MoA

JIRCAS

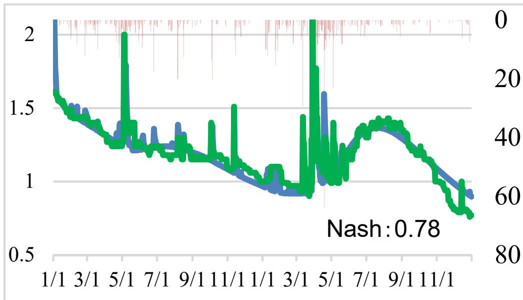
KATC

ATC

TARI

NIRC

The technical manual for contributing water use efficiency at irrigation scheme



March, 2022

Ministry of Agriculture

National Irrigation Commission

Arusha Technical Collage

Tanzania Agricultural Research Institute

Kilimanjaro Agricultural Training Center

Japan International Research Center for Agricultural Sciences

FOREWORD

The National Irrigation Commission (NIRC) of the United Republic of Tanzania is an Independent Institution under the Ministry of Agriculture, which was established under Section 3 of the National Irrigation Act No.4 of 2013 as an Independent Department of the Government under the Ministry responsible for irrigation. The Commission is a body corporate that is responsible for coordination, promotional and regulatory functions in the development of the irrigation sector.

Not only that but also, NIRC is responsible to collaborates with both National and International research Institutions to conduct different kind of research which are reflecting promotion of irrigation practices, development and management of irrigation infrastructure taking into account Integrated Water Resources Management to enhance water use efficiency as well as National Economic Development.

In this joint research project "Study on improving water efficiency in irrigation scheme in Africa (WEIRS for Rice)" which conducted in collaboration with other Government institutions (TARI, ATC, KATC) and JIRCAS, NIRC has effectively participated in different kind of activities such as plot leakage measurement, Plot Compaction, Canal surface Overlay and Update of division boxes improved our staffs competence in conducting research work especially in improving water use efficiency in crop production.

Lastly but not least, NIRC welcomes JIRCAS again and other researchers to jointly utilize our resources for mutual benefit and we are able to cooperate in all matters.

March, 2022

Daud K. Nikodemus

Director General,
National Irrigation Commission (NIRC)

MKURUGENZI MKUU
TUME YA TAIFA YA UMWAGILIAJI
S.L.P. 146 - DODOMA

FOREWORD

Globally, rice is a major food crop preferred by nearly half of the world's population (Patunru & Ilman, 2020). In Sub-Saharan Africa, Tanzania ranks second after Madagascar in terms of rice production and consumption (Kadigi et al., 2020). Consistently, rice is the second leading food crop and cash crop in Tanzania after maize. On average, about 30 percent of rice is consumed by producing households. Almost all the remainder is absorbed into the domestic market, with consumption highest in larger urban areas. Around 42 percent of all rice produced is marketed (a larger portion than any other food crop), but this is largely because of the influence of large-scale growers. Its annual production is estimated to be 2.2 million metric tons accounting for about three-quarters of the total rice produced in East Africa – making the country the top producer in the region (URT, 2019). The government of Tanzania is implementing several value-added initiatives including the 2019-2030 National Rice Development Strategy towards enhancing rice production and trade competitiveness.

However, despite the notable potential of rice development in Tanzania, it is still constrained by various challenges such as poor infrastructural development, limited technology and innovation adaptation, limited extension services, trade restrictions such as export bans. If Tanzania needs to expand its rice trade competitiveness in both regional and international markets, the government needs to promote and upgrade infrastructural networks including irrigation and road networks in cultivation areas, processing areas as well as Research and development in identifying better markets, better agricultural practices such as better seeds, control of pests and diseases, to produce better quality rice with international standards capable of standing trade competition. This shall enable the country in widening the market share of rice in both regional and international markets. In this regards Japan's Ministry of Agriculture, Forestry and Fisheries instructed JIRCAS (Japan International Research Center for Agricultural Sciences) to conduct the joint research titled "***Study on Improving Water Efficiency in Irrigation Scheme in Africa*** (WEIRS for Rice)". Which was implemented from February 2017 to March 2022 through support of the Japanese Government. The research was implemented in collaboration with Tanzania Ministry of Agriculture (MoA), National Irrigation Commission

(NIRC), Arusha Technical College(ATC), Tanzania Agricultural Research Institute Selian Center and Kilimanjaro Agricultural Training Center (KATC). Since then the research managed to accomplish different findings related to water resources, irrigation infrastructure, water saving rice cultivation which once was the problem faced farmers in Kilimanjaro and Arusha regions.

ATC as one of the collaborator in the research, we would like to express our great thanks to the Japannese Government, Ministry of Agriculture, Forestry and Fisheries of Japan, JIRCAS and all partners for the support and cooperation in this research.

Furthermore, the manual compiled from the research project is meant to train and develop the skills of expertise and farmers for rational decisions, henceforth government engineers need to provide the necessary scientific, technical, and agricultural knowledge of hydrology, hydraulics, and cultivation by observing the steps written in this Irrigation Manual for the goals intended to be achieved.

Special thanks are owed to JIRCAS Committee (Japan International Research Center for Agricultural Sciences) for their economic support in manual preparation research, technical review and for encouraging the publication of this Manual.

Last but not least, a lot of appreciations to those whose hard work contributed to the success of this valuable Irrigation manual in which the knowledge to users will bring more production, competitive and profitable rice sector that will deliver increased output for internal consumption as well as for export, and contribute to reducing poverty, improving food security and providing a better quality of life for all Tanzanians

March, 2022

Dr. Musa N. Chacha
Rector, Arusha Technical College

FOREWORD

Tanzania Agricultural Research Institute (TARI) is a semi-autonomous body under the Ministry of Agriculture responsible for all agricultural research activities conducted by public and private research institutes or organizations in Mainland Tanzania. TARI mandate is to conduct basic and applied research, regulate, promote, coordinate agricultural research on crops, crop products and by-products, soil and water management, soil mapping, agro-forestry, agricultural engineering, socio-economics, biotechnology and climate change management in Tanzania. TARI aims at strengthening national agricultural research system to enhance development and dissemination of technologies and innovations to address the real needs of farmers and other agricultural stakeholders.

We extend our sincere appreciation to all members of the JIRCAS and other stakeholders who in one way or another contributed to the preparation of this manual. It is our great hope that this manual will contribute to enhancing production and productivity of rice sub sector in Tanzania.

March, 2022

DIRECTOR GENERAL
TANZANIA AGRICULTURAL RESEARCH INSTITUTE
P. O. Box 1571
DODOMA

Dr. Geoffrey Mkamilo
Director General,
Tanzania Agricultural Research Institute

KATC FOREWORD

The **Kilimanjaro Agricultural Training Center, Moshi** (**KATC**) in the Kilimanjaro Region of the United Republic of Tanzania, an educational institution under the Ministry of Agriculture, was established to provide training to farmers on good agricultural practices so as to improve rice production and productivity in Tanzania. KATC also provides training at Certificate and diploma levels, and collaborates with research institutions for collaborative research.

In a this joint collaborative research project ***"Study on improving water efficiency in irrigation scheme in Africa (WEIRS for Rice)"*** KATC has effectively participated on experiments at plot level, specifically on Water saving cultivation techniques, AWD (Alternative Wetting and Drying) both at the centre and in farmers' fields. Data from the trial plots were submitted to JIRCAS.

We thank JIRCAS for this collaboration. Our tutors who participated in a project are now competent in research work due to experiences they gained in this project

Lastly but not least, KATC welcomes JIRCAS and other researchers to jointly utilize our resources for mutual benefit.

Shauritanga N. Nicodemus (Mr.)

Principal of KATC – MOSHI

Kilimanjaro – Tanzania

PRINCIPAL
Kilimanjaro Agricultural Training Centre
P. O. Box 1241 Moshi - Tanzania

FOREWORD

In African countries, the demand for rice is continuously increasing due to population growth and the spread of rice eating culture. Japan launched the Coalition for African Rice Development (CARD) at the 4th Tokyo International Conference on African Development (TICAD4) held in 2008, and set a goal of doubling rice production in sub-Saharan Africa from 14 million tons to 28 million tons by 2018, which has been achieved. However, based on the situation in which the demand for rice greatly exceeds its supply, CARD2 was launched at TICAD7 held in 2019 with the goal of further doubling rice production by 2030 (rice production of 56 million tons was targeted). The Japan International Research Center for Agricultural Sciences (JIRCAS) cooperated in CARD and cooperates in CARD2 with 10 international organizations and research institutes related to Africa.

To date, in response to the growing demand for rice in Africa, development of paddy fields, installation of the irrigation facilities, as well as dissemination and improvement of cultivation techniques in low-land rice field, which were implemented by international donors, have resulted in relatively high yields in some areas. However, many areas, in which irrigation facilities had been installed, have not met expected achievements due to several issues. For example, decreasing amounts of water availability resulting from instability of river flow and deterioration of water-use facilities as time passed, and uneven water allocation between upstream and downstream in irrigation areas, with excessive water intake upstream while there is water shortage downstream.

Japan started its support for rice cultivation in Tanzania in 1974. Since then, Japanese experts have conducted activities aiming to establish the techniques of irrigated rice cultivation in the Lower Moshi district. Since the 1980s in this district, irrigation facilities have been developed by yen loans, and following technical and financial support have helped spread irrigated rice cultivation to neighboring areas so that the northern region of Tanzania became Africa's leading rice cultivation zone. In recent years, however, it has become necessary to restructure the agricultural development methods from the perspective of deterioration in water facilities, decrease of irrigated area, as well as issues related to environmental changes and poor management, and farmers' economic independence.

Under these circumstances, Japan's Ministry of Agriculture, Forestry and Fisheries instructed JIRCAS to conduct a study on Improving Water Efficiency in Irrigation Schemes in Africa. JIRCAS conducted this research project in Tanzania with the Tanzanian Ministry of Agriculture, the National Irrigation Commission, Arusha Technical Collage, Tanzania Agricultural Research Institute Selian Center, and Kilimanjaro Agricultural Training Center from April 2017 to March 2022.

After 2020, it became quite difficult to travel overseas from Japan due to the COVID-19 pandemic. In spite of these circumstances, we have continued a variety of experiments and research thanks to the cooperation of Tanzanian partners, and published several papers as a result of this research, moreover we also compiled this "Technical Manual for Improving Water Efficiency in Irrigation Schemes". We express our gratitude to all those who have cooperated with us in this research project. Furthermore, Ms. HIROSE Chikako, who was engaged in this research, passed away suddenly due to illness in January 2021. As well as Dr. Nuru Ressa Mziray, who played a leading role in our Tanzanian counterpart Arusha Technical Collage, passed away due to the coronavirus on the same year in August. Their contributions to the research project were magnificent and we sincerely express our condolences.

The manual compiled here is the result of this research project. It is our great hope that this manual contributes to the promotion of rice cultivation in sub-Saharan Africa.

March 2022

NAKASHIMA Kazuo
Program Director,
Japan International Research Center
for Agricultural Sciences

Preface

In sub-Saharan Africa, rice production falls short of consumption. As a result, the region's rice importations from Asia or North America have been increasing year by year. In addition, according to "Prospects for Global Food Supply and Demand in 2029" by the Ministry of Agriculture, Forestry and Fisheries of Japan, the importing of rice in Africa is estimated to increase from 16.3 million tons to 24.7 million tons (MAFF, 2020).

Given such situations, at the Fourth Tokyo International Conference on African Development (TICAD IV, 2008), international organizations, such as the Japan International Cooperation Agency (JICA), launched the initiative known as the "Coalition for African Rice Development (CARD)," with the goal of doubling rice production in Africa in ten years (2008–2018).

Although doubling rice production was achieved in 2018 by implementing CARD Phase 1, the demand for rice is still increasing due to the increase in population and the spread of rice food in Africa. For this reason, at TICAD 7 held in Yokohama in 2019, CARD Phase 2 was launched with the goal of further doubling rice production by 2030 (JICA, 2019).

While employment in agriculture occupies 59% (UNDP, 2015), the GDP share of the agricultural sector in sub-Saharan Africa is only 16% (FAO, 2014). Thus, productivity improvement of the agricultural sector is one important issue that needs to be tackled in poverty reduction.

CARD conducts various activities aimed at increasing agricultural production including expanding cultivatable land (irrigated, rain-fed, and upland). In the case of rain-fed cultivation, rice cultivation practices in Japan, such as bund construction and transplanting, were introduced through MAFF and JICA projects. In the case of irrigated cultivation, large-scale irrigation projects were conducted by Japan and other donor countries.

Irrigated land area accounts for 24% of total area devoted to rice cultivation in Africa (Khagy et al., 2002). The yield is 3.4 t/ha, which is higher than that for rain-fed rice (2.0 t/ha) (Somado et al., 2006). Many large-scale irrigation schemes have been developed by donor countries. There are some cases where planned areas could not be irrigated because irrigation water could not reach the terminal plots, and so this assistance cannot be used effectively.

Analyzing this problem and proposing countermeasures can contribute to the efficiency of water resource use, as well as to effective assistance, efficient use of water resources, and the stable supply of food in Africa.

Factors that affect inability to irrigate the planned area can be divided into water sources, intake facilities, waterways, and field conditions according to the water conveyance route.

This manual explains some of the technologies contributing to water resource use efficiency by water conveyance route.

The manual is classified into the followings according to the content/user:

1) Engineering improvement of canals and plots user: government engineering staff like NIRC.

2) Water management users: government staff (engineering and extension division) and water users' association (WUA).

3) Water saving cultivation user: government staff (extension division) and farmers.

The following manuals were already prepared and utilized with Japanese technical cooperation in Tanzania.

Engineering manuals: Standard Design Manual (edited by JICA and Tanzania Government, managed by NIRC) and Rehabilitation Manual (edited by JICA and Tanzania Government, managed by NIRC).

Water management manuals: Manual for Water Distribution in Irrigation Scheme (edited by JICA and Tanzania Government, managed by NIRC)
https://www.nirc.go.tz/uploads/publications/en1566294701-Water%20distribution%20manual%20V1-converted.pdf

Cultivation manual: Rice Cultivation Technology (edited by JICA and Tanzania Government, managed by Ministry of Agriculture).

Additionally, the “JICA Technical Manual for Rice Cultivation in Africa” was published in 2021 in which the JICA manuals published in African countries were integrated.
(https://riceforafrica.net/wp-content/uploads/2022/05/jica_manual_1apr2021_en.pdf)

This manual explains some methods that contribute to improving water utilization efficiency in response to water resource constraints and facility deterioration that will become more serious in the future and complements the above manual.

For this reason, this manual introduces technologies that are not introduced in the JICA manual on the premise that the abovementioned manuals established by JICA are used.

