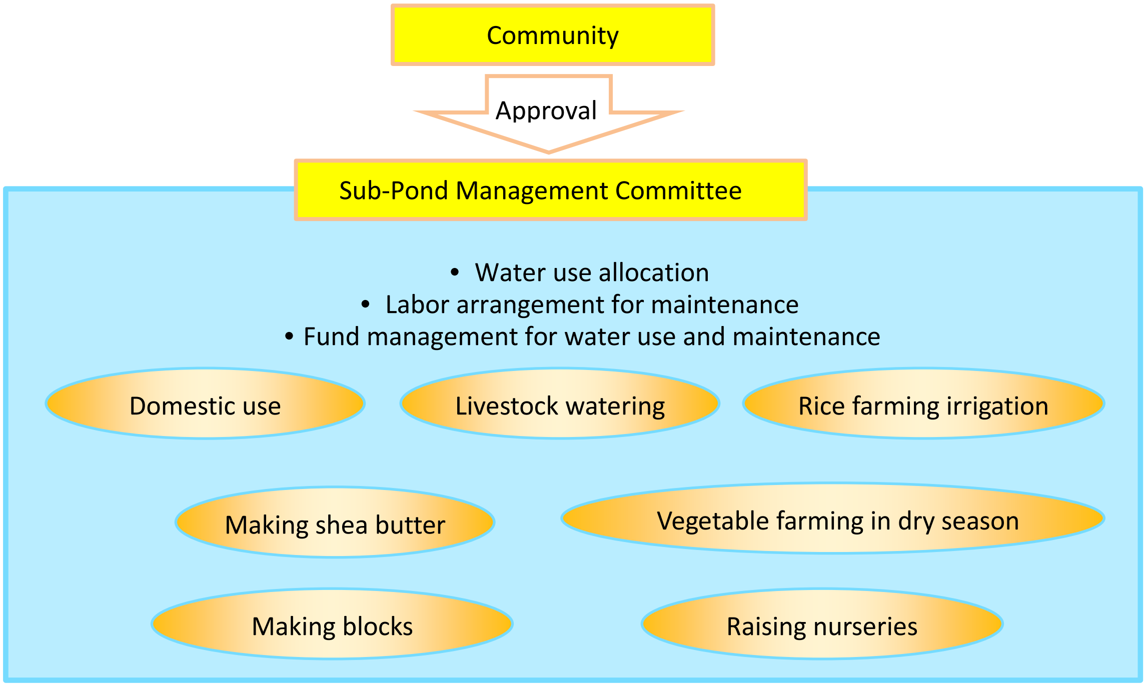


Fig. 4.5 Water management framework for sub-pond thought to be suitable in the northern part of Ghana

A water management framework needs to be established, based on the following information:

I. Role of local government and traditional authorities[2], and framework and status of activities of related pre-existing organizations

→This information is necessary to decide the activities and role sharing of new water management framework. It is also necessary to consider the possibility of building on the existing organization.

II. Status of existing water use

→This information is necessary to determine the necessity of coordination among water users and to make a facility management plan or a water distribution plan.

[2] The traditional governance system is called the 'chief system' and is endorsed by the Ghana Constitution as a traditional authority. Traditional chiefs take office in accordance with each racial customary law. The system has layers such as chief in the community and chief in the local area. There is the National House of Chiefs at the national level.

In the Upper East Region, northern Ghana, where irrigation is implemented using a large reservoir (dam), organizations of reservoir users have been promoted, which mainly consist of irrigation farmers. However, such organizations do not always play a major role in managing the reservoir. Management activities for organizations for small reservoirs are limited due to current activities mainly by local communities and participation of the local government.