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Abbreviation

Abbreviation	Full name
ASTM	American Society for Testing and Materials
ATC	Arusha Technical Collage
AWD	Alternate Wetting and Drying
BS	British Standard
CSV	Comma-Separated Values
DEM	Digital Elevation Model
GA	Genetic Algorithm
GRG	Generalized Reduced Gradient
IRR	Internal Rate of Return
JICA	Japan International Cooperation Agency
JIRCAS	Japan International Research Center for Agricultural Sciences
KATC	Kilimanjaro Agricultural Training Center
KML	Keyhole Markup Language
LMIS	Lower Moshi Irrigation Scheme
LOMIA	Lower Moshi Irrigators' Association
MAFF	Ministry of Agriculture, Forestry and Fisheries Japan
NIRC	National Irrigation Commission
NSE	Nash-Sutcliffe efficiency
PIM	Participatory Irrigation Management
SCEUA	Shuffled Complex Evolution
TARI	Tanzania Agricultural Research Institute
WRPD	Water Requirement per Day
WUA	Water Users' Association

Supervising Editor: (Alphabetical order)
Dr. Frank Mmbando (TARI)
Dr. HORINO Haruhiko (Osaka prefectural Univ.)
Dr. KITAMURA Koji (National Agriculture and Food Research Organization)
Dr. Musa N. Chacha (ATC)
Mr. Nicodemus Shauritanga (KATC)
Ms. Rukia B. Makweta (KATC)
Mr. Saidi Hussein Ibrahim (NIRC)
Dr. TORIYAMA Kazunobu (Yamagata Univ.)
Dr. YAMAJI Eiji (Tokyo Univ.)
Dr. Yona Anderson (ATC)

Author

Chapter 1
HIROUCHI Shinji (JIRCAS)

Chapter 2
HIROSE Chikako (JIRCAS), HIROUCHI Shinji (JIRCAS)

Chapter 3
HIROUCHI Shinji (JIRCAS), Buzimi Mabula (NIRC), Juma O. Mdeke (NIRC), HIROSE Chikako (JIRCAS)

Chapter 4
HIROUCHI Shinji (JIRCAS), Buzimi Mabula (NIRC), Juma O. Mdeke (NIRC), HIROSE Chikako (JIRCAS)

Chapter 5
HIROUCHI Shinji (JIRCAS), Buzimi Mabula (NIRC), Juma O. Mdeke (NIRC), HIROSE Chikako (JIRCAS)

Chapter 6
HIROUCHI Shinji (JIRCAS), Buzimi Mabula (NIRC), Juma O. Mdeke (NIRC), HIROSE Chikako (JIRCAS), UNO Kenichi (JIRCAS)

Chapter 7
YANAGIHARA Seiji (JIRCAS), Zawadi Mbwambo (KATC), Nestory Pantaleo (JIRCAS), Christofa Marka (JIRCAS)

Chapter 8
SHINDO Soji (JIRCAS), UCHIMURA Motomu (JIRCAS)

Special Thanks
Dr. Nuru Mziray (ATC)
Mr. Valencｉ Shirima, Ms. Getrude Silayo (KATC)
Mr. Fred Mawolle (KADP)
Ms. Violeth N. killeo, Mr. Gift Mayagila (Arusha region)

Acknowledgement
Ms. HIROSE passed away in January 2021. Dr. Nuru Mziray passed away in August 2021. Both were focal persons for our study. Also, their contribution for this manual was enormous. We were all very sorry for their loss. May they rest in peace.

Foundation
This manual is funded by Ministry of Agriculture, Forestry and Fishery Japan

1. Estimating the effect of measures to improve efficiency of water resource utilization

1.1. Changes in irrigation area in the Lower Moshi Irrigation Scheme

Irrigation area of Lower Moshi is far below the planned area of 1,500 ha, except for 1990 and 2020

・Planned irrigation area of Lower Moshi was 1,500 ha per year after revision by JICA expert in 1987;
・Planned irrigation area was calculated to be irrigable even in 5 year probability drought year;
・After completing construction at Lower Moshi (1987), the annual irrigation area almost reached 1,500 ha for only two years, in 1990 (1,492 ha) and 2020 (1,482 ha) (**Fig. 1.1**);
・Up to 2002, actual irrigation area was recorded;
・After 2014, irrigation area was estimated by satellite image (e.g. Landsat and Sentinel, EO Browser https://apps.sentinel-hub.com/eo-browser/ and Copernicus https://scihub.copernicus.eu/dhus/#/home).

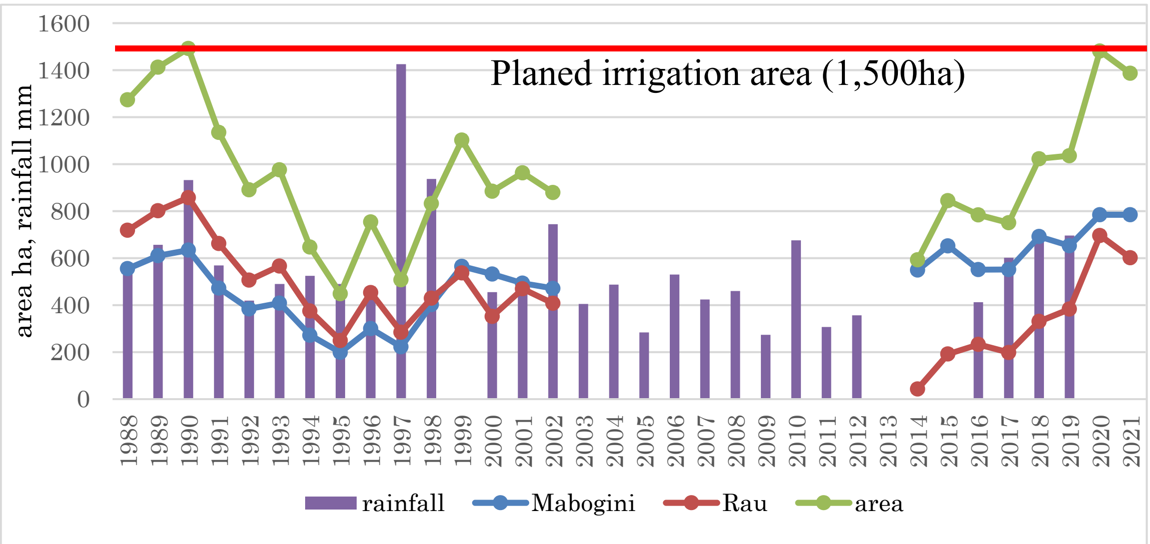


Fig. 1.1 Actual irrigation area and annual rainfall in Lower Moshi

1.2. Effect of measures to improve the efficiency of water resource utilization in the Lower Moshi

At Lower Moshi, although the actual irrigation area was 1,079 ha in 2019, if the measures are introduced, the irrigation area would increase to 2,304 ha (i.e. 1,225 ha increase)

Followings are indicated in **Fig. 1.2**:
Left bar indicates actual irrigation area in 1990 (by sub-LOMIA); center bar indicates the actual irrigation area in 2019 plus incremental area if the water use efficiency measures are implemented (by sub-LOMIA); and right bar indicates the incremental area when implementing the water use efficiency measures are added onto the actual irrigation area (by sub-LOMIA).

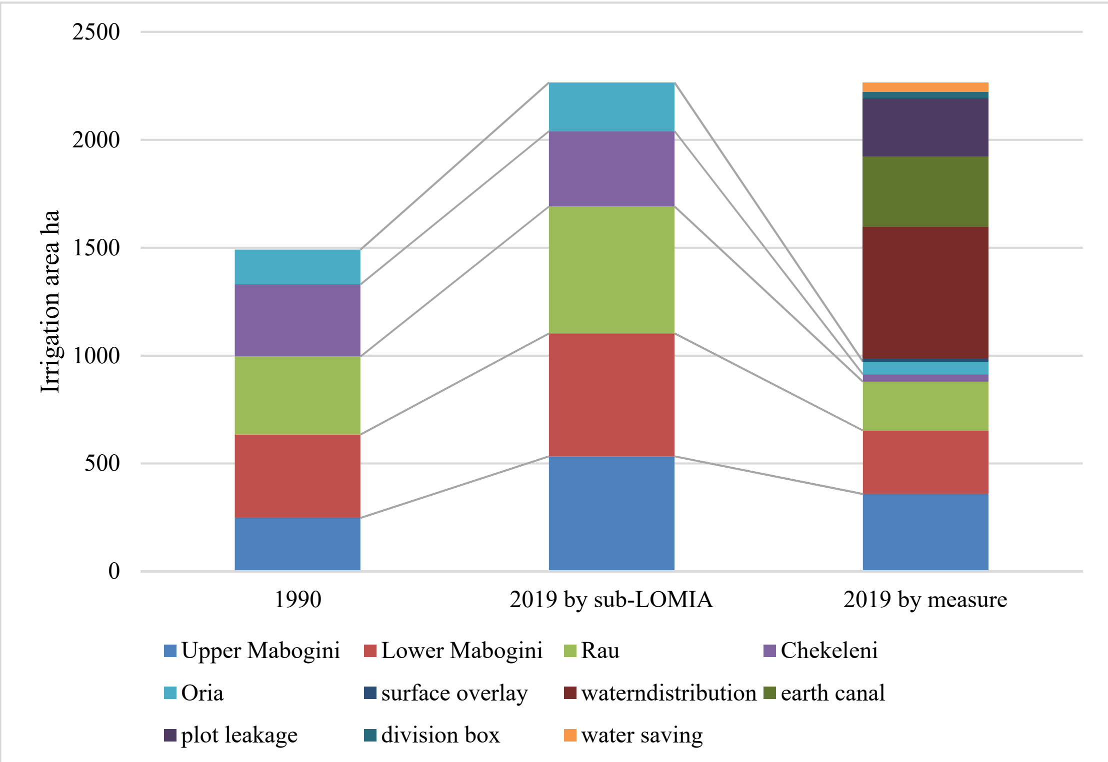


Fig. 1.2 Comparison of actual irrigation area in 1990 with irrigation area if the water use efficiency measures are implemented in 2019

Fig. 1.3 shows the ratio of the increased irrigation area if the water utilization efficiency measures were implemented in the actual irrigation area in 2019 by measures. Water distribution, soil canal countermeasure construction method, and crushing compaction construction method have large proportions.

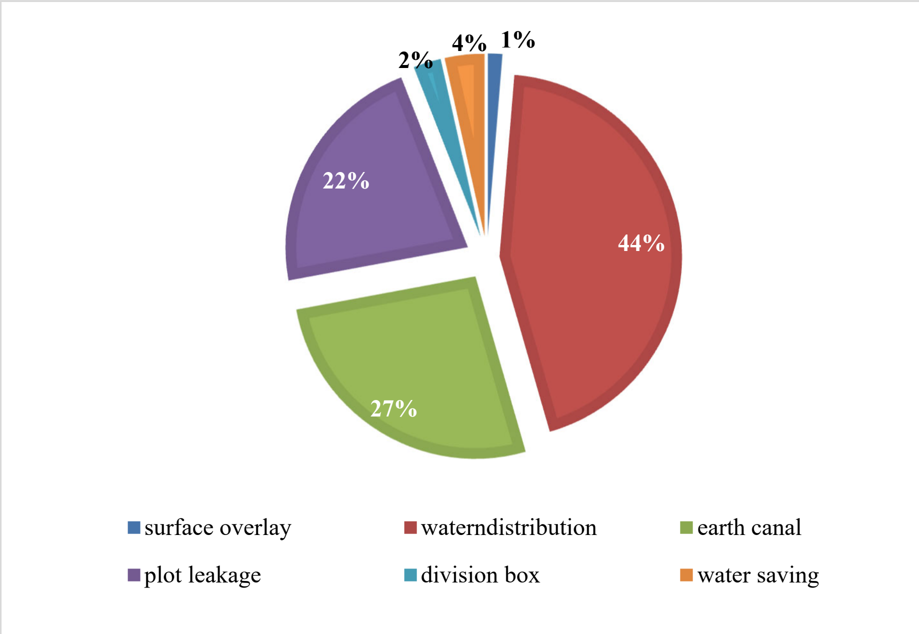


Fig. 1.3 Additional irrigable area contribution ratios for water use efficiency measures

The cost and economic evaluation (internal rate of return, IRR) for implementing water use efficiency measures in 2019 is shown in **Table. 1.1.**

Feasibility changes depend on the long-term interest rate of the government at implementation time and estimations of service life. As a guide, the interest rate of long-term bonds (treasury bonds) is 11.44% (September 2021[1]), and the inflation rate of Tanzania is 3.2% (2021[2]) (**Fig. 1.4)**, meaning that the real interest rate is 8.2%. If the IRR is higher than this, the measure is feasible.

[1] https://www.bot.go.tz/TBonds
[2] https://www.imf.org/en/Countries/TZA

Table. 1.1 Cost and IRR for water use efficiency measures by sub-LOMIA (1,000USD)

	Upper Mabogini	Lower Mabogini	Rau ya Kati	Chekeleni	Oria	Total	IRR
Water distribution	0	0	0	0	0	0	-
Surface overlay	-	-	51	-	-	51	20%*
Earth canal	10	8	6	1	2	26	-
Plot leakage measurer	0	1,615	1,241	187	324	1,584	10%
Division box	20	16	13	2	4	54	78%
Water saving cultivation	0	-	-	-	-	0	-
total	30	1,639	1,311	190	330	1,715	

* for the case that construction length is 4,000 m

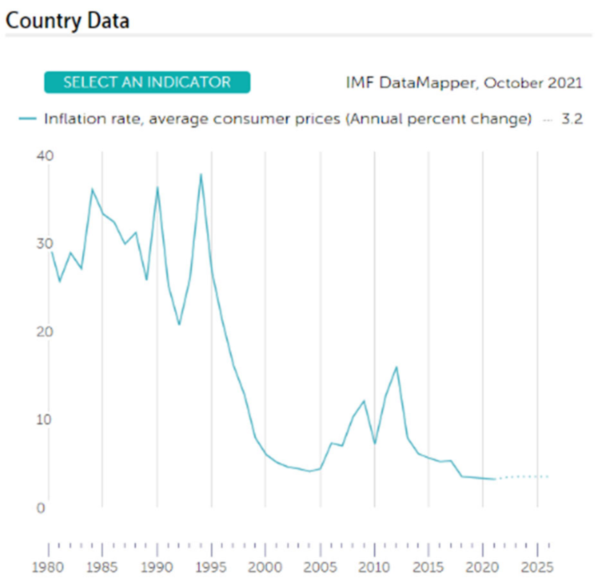
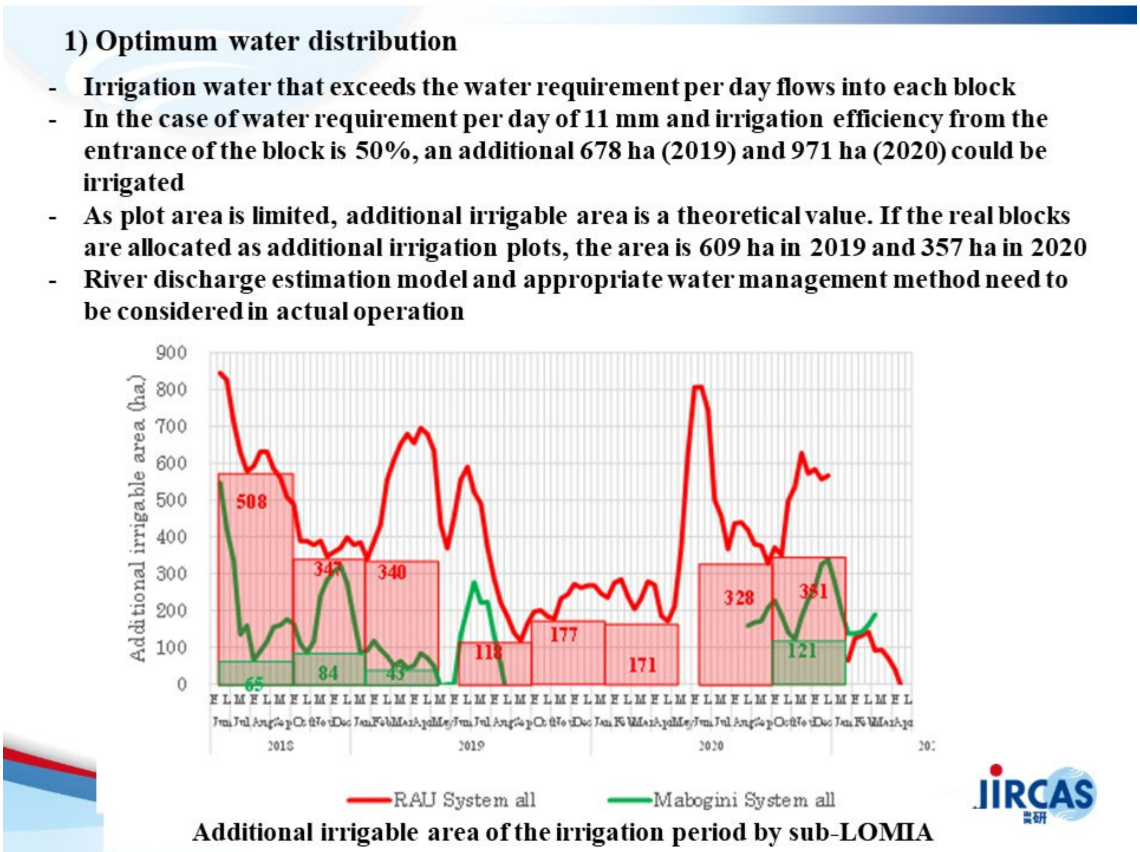


Fig. 1.4 Inflation rate (consumer prices) over time in Tanzania (source: IMF)

1.3. Outline of water use efficiency measures

Seven measures are introduced as water use efficiency measures:
1) Optimum water distribution
2) Canal surface overlay
3) Earth canal leakage
4) Renewal of division boxes
5) Crush and compaction (plot leakage measure)
6) Water saving cultivation
7) Water management



2) Canal surface overlay

- Average improvement ratio of roughness coefficient (RC) is 0.86
- Algae emerges on the surface after 3 months in service: RC 0.0155→0.0181
- Removal by squeegee, RC 0.0178→0.0163, within farming activity
- The same cross-section of Lower Moshi canal (water depth 0.6 m) leads to a flow volume increase of 0.071 m^3/s (16%)
- If introduced in Rau system, additional irrigable area is 16 ha
- Cost (direct cost: overlay quantity 2.5 m^2/m) of acrylic is half of epoxy resin
- Service life is being investigated
- If service life is 2 years and construction length is less than 4,000m, it is feasible (IRR exceeds 20%) (repair twice per year, repair cost 8.9USD/100 m)


Surface cleaning


Check strength


Spray

RC by materials and cost (USD/m)

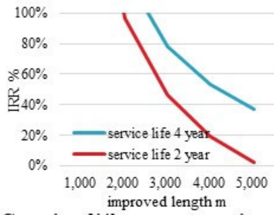
	Before	After	Ratio	Cost
RS1-7 Acryl	0.0184	0.0155	0.84	6
MS7-1 Acryl	0.0170	0.0148	0.87	6
MS7-1 Epoxy	0.0139	0.0121	0.87	12
Average	0.0164	0.0141	0.86	


Before


After


Algae


Removal of



Service life, construction length, and IRR

3) Earth canal leakage

- Cost for vinyl sheet lining is 1/10 of concrete lining
- IRR of concrete lining is more than 16% (for service life of 10 years)
- Laying 30 m of vinyl sheet lining saves half of the plot seepage (water requirement per day is 11 mm/d)
- Cost for vinyl sheet lining is 80 USD/ha (6% of the 1,350 USD/ha income from paddy rice cultivation)
- If vinyl sheet lining is implemented in all MS6-1 earth canals (32.1 ha, 1,820 m, 1,500 USD), the irrigable area increases by 10.7 ha
- Vinyl sheet lining is effective, cost bearer and waste disposal method should be considered


Material (vinyl sheet)


Elimination of garbage


Cutting


Laying


Flowing


One season after operation

Cost for measures

	Length (m)	Price (USD)	Unit price (USD/m)
1) Concrete lining	90	4,416	49.1
2) Masonry lining	90	3,415	37.9
3) Geomembrane lining	90	4,322	48.0
4) Polyethylene sheet lining	90	361	4.0

4) Renewal of division box

- Leakage occurs as the surrounding of division box (DB) is eroded
- Leakage change by board renewal: 4.5 m^3/h (54 m^3/12 h)→3.6 m^3/h (43 m^3/12 h)
- 11 m^3/12 h of leakage is saved by board renewal: equivalent to irrigation water volume of 500 m^2 (WRPD is 22 mm)
- 53.6 m^3 leakage is saved (= 2,400 m^2 paddy field), if all DBs in the block are repaired
- Average leakage at MS5-1 is 268 m^3 (53.6 m^3/box), additional irrigable area is 1.22 ha (3.1% (1.22/39.67) of block area), five DBs at MS5-1 (1,870USD), income from paddy is 1,350 USD/ha = 1,647 USD/1.22 ha, and IRR is 28% (service life is 5 years)
- 30 ha is additionally irrigable in whole Lower Moshi


Investigation of DB


Deterioration of DB


Leakage test (before renewal of board)


Leakage test (after renewal of board)


Removal


Renewal

Result of leakage test (before/after board renewal)

	Original		Renewal	
	Water level decrease (cm/min)	Leakage vol (m^3/h)	Water level decrease (cm/min)	Leakage vol (m^3/h)
Division box 1	not ponding	-	2.2	3
Division box 2	3.5	4.7	3	4.1
Division box 3	3.8	5.1	2.9	3.9
Division box 4	2.8	3.8	2.1	2.8
Ave		4.5		3.6

5) Plot leakage measure (crush and compaction)

<Experimental construction>
- WRPD: 23.7→13 mm, no difference among the compaction times

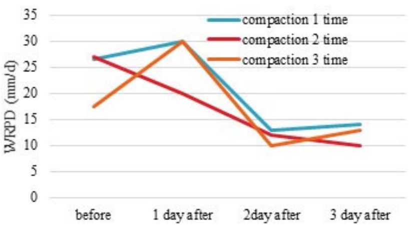
<Farmers' plots>
- With measure: 17.0→12.0 mm/d, control: 15.5→18.0 mm/d
- For WRPD of 17.0→12.0 mm, irrigable area increases by 44% (i.e. (17 − 12)/11.3)
- Direct cost: 5,888 USD/ha, income from paddy is 1,350 USD/ha, increase area is 0.44 ha/ha, IRR is 10.0% (evaluation period is 20 years)
- If implemented to all actual cultivated area at Lower Moshi in 2019 (613 ha), increases area by 269 ha (Upper Mabogini (359 ha) is excluded)


Topsoil treatment

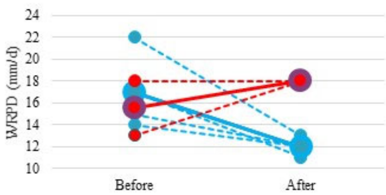

Hard pan crush


Compaction


Topsoil return



Result of experimental construction



WRPD at farmers' plot (blue: const, red: control, WRPD of first day is excluded, solid line is average, dashed line is individual plot)

6) Water saving cultivation

Training of irrigation water measurement

Variety used
TXD306 (SARO5)

Cultivation method
Plant density: 20cm × 20cm (2plants/hill)
Fertilizer: Split application of Nitrogen120 kg/ha (Basal, 14DAT, 45DAT; Basal can be compound fertilizer)
Ditch constructed at 14DAT

Irrigation treatment
Constant irrigation(CI)
AWD7.5 (Keep water level more than -7.5cm)
AWD15 (Keep water level more than -15cm)

- Difference of order in irrigated water volume at UM(WD7.5<AWD15<CI) and that at LM(CI<AWD7.5<AWD15) suggests that ground water level may affect efficiency of water saving by AWD.
- It suggests that AWD does not improve rice yield since there was no significant difference within both UM and LM. However, further survey may be necessary since significant difference in rice yield between UM and LM was observed.

Irrigated water volume in the treatment(mm)

Farmers' field at UM

Treatment	Water volume		Mean	SD
CI	1552	1638	1595	43
AWD7.5	1574	1217	1396	179
AWD15	1434	1479	1457	22

Farmers' field at LM

Treatment	Water volume		Mean	SD
CI	2296	1850	2073	223
AWD7.5	2876	2219	2548	329
AWD15	3423	2214	2818	605

Rough rice yield in the treatment(t/ha)

Farmers' field at UM

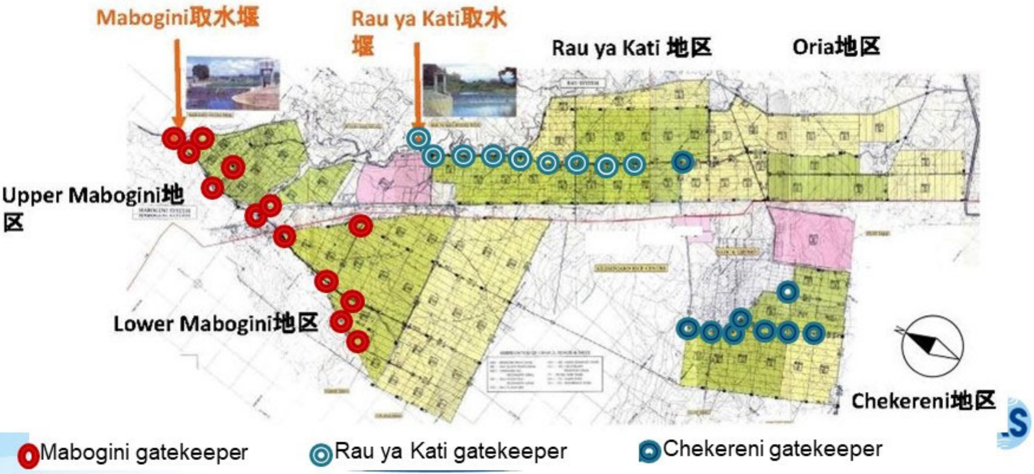
Treatment	Yield		Mean	SD
CI	9.9	9.3	9.6	0.4
AWD7.5	10.9	9.1	10.0	1.3
AWD15	10.2	9.7	10.0	0.4

Farmers' field at LM

Treatment	Yield		Mean	SD
CI	6.8	8.5	7.6	1.2
AWD7.5	8.4	8.4	8.4	0.0
AWD15	7.7	7.4	7.5	0.2

7) Water management

- In the upstream part of the main canal, more water is distributed than necessary, and there is a chronic water shortage downstream
- Water management is done by three gatekeepers, with no mutual coordination
- Five sub-LOMIAs operate independently and Central LOMIA is not functioning
- In order to improve water efficiency, we propose to reconstruct the water management system centered on Central LOMIA, disclose information on water distribution, and reconstruct the water management plan under the initiative of the government
- At the same time, diversion works and other irrigation facilities need to be renovated to ensure equal water distribution



2. Optimum water distribution

It is important that intake water for the irrigation scheme is distributed for use depending on the necessary water volume of blocks.

Fig. 2.1 shows actual irrigation water volume of blocks in the Lower Moshi Irrigation Scheme (block irrigation intensity determined by dividing irrigation water volume by block irrigation necessary water volume is indicated in this figure). Block irrigation necessary water volume of Lower Moshi is 22 mm/d (green line), and actual irrigation water volume of the block is excessive (detail explained in section 2.3)

Block irrigation necessary water volume is determined by considering water requirement per day (WRPD) and irrigation loss (section 2.2). Also, as explained in section 2.1, irrigable area of the specific period can be determined by possible intake water volume of the period. Thus, when the possible water intake volume is assumed, irrigable area of the period can be assumed. Therefore, irrigation water can be distributed more efficiently and appropriately than it is under actual conditions. Possible water intake volume can be estimated by estimating river discharge.

Thus, it is necessary to measure WRPD as explained in section 2.2 and to estimate river discharge explained in section 2.3 for implementing appropriate water distribution. Taking Lower Moshi as an example, an example of calculating the irrigable area based on the actual water intake volume is explained in section 2.3.6.3.6.

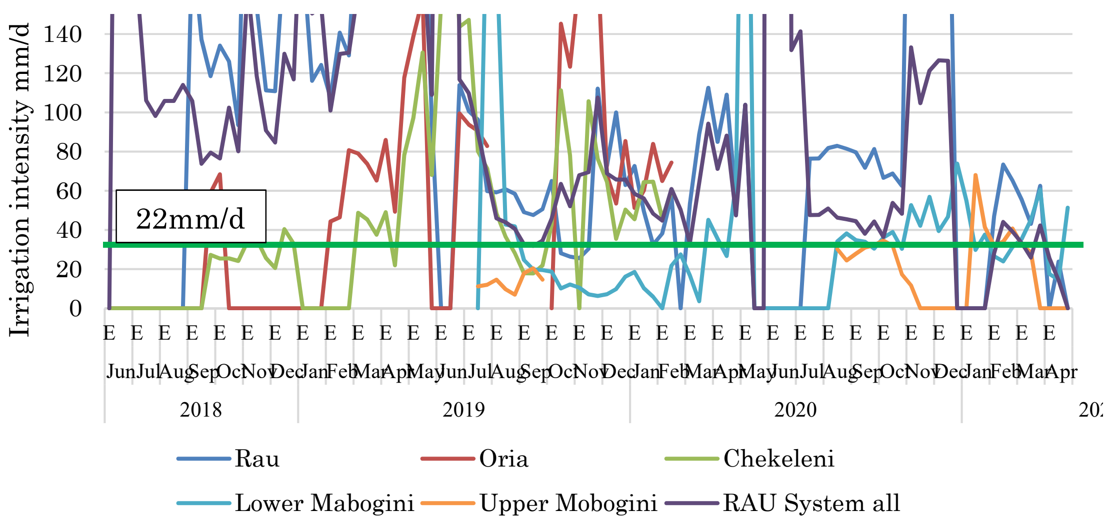


Fig. 2.1 Actual irrigation intensity by sub-LOMIA for the period June 2018 to October 2021

2.1. Irrigable area

The route of irrigation water to a plot follows: intake facility–main canal (concrete canal)–irrigation block–secondary canal (concrete canal)–division box–tertiary canal (terminal canal: earth canal)–a plot (**Fig. 2.2** and **Fig. 2.3**)

Block necessary irrigation water volume = plot necessary irrigation water volume + secondary canal loss + tertiary canal loss

Water intake volume = block necessary irrigation water volume + main canal loss

Irrigable area = maximum possible water intake volume × convey loss/plot necessary irrigation water volume

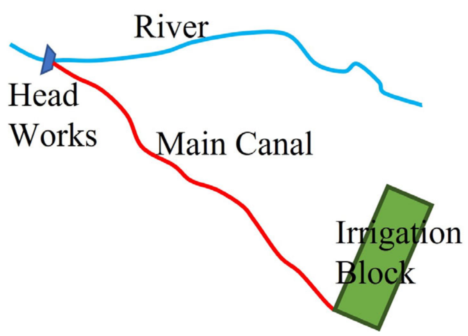


Fig. 2.2 Image of Irrigation Scheme

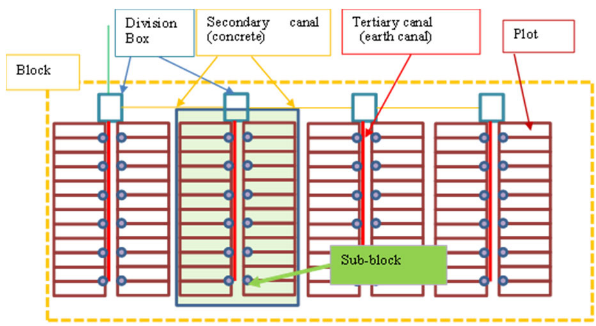


Fig. 2.3 Image of Irrigation Block

- Canal loss (convey loss) is defined as water lost as the water passes from the intake point to a plot, e.g. canal leakage. The convey loss rate varies with the distance from intake point to a plot and canal conditions (e.g. concrete or earth canal, and deterioration situation). The convey loss rate of Lower Moshi is 0.5.
- Earth canal loss (leakage and water head loss) is greater than for concrete canals. Block necessary irrigation water volume should be estimated at double that of the plot necessary irrigation water volume (the volume of water will decrease if earth canal leakage measures or effective water distribution are implemented).
- The plot necessary irrigation water volume can be determined by

measuring real water leakage of the target plot (WRPD, section 2.2). The plot necessary irrigation water volume is 11.3 mm/d at Lower Moshi.