Management of water and facilities of three dams

		No.1	No.2	No.3
Water shortage (last 10 years)		2 years	6 years	5 years
Coping strategies to water shortage	- Actor	WUA	n/a	Chief
	- Activities	Irrigate less area irrigate other crops	None	Irrigate less area irrigate other crops
	- Main objective	Ensure dam water for irrigation	n/a	Ensure dam water for livestock
Maintenance of dam body	- Actor	Villagers (Mainly WUA real members)	Villagers	Villagers
	(Process)	Problem finders (dam supervisors) →WUA leaders →WUA meeting →Action	Problem finders (villagers)→WUA leaders→Village meeting→Action	Problem finders (villagers)→Assembly man→ Chief→ Village meeting →Action
	- Activities	Embankment repair (irregular) ：Stone covering on slope (Regular), Glass planting (Regular)	Embankment repair (irregular) ：Stone covering on slope (Irregular),	Embankment repair (irregular) ：Stone covering on slope (Irregular), Glass planting (Regular)
Canal maintenance	- Actor	WUA	WUA	WUA
	- Activities	Desilting, Weeding, Repair (Regular)	Desilting. Weeding, Repair (Irregular)	Desilting. Weeding, Repair (Regular)
Fee collection	- Actor	WUA	WUA	WUA
	- Fee payer	Rice/ vegetable irrigators	Vegetable irrigators	Vegetable irrigators
	- Uses of collected fee	Canal maintenance	Canal maintenance	Canal maintenance
Decision-making		WUA meeting	WUA meeting, Village meeting	WUA meeting, Village meeting

WUA: water users association

4.2.2 Case study

Two new water management organizations were established in the beginning of the experimental study: the farmers' group (the Rice Farming Group) that implements supplementary irrigation in experimental fields; and the Sub-Pond Management Committee (SPMC) that is expected to implement coordination on water use, maintenance management, fund management and other activities concerning the sub-pond.

Although there was an existing Dugout Management Committee (DMC) in the community before establishing the new organizations, new functions for water management were needed because:

I. The role of DMC was limited to monitoring the dugout and reporting the results to the Chief. It did not have any functions of water allocation or fund management.
II. The importance of fund management for water use was high for the sub-pond, because water was delivered by pump at a cost.

Therefore, based on discussions in the community, SPMC was established to take these roles. It was decided that SPMC and DMC would be independent because it was not necessary to coordinate water use between the sub-pond and the dugout.

The members of SPMC consisted of three persons from DMC and two from the Rice Farming Group. SPMC was established with approval of the community as applied to DMC. At an early stage of the experimental study, there was no necessity to allocate sub-pond water because the purpose of its water was limited to rice irrigation. Also, the need for maintenance activities was low because the sub-pond was new. Therefore, activities of SPMC were limited to monitoring the sub-pond, repairing the dyke's cover sheet and mowing the dyke (with the Rice Farming Group).

The water stored in the sub-pond was initially used only for rice cultivation. Later the Vegetable Farming Group (women's group) was established to grow vegetables using the water left in the sub-pond following rice cultivation. In addition, domestic water was also taken from the sub-pond because of drought. These situations meant that SPMC possibly needed to play roles in coordinating maintenance activities by all members of the community, or coordinating between water users' groups.

A summary of the water management framework in the experimental study is shown in Fig. 4.6.