- Possible water intake volume, necessary for calculating the irrigable area, is calculated by river flow estimation model (section 2.3).
- An example calculation of the irrigable area using actual intake volume is shown in section 2.3.6.3.6.(4).

2.2. How to measure water requirement per day

WRPD can be determined by measuring plot water-level difference.

- WRPD is a water-level change with time and is determined by measuring water level of a plot at fixed times.
- Water level is measured in at least three points in a plot to avoid measuring error.
- If there is rain during the measuring period, the data acquired during the period should not be used. If the data are used, then they should be corrected using rainfall data.
- As water requirements per day differ greatly even in adjacent plots, water level measures should be implemented at more than three plots in the same block.
- Water level measurement is performed using the following procedures (**Fig. 2.4**).

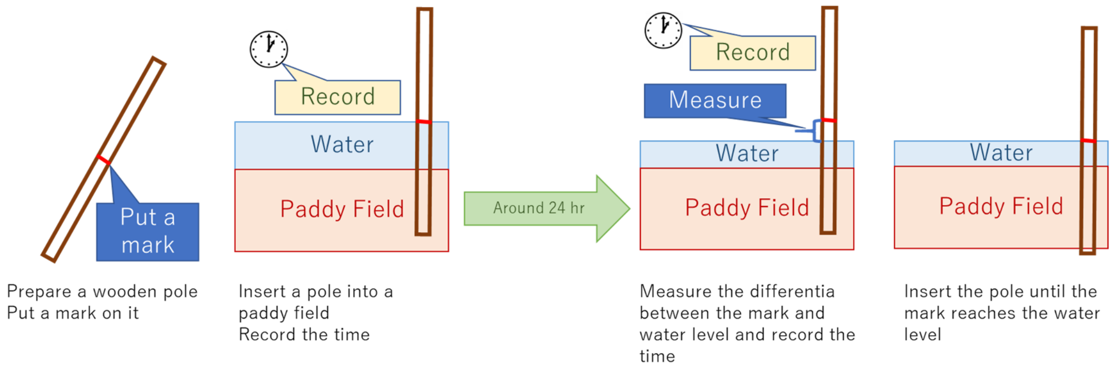


Fig. 2.4 How to measure WRPD

1) select measuring points where water is above paddy field ground level;

2) prepare wooden poles (like chopsticks) with a mark;

3) insert pole in the field until the mark reaches the water level;

4) record the time;

5) record water level from the mark and time of the next day;

6) ask farmers about the irrigation and drainage situation of the data collecting day;

7) continue steps 5 and 6 for 5 days.

2.3. How to estimate water discharge

2.3.1 Necessity and effectiveness

Irrigable area of the period changes with the possible intake water volume of the river.
If the river flow of the dry season can be estimated by the rainfall amount of the previous rainy season, irrigable area of the dry season can be estimated.

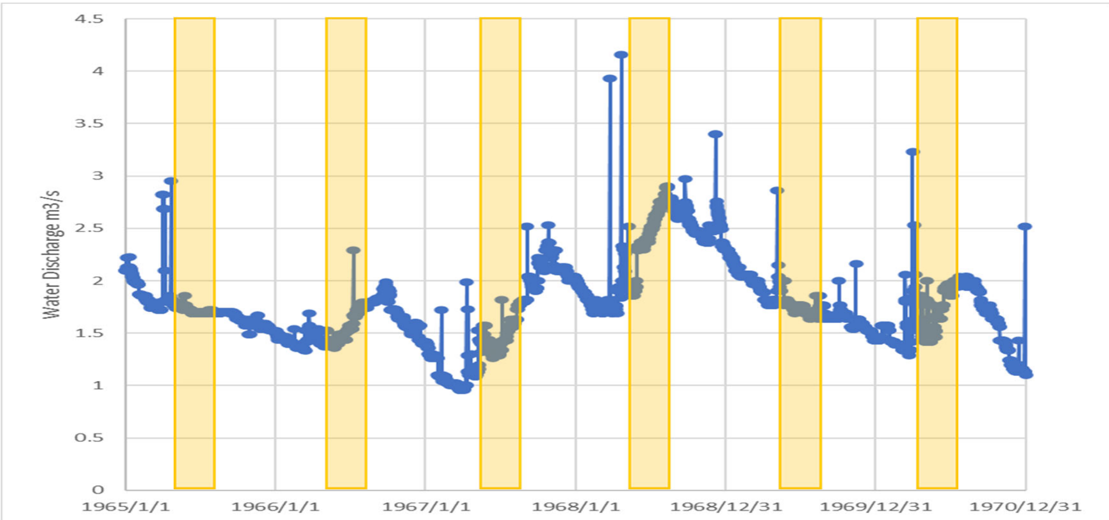


Fig. 2.5 Water discharge of the Njoro River (1965-1970): colored bands indicate rainy seasons

The water discharge of the Njoro River is shown in **Fig. 2.5**. Generally, water discharge increases in the rainy season, and decreases in the dry season. Irrigation volume of water in the dry season mostly depends on intake water from the river. Thus, if the water discharge of the dry season can be estimated, maximum irrigable area can be estimated.

2.3.2 Long-term changes of river discharge

River discharge data which is recorded by water basin authority is used. If river discharge estimation will be carried out at the river where there is no discharge record, the data shall be collected at least for 3 years.

- If the river discharge data of the target watershed are available from the water basin authority, those data should be used.
- If there are no records of river discharge data, at least 3 years of data are necessary (2 years for parameter identifications and 1 year for validation). If the number of parameters is large, it is desirable that the number of data (or years) for identifying parameter is also large.
  If new data collection is started, at least daily data should be collected. Because this manual is aimed at existing irrigation schemes, most of the irrigation water is taken from weirs constructed in a river. In this case, river discharge is estimated using **formula 1**:

River discharge = water intake volume + overflow volume from a weir (formula 1)

1) Overflow from a weir is calculated by **formula 2** (Iwasaki,1963):

$$Q = CBH^{3/2} \quad \text{(formula 2)}$$

where *C* is the flow coefficient given by **formula 3**, *B* is the width of the crest (m), and *H* is the height of head of water over the crest (m).

$$C = 1.6 * \frac{1 + 2a(\frac{H}{Hd})}{1 + a(\frac{H}{Hd})} \quad \text{(formula 3)}$$

where *a* is a constant and *Hd* is the design water head (m).
Transform **formula 3** into a function of *a*:

$$a = \frac{Cd - 1.6}{3.2 - Cd}$$ (formula 4)

Hd = 0.461 m and *a* = 0.554 at Njoro head weir (JICA, 1989).

2) Water intake volume

a) The case of a partial flume installed at the intake point

The water flow volume is determined by the standard and water depth of a partial flume. The standards for a partial flume are shown in **Table. 2.1** and **Fig. 2.6.**

Table. 2.1 Standard of a partial flume (unit: mm, JIS B7553)

Standard	W	A	B	C	D	E	F	G	K	L	N	(M)	(P)	(R)
PF-03	76.2	311	457	178	259	610	152	305	25	914	57	305	768	406
PF-06	152.4	414	610	394	397	610	305	610	76	1,525	114	305	902	406
PF-09	228.6	587	864	381	575	762	305	457	76	1,626	114	305	1,080	406
PF-10	304.8	914	1,343	610	845	914	610	914	76	2,867	229	381	1,492	508
PF-15	457.2	965	1,419	762	1,026	914	610	914	76	2,943	229	381	1,676	508
PF-20	609.6	1,016	1,495	914	1,207	914	610	914	76	3,019	229	381	1,854	508
PF-30	914.4	1,118	1,645	1,219	1,572	914	610	914	76	3,169	229	381	2,223	508
PF-40	1,219.2	1,219	1,794	1,524	1,937	914	610	914	76	3,318	229	457	2,711	610
PF-50	1,524.0	1,321	1,943	1,829	2,302	914	610	914	76	3,467	229	457	3,080	610
PF-60	1,828.8	1,422	2,092	2,134	2,667	914	610	914	76	3,616	229	457	3,442	610
PF-70	2,133.6	1,524	2,242	2,438	3,032	914	610	914	76	3,766	229	457	3,810	610
PF-80	2,438.4	1,626	2,391	2,743	3,397	914	610	914	76	3,915	229	457	4,172	610

The water flow volume of a partial flume is calculated using **formula 5**. The *K* and *n* in **formula 5** can be acquired by the standard shown in **Table. 2.1**and *K* and *n* shown in **Table. 2.2**.

$$Q = Kh^n$$ (formula 5)

where *h* is the water depth at the orange rectangle in **Fig. 2.6** (m).

Table. 2.2 Flow coefficient (*K*) and *n* of a partial flume

standard	K	n	standard	K	n
PF-03	635	1.547	PF-30	7,863	1.566
	638	1.550	PF-40	10,632	1.578
PF-06	1,372	1.580	PF-50	13,436	1.587
PF-09	1,927	1.530	PF-60	16,268	1.595
PF-10	2,487	1.522	PF-70	19,124	1.601
PF-15	3,803	1.538	PF-80	22,002	1.607
PF-20	5,141	1.550			

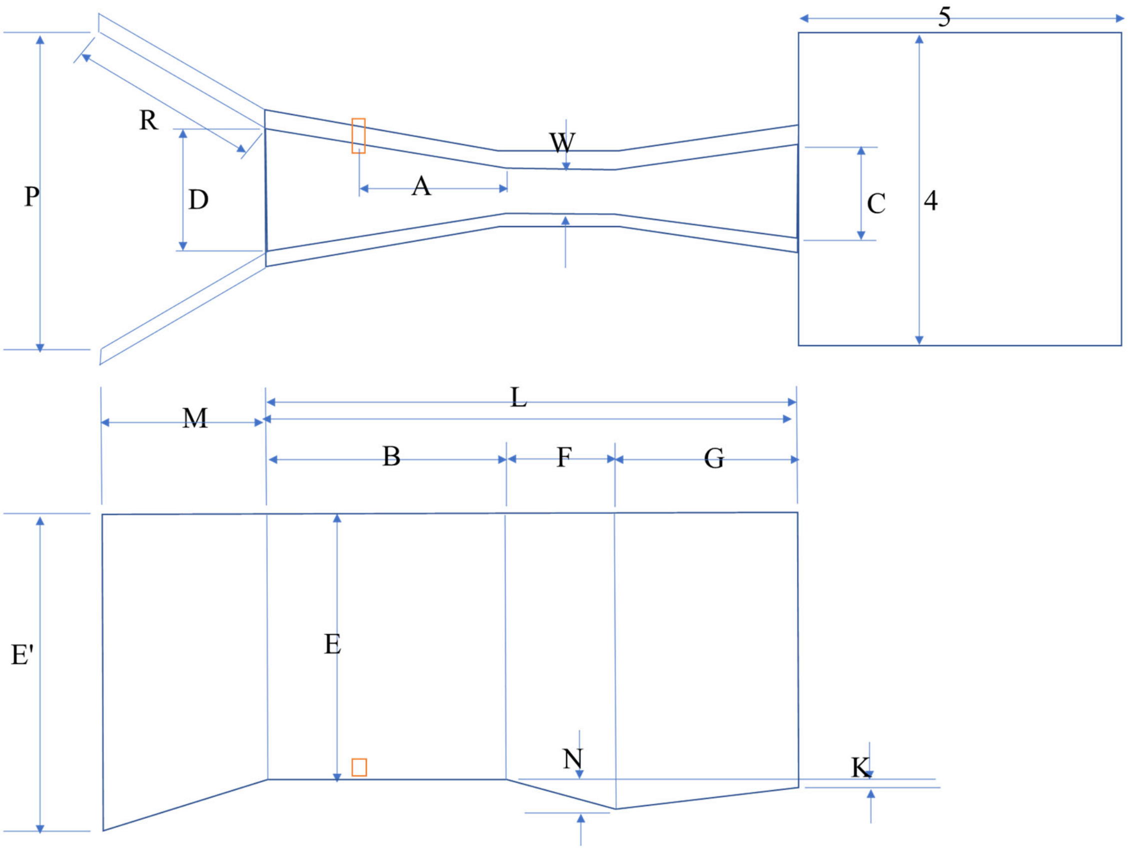


Fig. 2.6 Dimensions of a partial flume

b) The case of a gate installed at the main canal

Water flow volume can be calculated using the water depth and opening (opening height) of a gate. The water flow volume of a gate can be obtained by following measures depending on a relation between water level and gate block level (**Fig. 2.7** and **Fig. 2.8**).

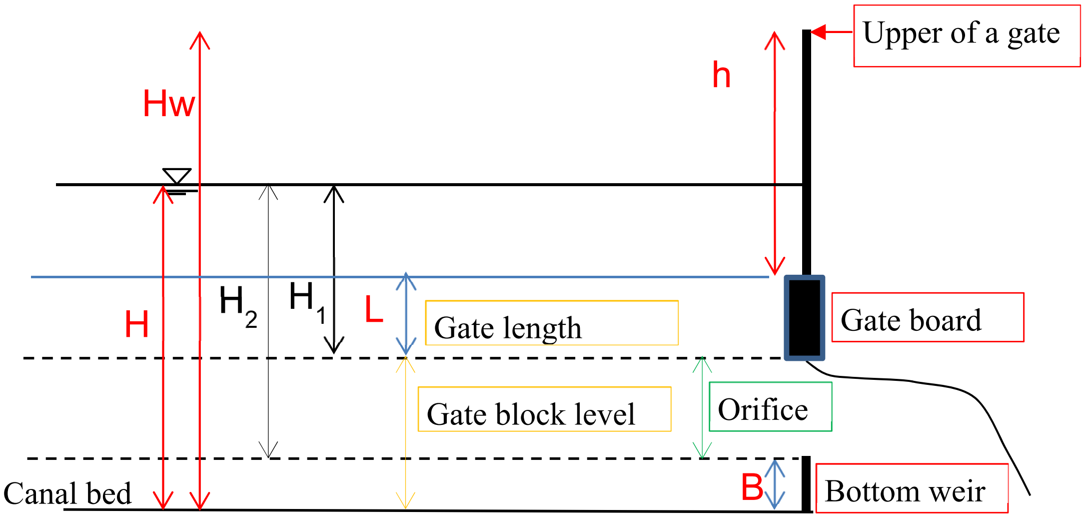


Fig. 2.7 Gate size location (diagram)

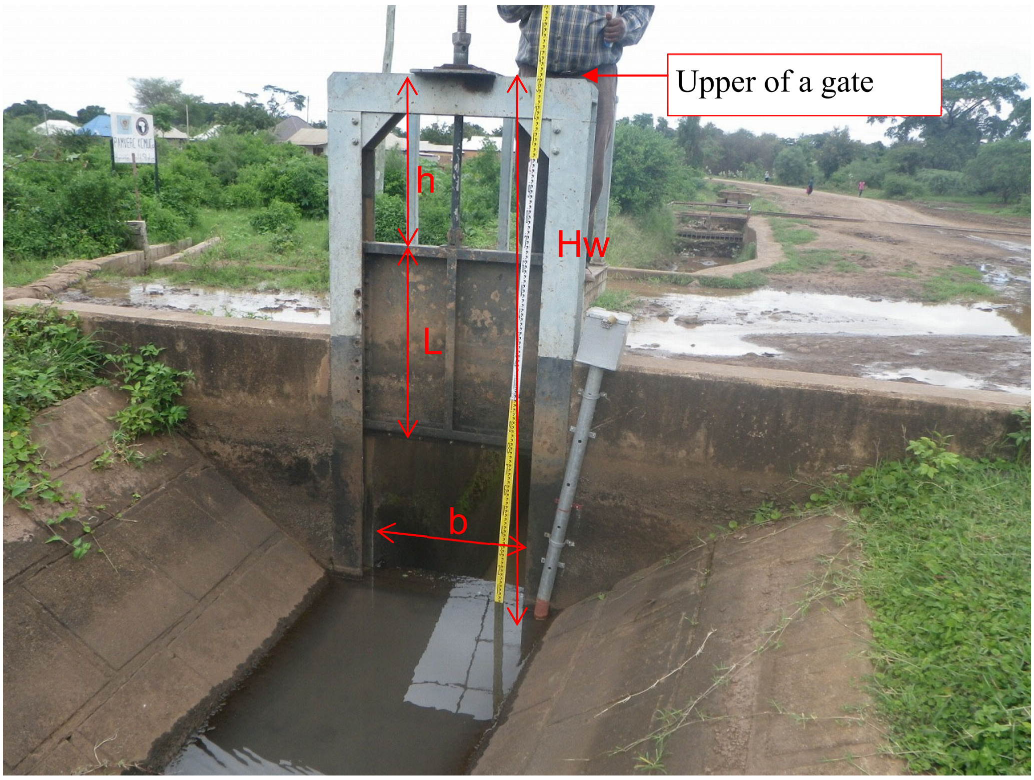


Fig. 2.8 Gate size location (picture)

- In the case that water level (*H*) is higher than gate block level (*H*w – *h* – *L)* (opening section to downstream is lower than water level: submerged weir, orifice) (**Pic. 2.1**)):

$$Q=\frac{2}{3}\cdot C\cdot b\sqrt{2g}\left(H_2^{\frac{3}{2}}-H_1^{\frac{3}{2}}\right) \quad \text{(formula 6)}$$

where Q is the volume of water flow (m^3/s), C is the flow coefficient, b is width of the cross section (m), H_1 is water depth from water surface to upper side of orifice given by $H_1 = H - (Hw - h - L)$ (m), H_2 is water depth from water surface to the bottom of the orifice given by $H_2 = H - B$ (m), g is acceleration due to gravity (9.8 m/s^2), B is the height of the bottom of the weir, Hw is the height from the canal bed to the upper part of a gate (m), L is gate length (m), and h is the height from the upper part of the gate to the upper of the gate board (m).

- In the case that water level (H) is lower than gate block level ($Hw - h - L$) (gate board is above the water level: rectangular weir) (**Pic. 2.2**)):

$$Q=K\cdot b\cdot H^{\frac{3}{2}} \quad \text{(formura 7)}$$

where Q is the volume of water flow (m^3/s), K is the flow coefficient, b is the width of the cross section (m), H is the overflow depth (m), and g is the acceleration due to gravity (9.8 m/s^2)

The K can be obtained from the gradient of the graph in which actual Q and the terms of the right-hand side of formulas 5 or 6 excluding water flow coefficient are plotted, after measuring at least three values of water flow volume of different water depth. A calculation example is shown in **Fig. 2.9**. In this case (gate installed in a main canal of the Rau system), C (gradient) is 0.547 ($R^2 = 0.933$).

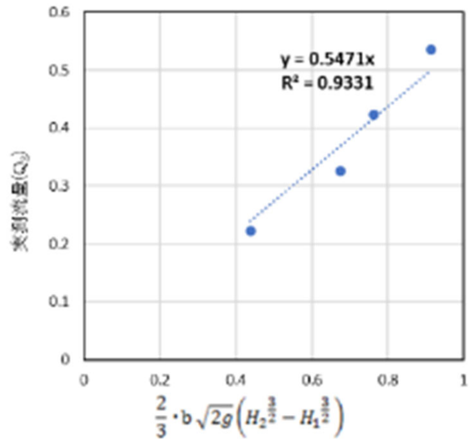


Fig. 2.9 Relationship between $\frac{2}{3}\cdot b\sqrt{2g}\left(H_2^{\frac{3}{2}}-H_1^{\frac{3}{2}}\right)$ actual Q (Rau gate)

Pic. 2.1 Situation of submerge weire

Pic. 2.2 Situation of rectangle weir

<reference> How to measure canal flow volume

Canal flow volume can be obtained by water flow velocity × cross-section area. Water flow velocity of a canal differs depending on position. Thus, a canal is divided into sections and water flow velocity of each section is measured to obtain the water flow volume of the section. A canal water flow volume can be obtained by summing up water flow volume of each section.

In the case that a canal cross-section is as shown in **Fig. 2.10**, the canal waterflow volume can be obtained by summing up the following three water flow volumes (a)–(c):

(a) multiplying the area of the left triangle and water flow velocity measured at the center survey line of the triangle gives the water flow volume of the

section;
(b) multiplying the area of the center rectangle and water flow velocity measured at the center survey line of the rectangle gives the water flow volume of the section;
(c) multiplying the area of the right triangle and water flow velocity measured at the center survey line of the triangle gives the water flow volume of the section.

The water flow velocity of the survey line is obtained by the average velocity at the points where water depth is 20% and 80% of the survey line water depth. A current meter (e.g. electromagnetic or propeller) is used to measure water flow velocity.

One point for the center of a canal slope (two points give values for both sides) and one point for the center of a canal is enough for a secondary canal (canal bed width 0.3–0.4 m, maximum water depth less than 0.5 m, and canal slope gradient 1:1) (**Fig. 2.10**).

In the case of large-scale main canal (total width around 2.0–3.0 m), water flow velocity is measured every 0.1–0.2 m and water flow volume is calculated by multiplying water flow velocity and cross-section area.

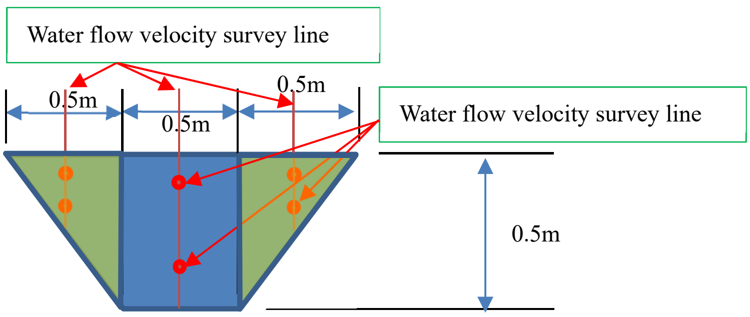


Fig. 2.10 Water flow velocity measuring points for a secondary canal

2.3.3 Rainfall

Rainfall data in the watershed area (e.g. meteorology agent data) are used.
When the elevation difference in a watershed area is large, rainfall data by elevation are used.

Generally, the amount of rainfall of a mountainous area differs with elevation. Thus, in cases where a mountainous area is included in the watershed, it is desirable that there are multiple points of weather station continuous data with elevation differing from each other (e.g. every 400 m).

If continuous data cannot be collected, data can be assumed from available data. In case that continuous data are not available and spot data are available, rainfall data are estimated based on the correlation of the point data where spot data are available, and the point data where continuous data are available.

Following is an example of Lower Moshi. The watershed of Lower Moshi has more than 4,000 m of height difference, with range of 780 m (Njoro head works) to 5,000 m. The watershed area by elevation is shown in **Table. 2.3** The points where long-term continuous data are available, and spot data are available in Lower Moshi are indicated in **Table. 2.4**.

Table. 2.3 Water shed area and its ratio by elevation

elevation	Njoro		Rau	
	Area km^2	Ratio	Area km^2	Ratio
<1000	24.8	0.29	6.4	0.05
1000-1400	16.7	0.20	27.6	0.24
1400-1800	9.6	0.11	18.3	0.16
1800-2200	7.7	0.09	22.1	0.19
2200-2600	4.9	0.06	13.7	0.12
2600-3000	4.0	0.05	10.4	0.09
3000-3400	2.9	0.03	6.8	0.06
3400-3800	3.6	0.04	5.2	0.04
3800-4200	5.7	0.07	5.1	0.04
>4200	4.2	0.05	1.4	0.01
Total	84.1		117.0	

Table. 2.4 Weather stations available in Moshi

Name of the station	Elevation	Data available year and data type
Moshi Meteo St	813	1930onward (Daily)
Lyamungu	1,268	1935 onward (Daily)
Kibosho	1,478	1969 onward (Daily)
Old Moshi Nursery	1,646	1947-1953, 1954-1979(Daily)
Kili 1E	2,200	1950-1969 (monthly)
Kili 2E	2,870	1950-1969 (monthly)
Kili 3E	3,810	1950-1969 (monthly)
Kili 4E	4,270	1950-1969 (monthly)
Kili 5E	4,800	1950-1969 (monthly)

Table. 2.5 shows the annual rainfall for every 400 m of elevation, based on the weather stations described in **Table. 2.4**. The rainfall of each 400 m of elevation is acquired by connecting adjacent stations by fitting a straight line. For example, the rainfall data of elevation 2,000 m (R2000) can be acquired by Old Moshi Nursery (elevation 1,646 m) and Kili 1E (elevation 2,200 m) using following formula:

$$R2000 = (2000 - 1646) \times (R2200 - R1646)/(2200 - 1646).$$

Acquired annual rainfall data by elevation and rainfall data at Kibosho where there are continuous data are regressively computed (**Table. 2.5**) to derive a simple regression formula. Rainfall by elevation is acquired by the formula given above.

Table. 2.5 Regression of annual rainfall by elevation and rainfall at Kibosho

Elevation	1,478 (Kibosho)	1,600	2,000	2,400	2,800	3,200	3,600	4,000	4,400
1957	2,894	2,638	1,991	1,620	1,502	1,090	616	276	318
1959	1,295	1,421	1,770	1,869	1,726	1,378	987	551	227
1960	1,612	1,667	1,814	1,859	1,806	1,386	888	447	193
1961	2,139	1,733	1,347	1,200	1,168	972	741	488	280
1962	1,489	1,795	1,334	977	912	675	401	193	103
1963	2,192	2,636	1,557	819	753	609	447	272	145
1964	2,127	2,616	1,378	549	500	411	315	199	106
1965	2,217	3,324	1,726	576	551	440	309	199	143
Result of Regression of Kibosho	C	788	1,355	1,762	1,674	1,361	1,001	562	64
	X	0.54	0.13	-0.29	-0.28	-0.25	-0.21	-0.12	0.06
	R^2	0.50	0.07	0.07	0.08	0.10	0.16	0.17	0.16

2.3.4 Watershed area

Watershed area is calculated from a topographic map made using Digital Elevation Model (DEM) data

The following DEM data are available:

- SRTM3 (free) vertical error 16 m;
- https://urs.earthdata.nasa.gov//users/new;
- PRISM (paid) vertical error 5 m equivalent to 1/25,000 topographic map;
- AW3D (paid) vertical error 1 m equivalent to 1/2,500 topographic map.

In the case of a watershed area of about 100 km^2, SRTM3 data are sufficient.

How to make a contour map is explained in <**reference 1**>. How to make a watershed map is explained in <**reference 2**: using QGIS>.

Watershed area by elevation is obtained by trimming watershed (polygon data) by elevation data (polyline) (using "<vector overlay><division by line>" in QGIS)

< **reference 1**> How to make a contour map using SRTM
Reference movie
https://www.youtube.com/watch?v=yXCbHm9slSA

(1) How to make DEM

1） Draw waypoint in a mesh where DEM data are extracted (**Fig. 2.11)**

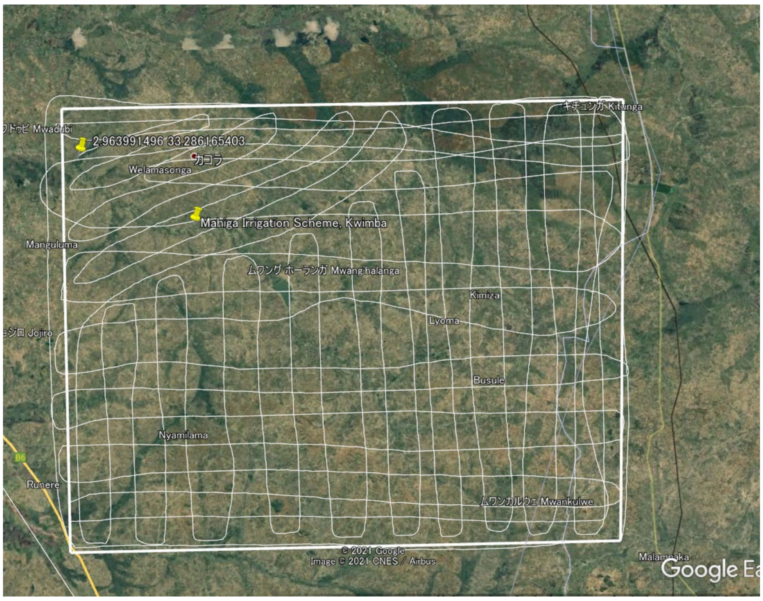


Fig. 2.11 Drawing a mesh

2） Drawn waypoint is saved as KLM format at any folder.

3） Open the GPS Visualizer (https://www.gpsvisualizer.com/convert?output_home） (**Fig. 2.12**)

4） Elevation data are obtained and the file is saved in CSV format (plane text) (from here, the procedure differs from the YouTube video);

Fig. 2.12 Screen of GPS Visualizer

5) CSV file is opened by <Layer><Add Layer><Add Delimited Text Layer> in QGIS. Geometry CRS is EPSG:4326 or WGS84. <Use spatial index> is checked.

(If you want to check whether waypoints are expressed correctly at this point, right-click the said file, <Export>, and <Save Selected Features> to export the necessary field in KML format (geometry type: point), and drag in to Google Earth. If the waypoints are correct, points are displayed on the original line (**Fig. 2.13**)

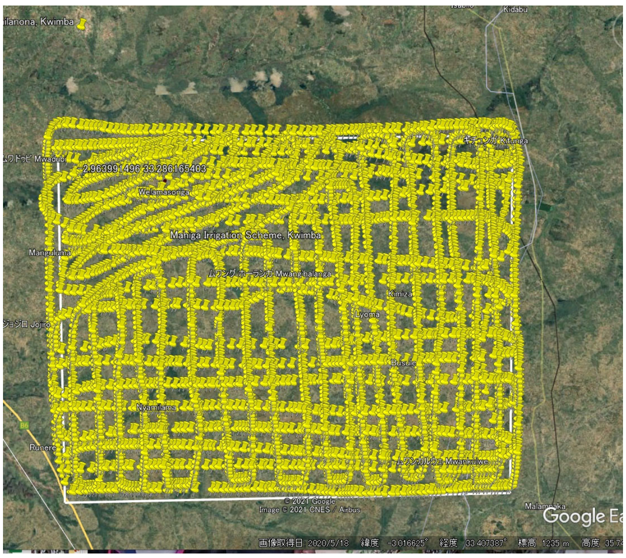


Fig. 2.13 Display of waypoint

6) Creating a raster file using <Interpolation><TIN interpolation> in the processing toolbox (**Fig. 2.14**)

The result does not differ much whether or not the Z-coordinate is used for interpolation.