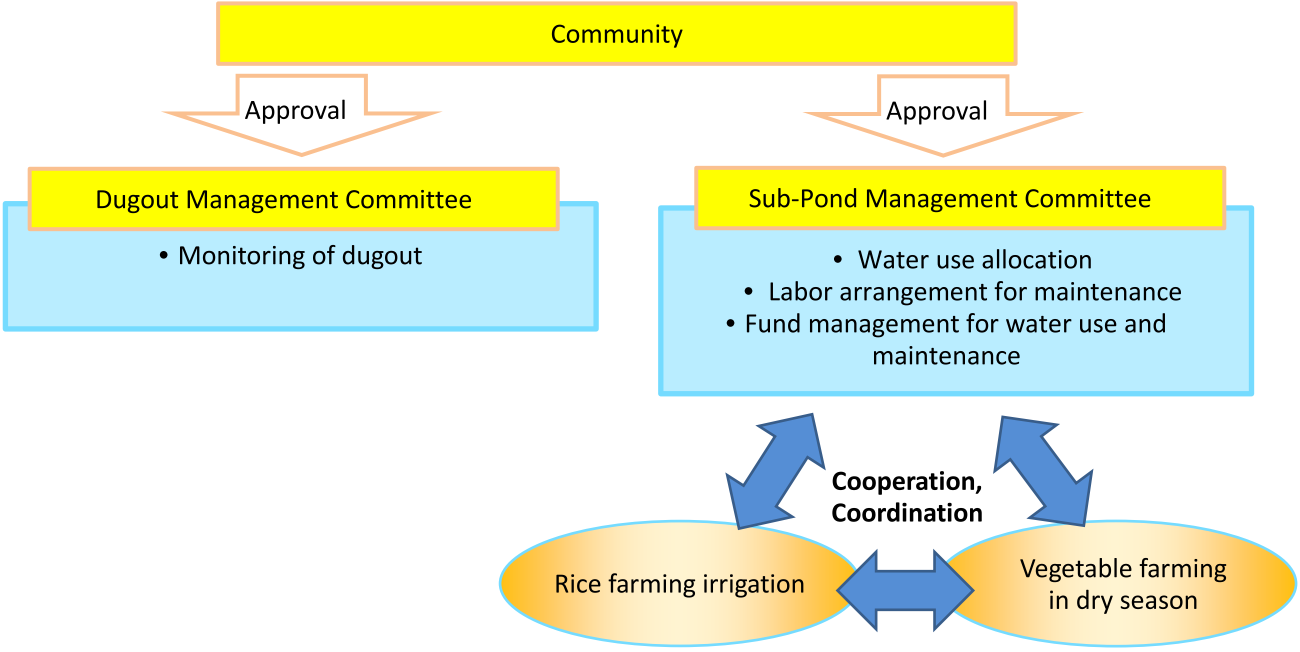


Fig. 4.6 Water management framework established in the experimental study

4.2.3 Lessons learned

It took some time before the stakeholders came to understand the necessities of maintenance activities such as desilting and water coordination among multipurpose water users, and to be able to start study of real activities. Medium-term instructions and supports are necessary for building of a framework including organizations that play these roles.

Building water management framework requires considering the role of the Chief in the community and obtaining his cooperation in areas where traditional authority exists.

4.3 Functions and main positions in water management organization

4.3.1 Principle

The basic functions required for a water management organization of a small reservoir are irrigation management, facility maintenance, fund management, making decisions, recording of activities and coordination among stakeholders. These functions are coordinated by the responsible person with cooperation of other members of the organization.

The constitution of positions in water management organization should be decided in accordance with the purpose and method of water use in order to fulfil the functions mentioned above. The people who serve in positions should be selected through the agreement of members. Basic functions and positions of water management organization is shown in Table 4.1.

Table 4.1 Basic functions and positions

Functions	Positions which is responsible for functions
Decision making	Chairman
Irrigation management	Water Manager
Facility maintenance	Facility Manager
Fund management	Treasurer
Organizing meetings	Organizer
Recording activities	Secretary

4.3.2 Case study

The activities of the two water management organizations established at the beginning of the experimental study were as follows:

I. Sub-Pond Management Committee

- Ensuring safety at the sub-pond
- Ensuring maintenance of the sub-pond facilities
- Efficient management of water in the sub-pond
- Collecting fees to run and maintain facilities

II. Rice Farming Group

- Irrigation operation needed for rice farming
- Maintenance of irrigation facilities excluding sub-pond facilities
- Fund management for operation and maintenance.

Based on these activities, the positions were decided (Tables 4.2 and 4.3) and the persons in charge of each position were selected with agreement of members. These positions and selections were agreed by community members and the Chief, from a viewpoint that the sub-pond water was a common resource of the community.

The establishment procedures of SPMC and Rice Farming Group are shown in Fig. 4.7 and Fig. 4.8, respectively.

Table 4.2 Constitution of positions in SPMC

Positions	Responsibility	Belonging Organization*
Chairman	Integration, conducting meetings	C
Treasurer	Accountancy	C
Secretary	Making record of discussions	G
Organizer	Information exchange, coordination	C

* C: DMC, G: Rice Farming Group

Table 4.3 Constitution of positions in SPMC

Positions	Responsibility
Chairman	Integration, conducting meetings
Vice-Chairman	Assisting the Chairman
Assistant of Chairman	Assisting the Chairman
Treasurer	Collecting, keeping, paying money
Secretary	Preparation of meeting, making record of discussion
Vice-Secretary	Assisting the Secretary
Organizer	Preparing the meeting venue, information exchange
Pump keeper	Pump storage
Pump mechanic (repairer)	Pump repair
Pump-operator/recorder	Pump operation and record of operation (2persons)

Sub-Pond Management Committee

1) Project organizer explained utilization and management of the sub-pond to the Chief and exchanged opinions