Display extent (or CSV file extent) is filled in <extent>, if the output raster size is small, the data are rough. However, if the output raster size is large, then processing requires much time. In this case study, 3,000 × 3,800 (extent is 25 km × 25 km, 6 m interval) is selected. Finally, a DEM file is created.

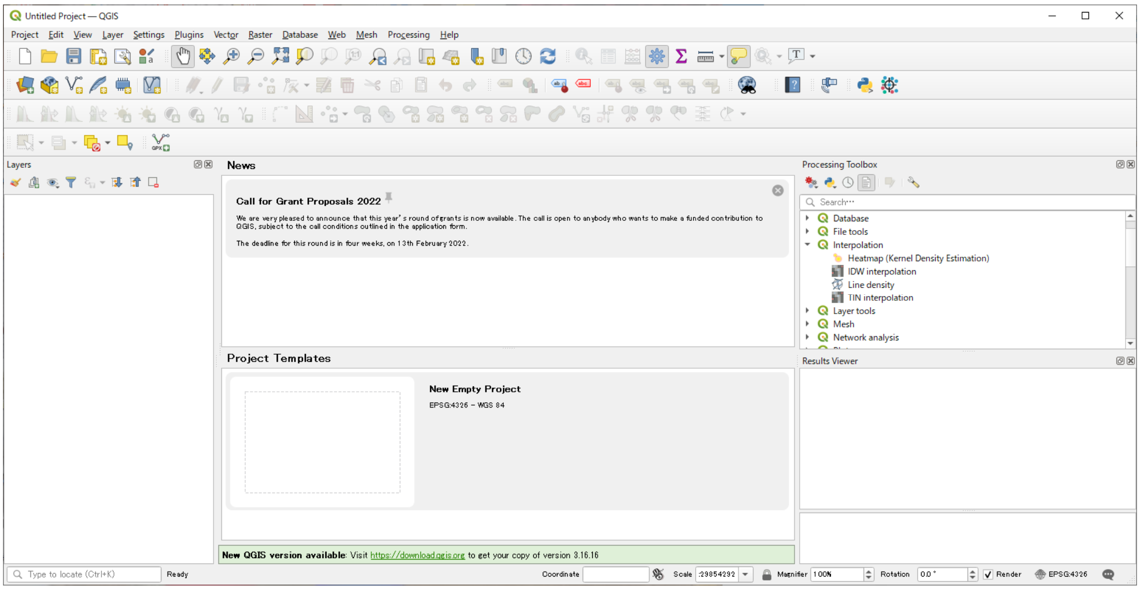


Fig. 2.14 TIN interpolation

(2) How to make a contour line

1) Contour line is created by selecting the created DEM and selecting <Raster><Extraction><Contour>.

2) As data are saved under a new file name, data are right-clicked, and <Export><Save Features As>, format is "KMZ" (if you want to check by Google Earth), geometry type is "line" are selected to save the data.

<reference 2> How to make a watershed map

1) For analyzing DEM by GRASS in QGIS, the DEM data are reprojected onto GRASS. The concrete procedure is <Raster><Projection><Warp(reproject

（https://docs.qgis.org/2.6/ja/docs/training_manual/grass/grass_setup.html）

2) Based on the projected DEM, the watershed is acquired by <GRASS><Raster><r.watershed>.

Minimum size of an exterior watershed basin is 5,000 (when using AW3D, because its resolution is high, the smaller the minimum size is, the longer time it takes (**Fig. 2.15**)

Reference address:

https://giscrack.com/automatically-delineate-a-watershed-in-qgis/

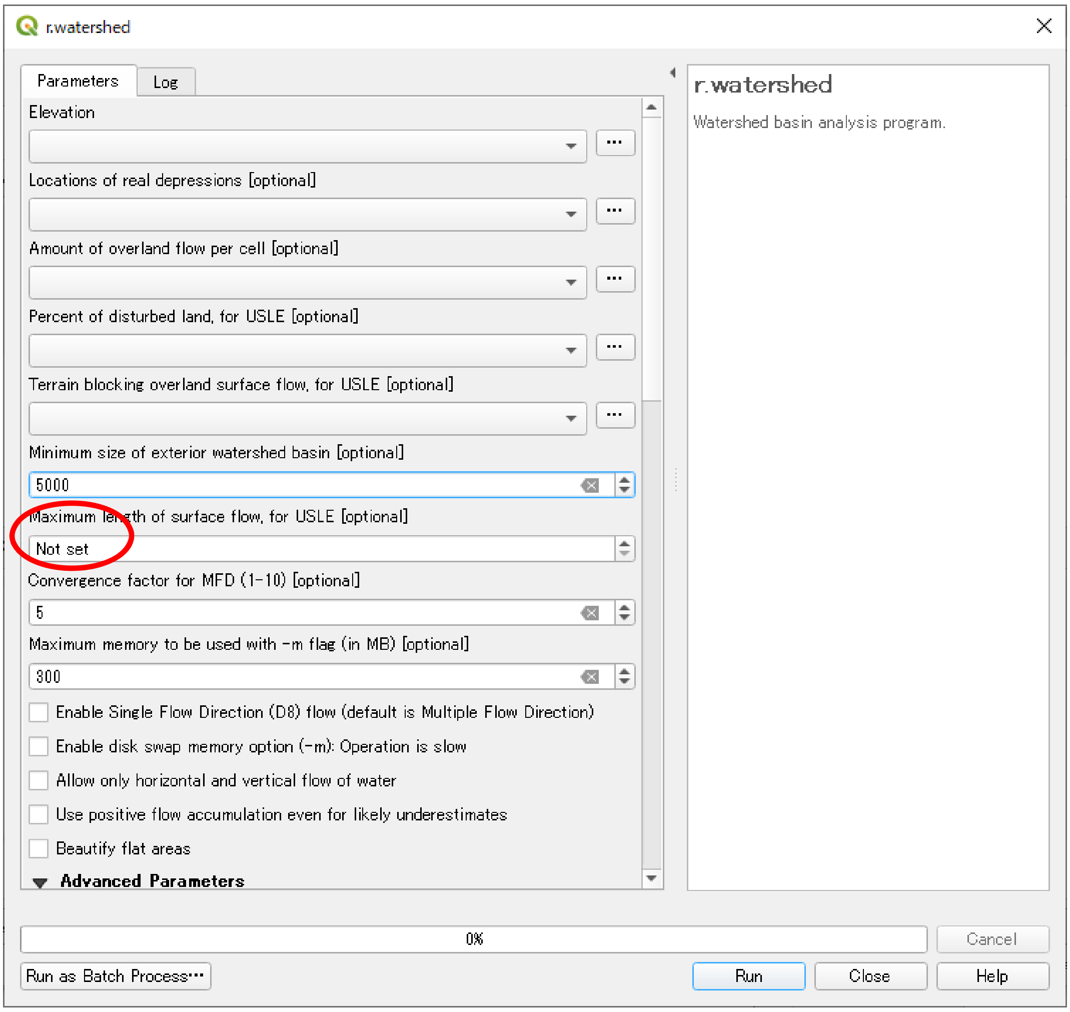


Fig. 2.15 Display of r.watershed

3) Converts a raster into a vector layer

If you want to display the river data on Google Earth, the data are converted into a vector layer.

"stream segment layer" is treated by <GRASS><Raster><r.thin>, after that the treated layer is treated by <GRASS><Raster><r.to.vect>, where "feature type" is line.

4) Watershed

Specific point (downstream end of watershed) is determined in "drainage direction layer", and watershed is displayed by <GRASS><Raster><r.water outlet>

If you want to display the watershed on Google Earth, the watershed layer in converted into a vector layer (feature type is Area). After that, right-click the watershed layer, <Export><Save Features As><Format: KML, Geometry type: Polygon>

The watershed area is calculated by the following procedure:
Right-click the watershed layer, <Open Attribute Table>, click <Field Calculator>, $area is described in expression. The area is calculated in m^2, if you want km^2, then $area/1,000,000 should be described in expression.

2.3.5 River discharge estimation method

Basically, the river discharge model estimates flood peak water volume using a tank model. In this manual, the tank model which can estimate long term discharge is used for river discharge estimation.

Following are typical river discharge methods:

- Rational method: estimates flood peak water volume. Peak water volume is calculated by the product of watershed area, rainfall intensity, and runoff coefficient.
- Storage function method: watershed area is divided into runoff and filtration areas. Runoff water volume of each area (runoff and filtration areas) is calculated and runoff from the whole watershed area is calculated by summing runoff from each area.
- Kinematic wave method: explains flood flow phenomena by water flow's low of motion and equation of continuity.
- Quasi-linear storage type model: consists of effect rainfall, slope, and river channel models.

Tank model: watershed area is represented vertically by several (2–4) tanks with side holes, and water flow volume is calculated.

2.3.6 Tank model

・There are four vertically arranged tanks
・Upstream of the point where river discharge is known is treated as one watershed
・Rainfall is corrected by elevation
・Excel and Python are explained as parameter identification methods
・Nash–Sutcliffe efficiency is used to evaluate parameters

2.3.6.1 Structure of tank

The tank model consists of four vertical tanks (**Fig. 2.16**)

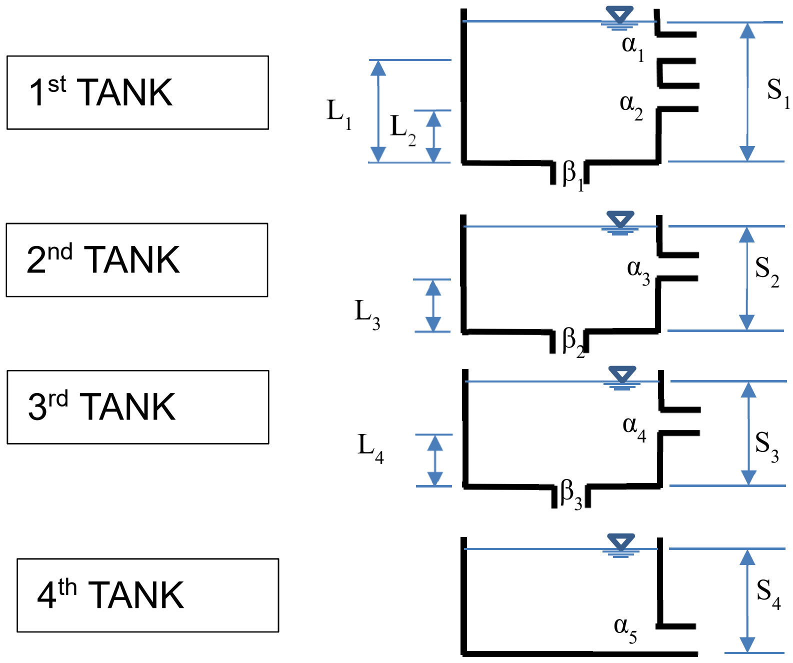


Fig. 2.16 Tank model

2.3.6.2 Fundamental equations of the tank model

The basic concept of the tank model follows:

1) Watershed is represented by four vertically arranged tanks;

2) Rainfall of the watershed flows into 1st TANK. Evaporation of the watershed is removed from 1st TANK;

3) Water stored in 1st TANK flows out from side holes set in different depths to a river. Also, water flows out from a bottom hole to the next lower tank, 2nd TANK;

4） For 2nd and 3rd TANKs, water flows in from the upper tank, flows out from side holes to a river and flows out from a bottom hole to a lower tank;

5) For the lowest tank (4th TANK), water flows out from side holes to a river, and there is no bottom hole.

Water storage volumes of each tank are expressed by the following formulas:

1st TANK

$S_1(t-1) \geq L_1(t-1)$

$S_1(t) = S_1(t-1) + p(t) - E(t) - ((S_1(t-1) - L_1(t-1)) \times \alpha_1 + (S_1(t-1) - L_2(t-1)) \times \alpha_2) - S_1(t-1) \times \beta_1$

$L_1(t-1) > S_1(t-1) \geq L_2(t-1)$

$S_1(t) = S_1(t-1) + p(t) - E(t) - ((S_1(t-1) - L_2(t-1)) \times \alpha_2) - S_1(t-1) \times \beta_1 - S_1(t-1) \times \beta_1$

$S_1(t-1) < L_2(t-1)$

$S_1(t) = S_1(t-1) + p(t) - E(t) - S_1(t-1) \times \beta_1$

2nd TANK

$S_2(t-1) \geq L_3(t-1)$

$S_2(t) = S_2(t-1) - ((S_2(t-1) - L_3(t-1)) \times \alpha_3) - S_2(t-1) \times \beta_2$

$S_2(t-1) < L_3(t-1)$

$S_2(t) = S_2(t-1) - S_2(t-1) \times \beta_2$

3rd TANK

$S_3(t-1) \geq L_4(t-1)$

$S_3(t) = S_3(t-1) - ((S_3(t-1) - L_4(t-1)) \times \alpha_4) - S_3(t-1) \times \beta_3$

$S_3(t-1) < L_3(t-1)$
$S_3(t) = S_3(t-1) - S_3(t-1) \times \beta_3$

4^{th} TANK
$S_4(t) = S_4(t-1) - S_4(t-1) \times \alpha_5$

where P is rainfall (mm/d) and E is evaporation (mm/d).

2.3.6.3 Identifying parameters

There are 16 parameters in the tank model. When identifying parameters, the optimum solutions tend to convergence near the initial values if initial values are given and the optimum solutions are found. Therefore, SCEUA (shuffled complex evolution; Duan, 1992) is recommended for identifying parameters (Tanakamaru, 1995).

The SCEUA computing process is too complex for use in MS-Excel. So, both the Excel method and SCEUA are explained to determine parameters in this manual.

2.3.6.3.1 Necessary period for identifying parameters

Because there are 16 parameters, the computing period necessary for identifying parameters is at least 2 years.

2.3.6.3.2 Standardization of parameters

According to Tanakamaru (1995), when the order of variables differs greatly depending on the variable, as it does in the tank model, the response surface becomes extremely flat and an efficient search cannot be performed. Nagai and Kadoya(1979) showed that it is effective to search for model constants with different orders by standardizing "each model constant (variable) with its initial value".

For this reason, optimization is attempted using variables that are standardized based on the upper and lower limits of the model constants (variables) shown by Tanakamaru (1995).

2.3.6.3.3 How to verify parameters

Nash–Sutcliffe efficiency (NSE) (**formula 8**; Nash and Sutcliffe, 1970) is used for verifying parameters:

$$\mathrm{NSE}=1-\frac{\Sigma\,(Q_{Obs}\text{-}Q_{cal})^2}{\Sigma\,(Q_{Obs}\text{-}\bar{Q}_{Obs})^2} \qquad \text{Formula 8}$$

where Q_{Obs} is observed runoff height, Q_{cal} is calculated runoff height, and $\bar{Q}_{Obs}$ is average of observed runoff height.

Observed runoff height is acquired by dividing observed runoff volume by watershed area.

The value of NSE ranges from −∞ to 1, and the closer to 1 it is, the higher is the adaptability of the model.