2) Based on the Chief's suggestions from a point of view of real management of the dugout and sustainable management of the sub-pond, it was decided that members of SPMC would comprise five people: three from DMC and two from the Rice Farming Group

3) Project organizer explained necessary management activities and positions for the sub-pond to the committee members based on activities of DMC

4) Members of SPMC and Chief decided positions in the committee

5) Persons in charge of each position were recommended and decided from members of the SPMC by participants in the community meeting

Fig. 4.7 Procedure from establishment to decision for positions on SPMC

Rice Farming Group

1) Project organizer explained the land consolidation plan for the experimental field and asked to select farmers with experience of rice farming as participants for the experimental study

2) Project organizer explained to the farmers participating in the experimental study, and to SPMC , the features of irrigation for rice farming and the role of participants:
-Irrigated rice farming needs plenty of water
-It is reasonable to use and manage the irrigation system as a common resource in order to use scarce water effectively
-It is necessary that participants form a group and implement irrigated rice farming cooperatively in order to manage the irrigation system as a common resource
-Maintenance is important for sustainable use of irrigation facilities and users need to shoulder its cost
- Participating in the experimental study means becoming a pioneer; therefore, participants should initiatively inform farmers of the knowledge and technology obtained by participation

3) The farmers participating in the experimental study agreed to form a group and establish the roles of participants

4) Members of the Rice Farming Group decided positions and the persons in charge of these positions

Fig. 4.8 Procedure from establishment to decision for positions on the Rice Farming Group

4.3.3 Lessons learned

The positions of a water management organization should reflect the activities which the organization should implement. When a new water management organizaition is estabished or new function is added, the positions should be decided based on careful consideration of the purpose and contents of the new organization or function.

4.4 Formulation of rules

4.4.1 Principle

Rules on usage and management of water are necessary for sustainable water resources utilization. Rules must be formulated such that:

i. Boundaries (plan) of water use and responsibility of users are clearly defined
ii. Persons who are affected by rules possess rights to reform the rules
iii. Persons who act against rules receive graduated sanctions.

Rules should include how to share roles among members, way of operation of irrigation, maintenance of facilities, fund management and how to make decisions.

4.4.2 Case study

Farmers who participated in the experimental study formulated the rules (Table 4.4) before cultivation started. The rules were documented and kept by the Secretary.

Table 4.4 Rules of the Rice Farming Group

Main contents
Positions and their responsibility
Positions and their responsibilities. Term of the role shall be one year. The person in charge of each occupation shall be elected by group members.
Operation of irrigation water
The member farmers shall select the same kind of seed and plant at the same time in order to use irrigation water efficiently. Dates of water distribution shall be decided in advance by the member farmers. Each member farmer shall participate in water distribution when their plot receives irrigation water. Those who do not shall be noted and compelled to pay a penalty. Members shall cooperate on pump operation.
Maintenance of facilities
Member farmers shall maintain bunds around his/her fields. Bunds dividing fields shall be maintained by the upstream farmer. Farmer group shall maintain irrigation and drainage canal as group property. Frequency of maintenance activities shall be decided by agreement of members. Members who cannot attend the activities shall inform the reason for absence to other members. Farmer group shall contribute to maintenance of the new reservoir. The penalty for non-obeying operation and maintenance rules is decided by members.
Management of funds

Main contents
The cost for pump operation, pump maintenance and necessary materials for operation and maintenance shall be funded from a group account. After harvest, the Treasurer shall collect money from members toward expenditure for pump operation, maintenance and renewal of facilities together with any penalty. The Treasurer shall deposit the collected money to a group account. The penalty for non-payment is decided by members.
Decision making
The norms and activities of the group shall be discussed and decided by members. The farmer group meeting shall be held at least once before rice cultivation and as necessity arises. If issues cannot be resolved by the farmer group meeting, the group shall consult the Chief of the community. The penalty for absence from group meetings is decided by members.

The interviews conducted after the first experimental cultivation season showed that member farmers found that the rules were valuable, especially penalty rules. However, information related to penalties, such as non-attendance at group meetings or for irrigation, was not recorded correctly. Consequently, guidance on taking records was given to the Secretary.

At the beginning of the second cultivation season, members verbally confirmed the rules and made some necessary changes. At the same time, they found a difference of opinion on conditions of penalty and made agreement that there would be no exemption.

4.4.3 Lessons learned

When introducing water management to farmers who are irrigating rice for the first time, it is insufficient to support them in formulating the rules or to give them written rules. Facilitators (e.g. Extension officers, staff of NGO, etc.) must support them continuously to follow and modify the rules and make them their own.

In case farmers are illiterate, it is suggested that farmers confirm rules verbally and regularly, e.g. before cultivation season, to entrench rules in a group.

4.5 Operation of irrigation by a group

4.5.1 Principle

To efficiently utilize water in a dugout for rice farming, it is necessary for rice farmers to operate irrigation collectively based on their understanding of the amount of water in the dugout and amount they are using throughout the cultivation season.

4.5.2 Case study

Irrigation was operated in groups such that no individual farmer used water on their own.

It was planned to irrigate once a week after panicle formation stage. There were 12 plots to irrigate so two plots were irrigated in a day in a period of six days. When it rained and soil moisture was enough, irrigation was postponed for two or three days.

Two pump operators were selected from group members. They carried the pump from pump keepers' house and operated it. It was agreed that member whose plot was to be irrigated must come to the field to look after and repair their bunds, set additional hose for irrigation, set small ditch or intermediary bunds to retain water. If not, that member must pay penalty.

As irrigation schedule was changed in accordance with rainfall situation, new irrigation dates were decided by the Secretary of the group who also served as the pump operator. It is agreed among members that when irrigation date was changed, the secretary make special effort to communicate to other members so that members can be present.

Fig. 4.9 Spreading water

Pump operation time and fuel purchase were recorded as shown in the record sheet (Table 4.5) so that any member can make inquiries.

Table 4.5 Record sheet of pump operation

Record of water distribution			Name:	
Date	Plot	Water distribution		
		Beginning time	Ending time	Duration
1/Sep	A3	13:00	13:45	0:45
1/Sep	A4	13:45	16:00	2:15

At the beginning, farmers had planned that the fuel cost should be charged based on the amount of water. However, they finalized that they payed equally divided fuel cost, because the condition of each plots are similar and it was difficult to measure the amount of water separately for each plot.

After one year of experience, member farmers concluded that this was a good system to collect fuel money evenly because some water leaked through the bunds, and each plot was using almost the same amount of water regardless of the frequency of directly receiving water.

4.5.3 Lessons learned

Irrigation schedule is flexible in accordance with rainfall situation. Member farmers must confirm well how to communicate in case of change of schedule.

To use water efficiently, it is important for member farmers to be present during irrigation and carry out the maintenance activities on their plot.

4.6 Maintenance of irrigation facilities

4.6.1 Principle

Well-planned maintenance activities are necessary to sustainably and effectively use irrigation facilities.

Cost of maintenance activities should be paid by users.

It is necessary to obtain agreement among the related people/organizations at the planning stage.

The facilities required for maintenance activities in irrigated rice farming are approximately classified into paddy field, canal, reservoir, pipe line and pump. Representative maintenance activities are summarized in Table 4.6 from the view point of activity, frequency and responsible people/organization.

Table 4.6 Examples of representative maintenance activities

Targeted facility	Activities	Frequency	Responsible people/ organization
Paddy field	Walk-around check	Daily	Farmers
	Care of levee, intake and outlet	Regular (before cultivation)/ Daily	
Canal	Walk-around check	Daily	Farmers' group
	Desilting and mowing	Regular (before cultivation)/ Daily	
	Rehabilitation	Irregular	
Reservoir	Walk-around check	Daily	Reservoir manager
	Mowing and tree trimming at bund	Regular	
	Desilting	Regular (end of rainy season)	
	Rehabilitation	Irregular	
Pipe line	Walk-around check	Daily	Farmers' group
	Rehabilitation	Irregular	
Pump	Storage	Daily	Farmers' group
	Engine oil change	Regular	
	Repair	Irregular	

Points to remember concerning maintenance activities are as follows:

I. The plan of maintenance activities should be established in order to implement activities effectively.
II. Some maintenance activities may involve the cost of purchase of materials, labor and so on. Therefore, it is important to consider who pays the cost and how it is paid, and obtain agreement among stakeholders at the time of planning.
III. Technical and fund support from experts and/or government may be necessary in the case of large-scale rehabilitation of a facility. Therefore, the maintenance plan may include support from an external organization.