According to Moriasi et al. (2015), NSE ≤ 0.5 is unsatisfactory, 0.5 < NSE ≤ 070 is satisfactory, 0.70 < NSE ≤ 0.80 is good, and NSE > 0.80 is very good.

2.3.6.3.4 How to use Excel for identifying parameters

As described above, when identifying parameters, the optimum solutions tend to convergence near the initial values if initial values are given and the optimum solutions are found. Thus, in the identification method using Excel, an approximate value is obtained by a global search method that changes the initial value and finds the optimum solution according to the initial value, and then this approximate value is used as the initial value to find the optimum solution by the local search method. The Solver function of Excel is used for both methods.

"Evolutionary (genetic algorithm)" is selected in the "Selecting a solving method" of the Solver function.

Using the solution obtained by the genetic algorithm (GA) as the initial value, select the local search method "GRG Nonlinear: Generalized Reduced Gradient" from the "Selecting a solving method" to obtain the parameters.

The calculation is repeated about 40 times, and the one with the best result is used as the parameter.

2.3.6.3.5 How to use Python for identifying parameters

As mentioned above, it is better to use SCEUA for parameter identification. However, SCEUA cannot be calculated in Excel, so it is necessary to calculate using a programming language.

Here, a calculation method using the programming language Python, which is easy to handle and has many basic programs open to the public, is described.

For the basic program (source code) of SCEUA, that published on Github (SPOTPY) (https://github.com/thouska/spotpy) is used.

The source code of the tank model also published on Github (tank-model) (https://github.com/nzahasan/tank-model) is used. The program is executed using Google colab.

(1) Program modification

The SCEUA program posted on Github uses a different model to the tank model. Therefore, when executing the program, it is necessary to modify it so that SCEUA can be used for parameter identification of the tank model.

(2) Setup program

In order to execute the tank model program, which is the core program, a setup program for execution is required.

SPOTPY has a setup program for running different hydraulic models. This setup program is modified to make the tank model executable. The modified source code is shown in the attachment.

As a precaution in use, it is necessary to rewrite the module that executes “import” in the source code to the program name corresponding to the tank model execution (when changing the main program name of the tank model).

In addition, although a variable can generate an arbitrary number with a random number, it is necessary to describe the upper and lower limits of the variable.

Also note that in Python the order starts from 0 (zero), so if the variable is 16, the variable x () in the code is from x (0) up to x (16), making 17 variables.

(3) Main program

In the tank model, the first tank (top tank) has two horizontal holes. Therefore, the heights of the two horizontal holes (upper and lower holes) from the tank bottom need to be “upper hole height” > “lower hole height”.

In SCEUA, the variable group (x (0) to x (15)) is cut out at an arbitrary place and exchanged (mutation).

Therefore, in some cases, “upper hole height” < “lower hole height”. In this case, it is necessary to modify the variables before calculating the runoff height in the tank model.

Specifically, when “upper hole height” < “prepared hole height”, a process is performed in which “upper hole height” and “prepared hole height” are exchanged. The source code is shown in the attachment.

(4) Object function

In the tank model, the variables are searched by SCEUA so that the objective function (evaluate observed river discharge and calculated river discharge with NSE) approaches 1.

In SPOTPY’s original model, the algorithm is designed to search to minimize RSME. In other words, the program is designed so that the objective function (“like” in source code) is minimized in the SCEUA algorithm.

The closer the NSE is to 1, the better is the variable. For this reason, it is necessary to modify the SCEUA algorithm so that the objective function “should be closer to 1” or “the objective function is the maximum” because NSE does not take a value of 1 or more. Or, by taking the reciprocal of NSE (NSE-inv), the minimum NSE-inv is -1.

Therefore, it is necessary to change the SCEUA algorithm along with NSE-inv, or change the NSE calculation module.

We use the reciprocal of NSE as the objective function and search so that the objective function is the smallest.

(5) Processing the data used for analysis

1) Data preparation

Prepare the data required for parameter identification (precipitation, mm/d; evaporation, mm/d; and river flow rate, m^3/s) in Excel for the identification period (more than 2 years).

2) Data are saved in CSV format (file name is “Njoro_id.csv”)
If you want to change the file name, you have to change the file name in line 55 of the program (spot_setup_tank3.py). Use a text editor or “Visual Studio Cade: free software” to rewrite the program.

<reference> code in line 55
Climatefile = open(self.hymod_path+os.sep+'Njoro_id.csv', 'r')
3) The saved file is opened by text editor (e.g. Lime or Notepad)
4) Delimiter – in Excel, often a tab or comma is changed to “;” (semicolon) and saved.

(6) Preparations for using Python
1) Create Google account
2) Create Google Drive
Create “python TANK” under “MyDrive”, and “algorithms” under “python TANK”
3) Copy of the program
The program which can be downloaded from JIRCAS Hp site is copied to Google Drive. The data which are created in (5) are also copied to “python TANK”.
4) Start Google Colab
5) “file”, “newnotebook”
6) Click the icon “files”, which is arranged on the left side
7) Click the icon “Mount Drive” to recognize the Google Drive. The access code is requested at the first time, and the drive is recognized according to instructions.
8) Program execution

The following program is executed (copy is available):

```
import numpy as np
!pip install spotpy
import spotpy
import matplotlib.pyplot as plt
```

```
import os
print (os.getcwd())
os.chdir('/content/drive/MyDrive/python_TANK')
print (os.getcwd())
```

After executing the program, check that the following is displayed: "/content/drive/MyDrive/python_TANK"

(7) Tank model program execution

```
from spot_setup_tank3 import spot_setup
from objectivefunctions import nashsutcliffeinv
spot_setup=spot_setup(nashsutcliffeinv)
from algorithms import sceua
sampler=sceua(spot_setup, dbname='SCEUA_tank_njoro', dbformat='csv')
rep=50000 #Select number of maximum repetitions times
sampler.sample(rep, ngs=33, kstop=100, peps=0.001, pcento=0.001)
```

where rep is the repeat computation number of times; ngs = 2 × number of the parameters (16 in case of tank model) + 1 = 33; and peps and pcento are the convergence conditions.

In the case of implementing parameter standardization

Change "from spot_setup_tank3 import spot_setup" to "from spot_setup_tank_std import spot_setup".

(8) Save the parameters
As NSE (objective value), computing result of the parameters, repeat computation number of times, computing time are displayed, these figures are recorded.

(9) Saving the output result
The calculation result up to the parameter identification is saved in Google Drive in the file named "SCEUA_tank_njoro".

Read this in Excel, rename it, and save it on a PC (not saved in Google Drive due to space limitations).

(10) Termination of computing

If increasing the repeat computation number and the NSE value does not change, then determine the parameter.

If the NSE value changes, the repeat computation number increases. In the Lower Moshi case, the repeat computation number of times of 200,000 is a good result.

The “like” output is shown in **Fig. 2.17**.

If the graph shows a downward-sloping tendency, increase the repeat computation number.

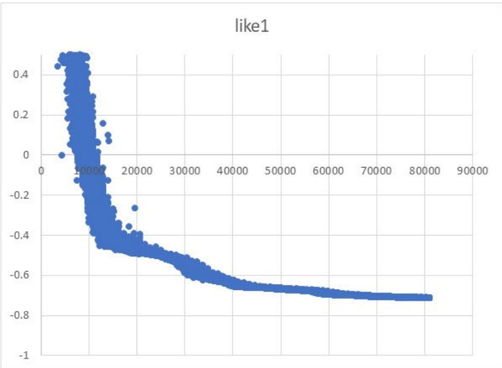


Fig. 2.17 Convergence situation of “like”

2.3.6.3.6 Parameter identification results and data verification using sample data

Based on the river discharge data (Njoro River) and precipitation in the basin in the Lower Moshi area, the parameters are identified using Excel and Python. The river discharge data are calculated by a tank model using a certain parameter (parameter identified based on the actual river discharge) based on actual precipitation data (virtual river discharge).

(1) Parameter identification by Excel (GA and GRG) and parameter verification
Initial values of parameters for identifying parameters are all 0.001.
Without standardization, the mean NSE of the GA in 39 trials is 0.2, and the mean of the GRG results using the GA results is 0.97.
When standardized, the mean NSE of the GA in 39 trials is 0.49, and the average of the GRG results using the GA results is 0.99.
When implementing only GRG without implementing GA, the NSE is −9.3.
These facts show that the parameter identification does not give good results even when carried out only by GRG. Also, standardization gives better results.
Fig. 2.18 shows the results of the GA and subsequent GRG for standardization. The NSE of GRG increases regardless of the GA result.
The results of parameter identification (**Fig. 2.19)** show that the parameters vary depending on the calculation results. Further, in this graph, ◆ is a parameter (true value in this simulation) used for creating virtual basin data.
Using the obtained parameters, the river discharge is reproduced from the precipitation in 1971–1972 and compared with the virtual river discharge data (**Fig. 2.20**). NSE of 0.8 or higher is considered very good (2.3.6.3.3).
Of the 39 trial calculations, 30 have NSE > 0.8 (**Fig. 2.20**). This indicates that there is no practical problem in performing trial calculation about 40 times and using the best result as parameters.

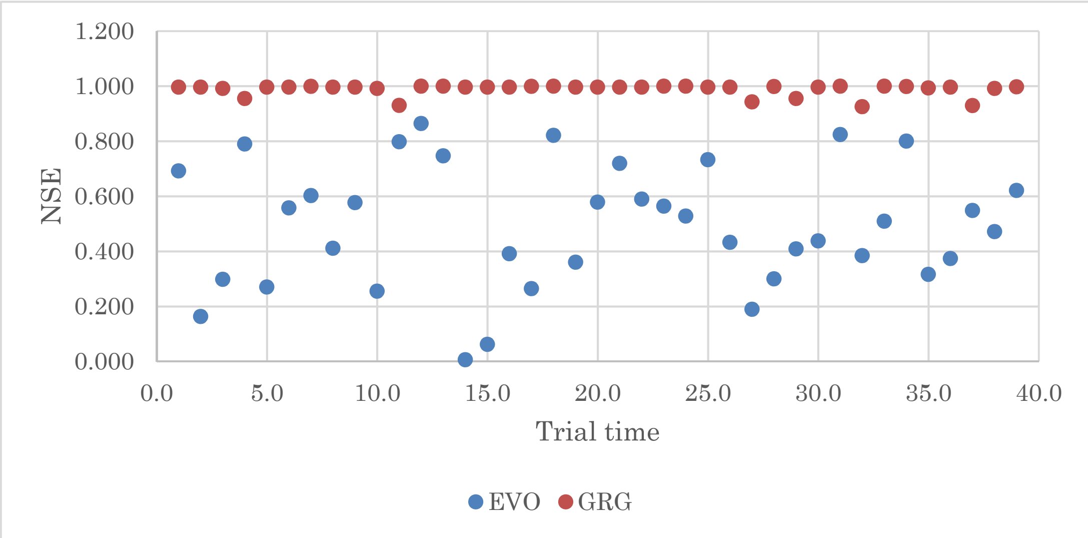


Fig. 2.18 Results of the GA and subsequent GRG (standardization)

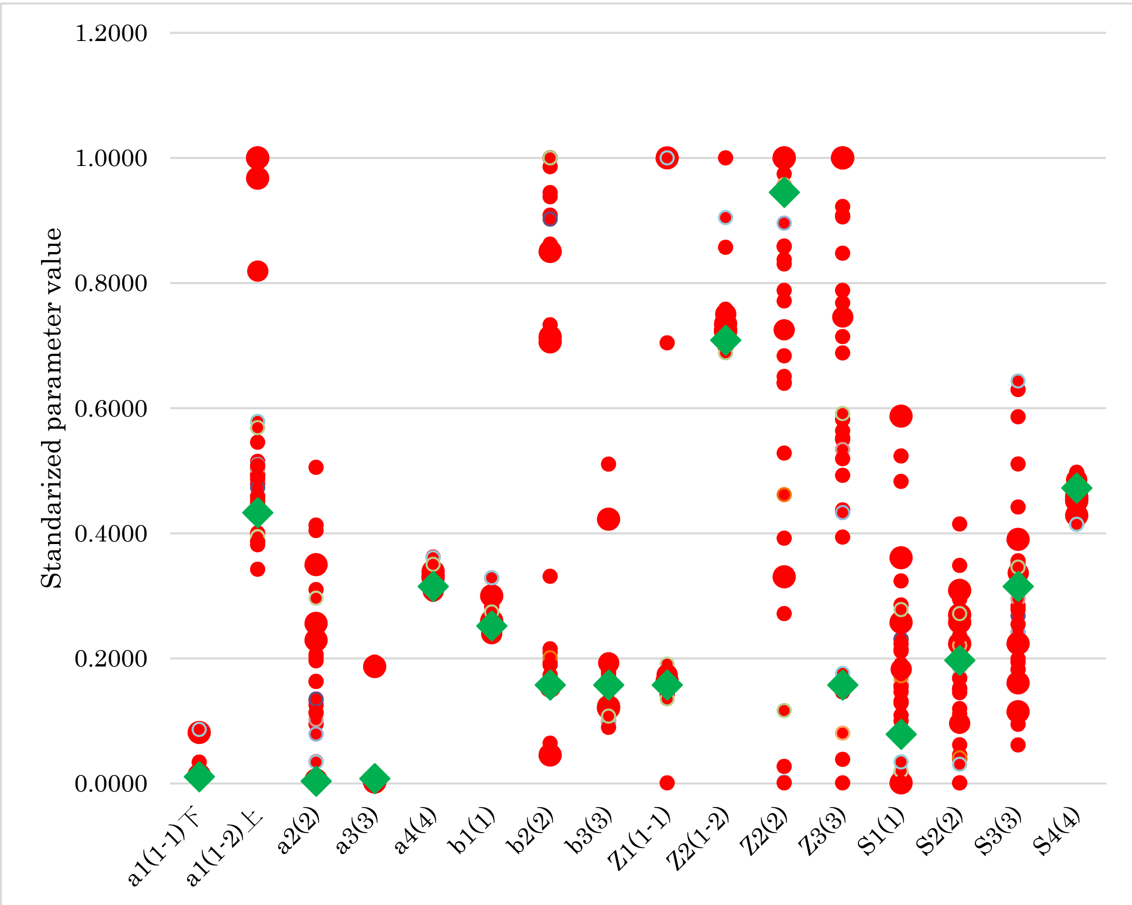


Fig. 2.19 Parameter identification results (using Excel)

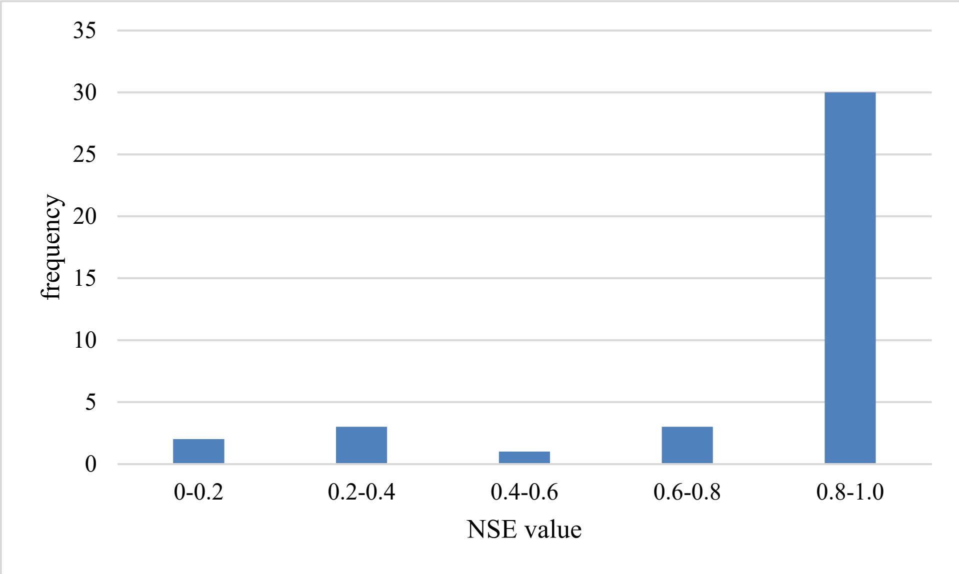


Fig. 2.20 Verification results of the identified parameters (using Excel)

(2) Parameter identification by Python (SCEUA) and parameter verification

Fig. 2.21 shows the parameter identification results by SCEUA. The parameters vary as well as the calculation results by Excel. ◆ is a parameter (true value in this simulation) used for creating virtual basin data in this graph.