4.6.2 Case study

In the experimental study, the responsible organizations were SPMC for sub-pond and the Rice Farming Group (the Vegetable Farming Group joined later) for the facilities situated downstream of the pump.

Fig. 4.10 Water leak from bund

Desilting and mowing of the earthen canal by the Rice Farming Group were planned as a group activity at the beginning. However, the earthen canal could not be used and so its maintenance activities were not implemented.

There was disagreement concerning whether farmers on the upstream or downstream side should take care of the middle bund. The farmers on the upstream side came to have this responsibility after discussion, and all farmers took care of the bund based on this rule. There were some cases where water seepage from the bund did not readily stop because of insufficient compaction and type of soil used.

During the experimental study, the pump machine broke down and the Rice Farming Group sent it for repairs. The cost of repair was shared among groups as shown in Table 4.7.

Table 4.7 Cost share for pump repair

Group, organization	Cost share (GHS)	Description
Rice Farming Group	20	2 GHS/person, 10 persons
Vegetable Farming Group	40	2 GHS/person, 20 persons
Project Organizer	20	

Regarding the sub-pond, grass was established and shrubs also grew up in parts where the thatch materials were used to cover the dyke to prevent erosion. Maintaining the plant cover on the embankment was agreed to be done by SPMC and the Rice Farming Group. The points to remember regarding these activities are as follows:

-Do not remove green grass

-Dry grass should be cut and use as mulch on the embankment

-Woody plants should be removed because they cause instability of the dyke when they grow

-Activities should be implemented by more than one person for safety.

Fig. 4.11 Woody plant on the dyke of the sub-pond

Fig. 4.12 Grass for covering material on the dyke of the sub-pond

4.6.3 Lessons learned

Accumulation of knowledge on implementation of maintenance activities was still insufficient among stakeholders. However, if the people understood the significance of activities and had some experience, then maintenance activities were performed by the water users themselves.

4.7 Funds management

4.7.1 Principle

The operation and maintenance fees for irrigation facilities should be paid for and managed by users. The fund management must be implemented systematically with transparency.

The points to remember concerning funds management are as follows:

I. Financial planning on operation and maintenance should be made based on the costs of purchasing the material for operation and maintenance.
II. The responsible person should record the income and expenditure of the group in an account book.
III. The responsible person should record the income collected from members with their names in an account book.
IV. It is desirable to open a group bank account and manage the fund.
V. It is recommended to set countermeasures against non-payments. For example, to keep a reserve.

4.7.2 Case study

A policy was set that the fuel fee for the water pump should be paid by the users. However, the fuel fee was paid by the Project Organizer in the first season, and the corresponding amount was collected from group members after harvest and saved in their bank account for fuel in the next season. This was because the effect of irrigation was not clear during the first season and, accordingly, it was difficult to estimate the amount of fuel fee that was necessary to collect and spend. The members of the Rice Farming Group decided to collect fees not in kind (i.e. rice) but in cash, because cash was payable even if the yield was low. The treasurer collected the pump operation fee and the penalties as defined in the rules. The collected money was deposited in their bank account. The treasurer also recorded the income and expenditure in a cashbook.

Table 4.8 Format of cashbook and example of description

Date	Description	Income (GHS)	Expense (GHS)	Balance (GHS)	Note
1-Oct-2015		110		110	
9-Oct-2015	Fuel cost		50	60	
15-Oct-2015	Fuel cost		10	50	
15-Oct-2015	Fuel cost		10	40	
30-Oct-2015	Monthly duty	20		60	All 10 members
30-Oct-2015	Penalty	2		62	Mr. ****, 15-Oct irrigation

Regarding the expenses for facility maintenance, the Project Organizer proposed a fund management plan to the Rice Farming Group, considering renewal of the facilities once every 10 years. Considering this plan, the group members started to save money at the rate of 2 GHS per month and per person for the renewal of facilities.

Not only a financial plan but also these members' opinions were considered in deciding the amount of fees to collect in the future.

The group members also pointed out that the treasurer should keep safety space for bank documents and get ready access to the bank with a transportation means (e.g. motorbike) provided by the other members.

SPMC agreed to collect funds from community people for maintenance of the sub-pond. However, they only implemented the mowing of grass on the dyke and this did not require expenditure, and so they did not collect and save any such funds during the study.

4.7.3 Lessons learned

At the beginning of experimental study, members of the Rice Farming Group recorded only the amount of income and expenditure in their account book. Consequently, they experienced difficulty with fund management and information sharing among members. Care should be taken on the instruction of basic methods for recording in an account book, including the description of income sources and uses.

For the maintenance of community facilities such as a sub-pond, it is important to encourage the monitoring and technical instruction by local government as well as discussion in the community because it generally takes time for all members to attain understanding of fee collection and savings.

4.8 Decision making

4.8.1 Principle

Organizational decision making, such as concerning the procedures and ways to implement water management activities, should be built through discussion and meeting by members.

The members should keep a record of discussions of the meetings and confirm the contents regularly.

4.8.2 Case study

In the study, decision making regarding the water distribution plan for rice irrigation as well as the fund collection plan for operation and maintenance was attained by exchange of opinions in meetings before these activities.

After irrigation started, members of the Rice Farming Group made group decisions such as changing the method of water distribution in accordance with the actual situation. There were some cases in which some members could not participate in water distribution because of miscommunication with the other members; all the members agreed to change the day of water distribution depending on the rainfall condition, but some members were not aware of this change when it was decided by the others.

The group members also decided to collect operation and maintenance fee as a monthly membership fee, with the explanation of the estimated rehabilitation fee from the Project Organizer.

In the beginning of the study, meetings were infrequent and limited to request by the Project Organizer. Later, the members decided to hold regular meetings almost once a month. The reason could be increased numbers of matters to consider and decide as a group, because they now shouldered the pump fuel fee. Additionally, the group recorded meeting discussions. However, there were insufficient records; therefore, it was thought that continuous instruction on the description method was necessary.

4.8.3 Lessons learned

It takes some time for a group to be able to make their own decisions smoothly. When they can do this themselves, then their independence as an organization is achieved.

4.9 Multiple use of dugout water

4.9.1 Principle

Sub-pond water provides more benefits when it has multiple uses.

4.9.2 Case study

During the study, fish cultivation was preliminarily tested. In July 2015, 500 tilapia fingerlings of body length of about 4 cm were released when some water had collected in the sub-pond (Fig. 4.13 and Fig. 4.14). In the following March 2016, 45 fish of body length about 17 cm were caught (Fig. 4.15 and Fig. 4.16). As time passes after pond construction, the number of plankton should increase and thus the amount of fish will increase. However, fish farming activities were not well coordinated in the experimental study.

Fig. 4.13 Fingerling

Fig. 4.14 Release of fingerlings

Fig. 4.15 Casting a net

Fig. 4.16 Harvested tilapia

After harvesting of rice, leafy vegetables were cultivated as shown:

- One rice plot was divided into 40 micro-plots of size 5 m × 5 m (Fig.

4.17).

- Twenty women formed the Vegetable Farming Group.
- Water was pumped up from the sub-pond into a container, and watering was performed with buckets (Fig. 4.18).
- Vegetables such as jute mallow (ayoyo), roselle (bra), cowpeas and amaranth (alefu) that grow rapidly and can be harvested several times were selected (Fig. 4.19 and Fig. 4.20).

Fig. 4.17 Vegetable plots

Fig. 4.18 Water container

Fig. 4.19 Harvesting

Fig. 4.20 Harvested roselle

Harvested vegetables were sold mostly in the community and some were consumed at home.

Members of the Vegetable Farming Group collected fees for fuel in preparation for the next cultivation season. To continue with vegetable cultivation, it will become necessary to cooperate and coordinate between the two farming groups concerning plot use and pump maintenance.

When the dugout had dried up, people living in nearby communities came to fetch water from the sub-pond (Fig. 4.21) approved by the chief of the community. Under the drought condition, domestic water had a higher priority than agriculture water. At the same time, if domestic water is continuously taken from the sub-pond, there will be a need to take actions for safety during water fetching and to maintain the trampled access point. Furthermore, there will be need to invite representatives of domestic water users to SPMC.

Fig. 4.21 Fetching water from the sub-pond

4.9.3 Lessons learned

Insufficient information was gathered on multiple water uses, but it was clear that sub-pond water was available for fish or vegetable cultivation. Thus a sub-pond could provide benefits not only to rice cultivation but also to increasing incomes or improving nutrition in a community.

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