Using the obtained parameters, the river discharge is reproduced from the precipitation in 1971–1972 and compared with virtual river discharge data (**Fig. 2.22**). NSE of 0.8 or higher is considered very good (2.3.6.3.3). Of the 39 trial calculations, 22 have NSE > 0.8 (**Fig. 2.22**). This shows that there is no practical problem in performing trial calculation about 40 times and using the best result as parameters.

Fig. 2.23 shows the variation between the true value and the calculation results for Excel and Python (the average of the absolute values of the differences between the true and calculated values) for each parameter. In this figure, data being below the red line indicate that Python has less variability than Excel.

As a result, there is no big difference between Excel identification (GA + GRG) and SCEUA. Therefore, if the identification period is 2 years, either method may be used to estimate river discharge.

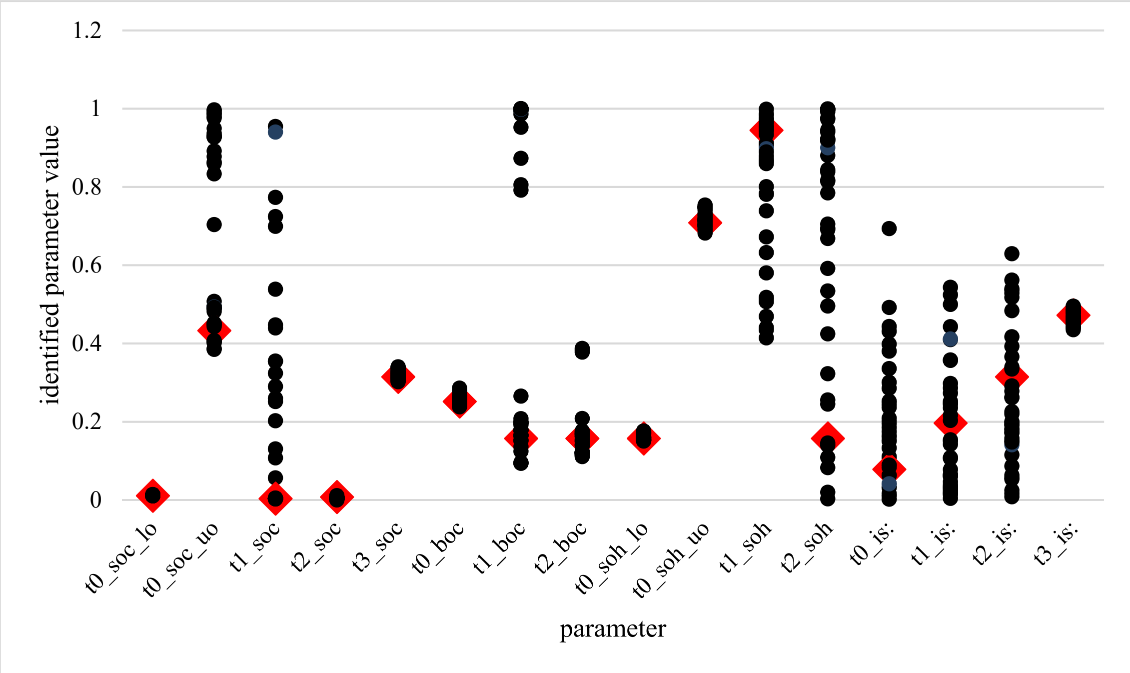


Fig. 2.21 Parameter identification result (SCEUA)

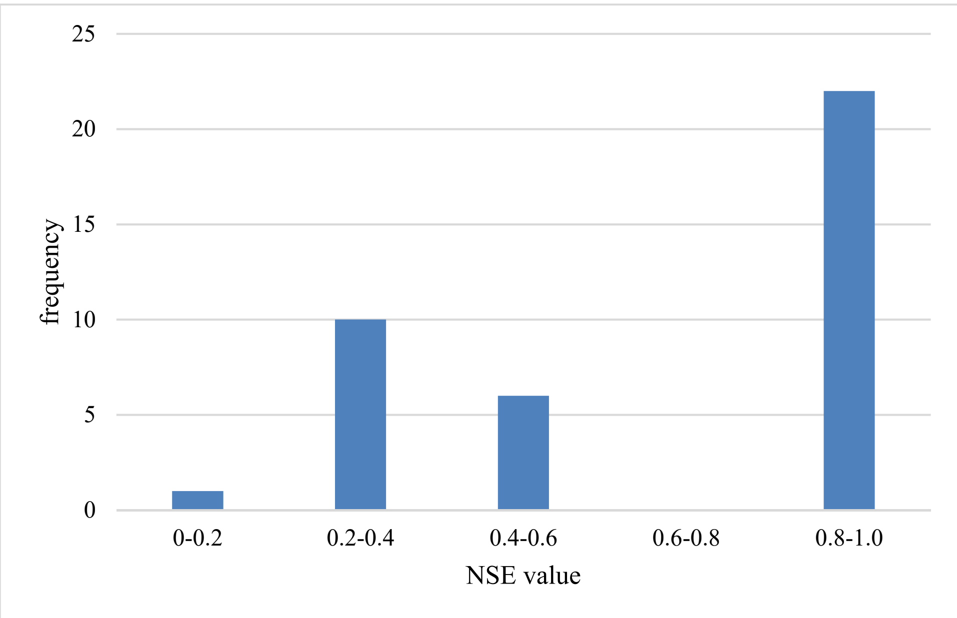


Fig. 2.22 Verification results of the identified parameters (SCEUA)

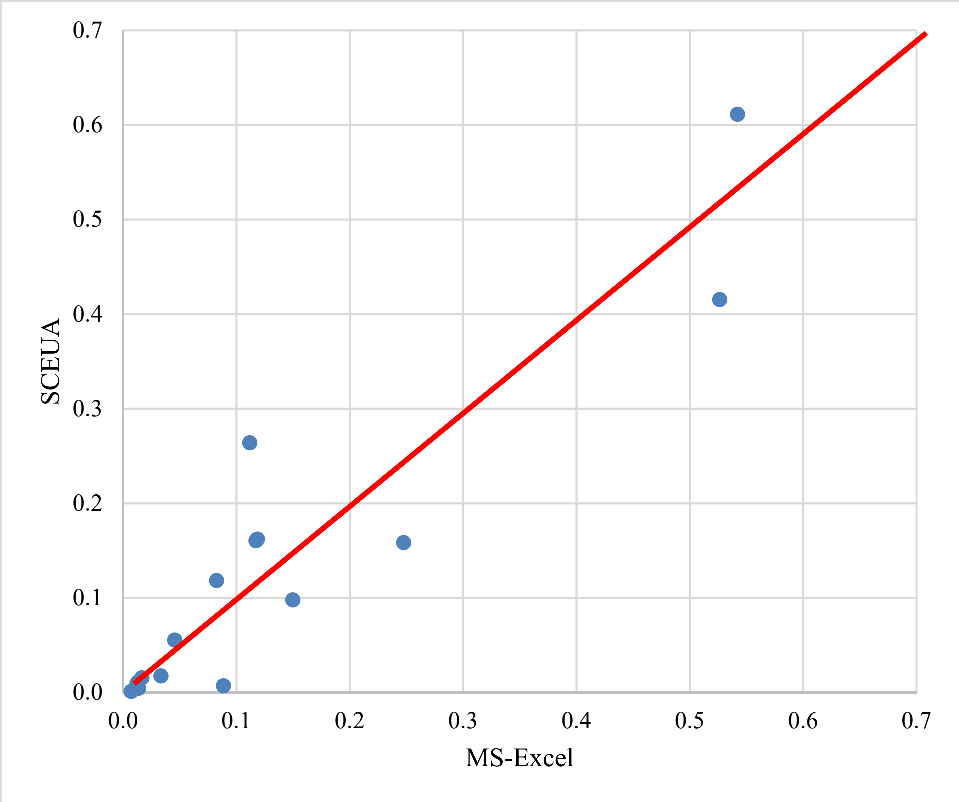


Fig. 2.23 Variation between the true and calculated values

(3) Irrigable area using parameters

Fig. 2.24 shows monthly rainfall after elevation correction in the Njoro watershed. Rainfall is low during August–October (8% of annual rainfall). The 2nd season of rice cultivation in the Lower Moshi begins in June–July and the 3rd season starts in September–October (the 1st season starts in December–January). Rainfall is low in the 3rd season, and irrigation water from rivers is important. Therefore, it is necessary to estimate how much water can be taken during September–October.

Using the parameters identified in the above explanation, the river discharge from January 1970 to April 1971 is calculated with the rainfall data available until July (expected river discharge after August at the time of the end of June). The result of the calculation is shown in **Fig. 2.25**.

Irrigable area is calculated based on river discharge. Details of how to calculate the area are given in section (4), and WRPD (including irrigation loss) of 22 mm/d and river discharge of 10-days average are used.

Minimum 10-day average in the 110-day period from September gives the irrigable area of the 3rd season, assuming that the irrigation period is 110 days. Also, the minimum 10-day average in the 110-day period from December gives the irrigable area of the 1st season. As a result, the virtual irrigable area of 3rd season is 562 ha and the area of the 1st season is 499 ha; the calculated irrigable area of the 3rd season is 522 ha (93%) and the area of the 1st season is 389 ha (78%) (effective rainfall is not considered)(**Table. 2.6**). If rainfall data until June are available, 80% of the maximum irrigable area can be estimated.

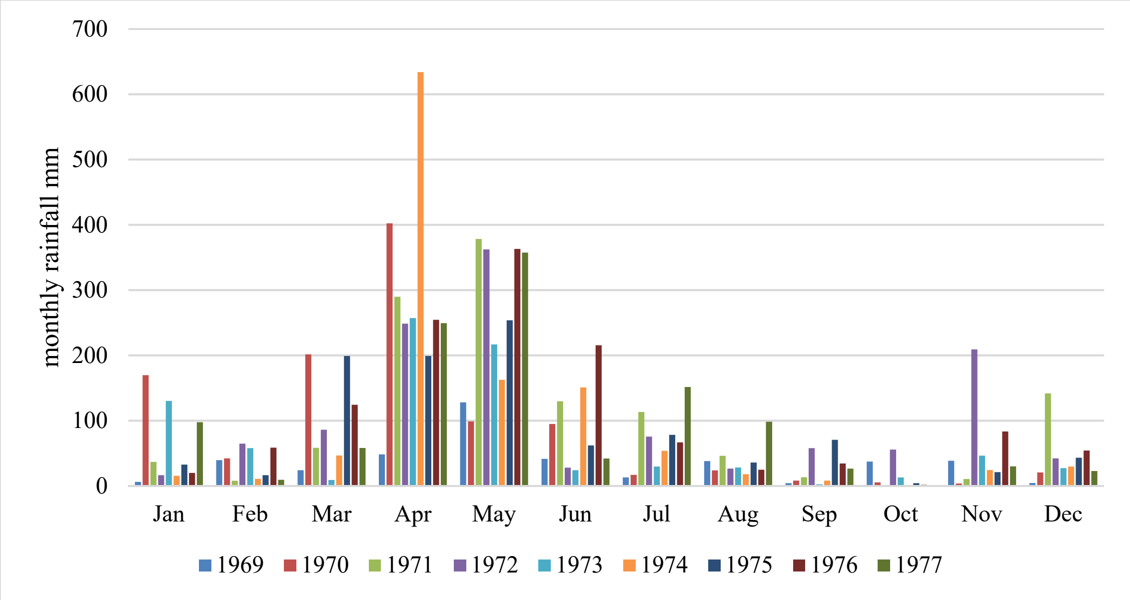


Fig. 2.24 Monthly rainfall at Njoro watershed (after elevation correction: 1969-1977)

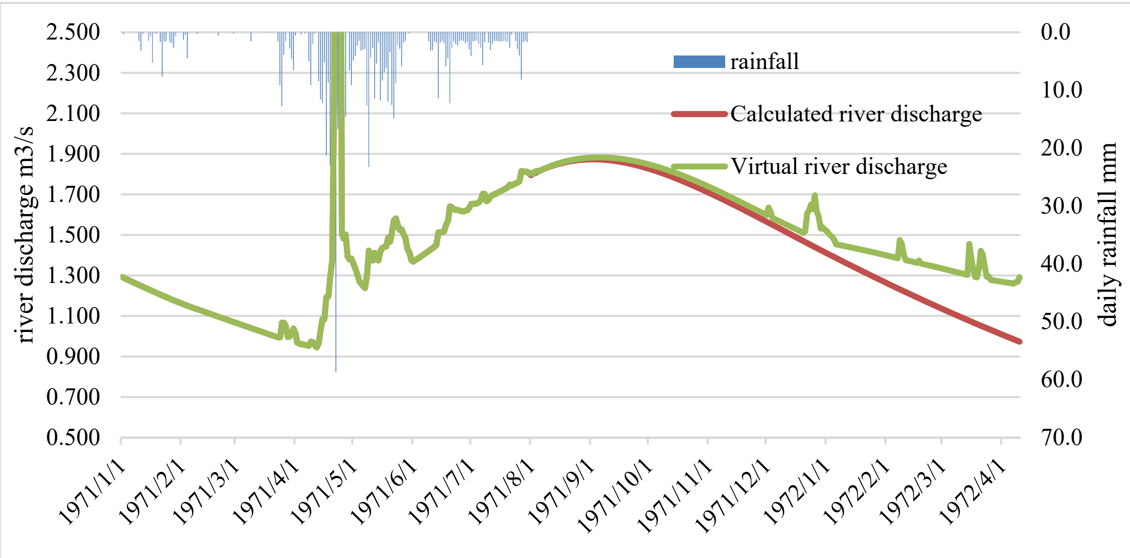


Fig. 2.25 River discharge change in case rainfall from August 1971 being zero

Table. 2.6 River discharge and irrigable area (calculation and virtual)

month		River Discharge (m^3/s)		Irrigable area (ha) Per 10 days average		Irrigable area (ha) Minimum of 110days	
		Calculated	Virtual	Calculated	Virtual	Calculated	Virtual
7	Early	1.76	1.76	691	691	522	562
	Middle	1.81	1.81	711	711		
	Late	1.85	1.85	727	727		
8	Early	1.87	1.88	734	738		
	Middle	1.87	1.88	734	738		
	Late	1.86	1.87	730	734		
9	Early	1.83	1.85	719	727		
	Middle	1.80	1.82	707	715		
	Late	1.75	1.78	687	699		
10	Early	1.71	1.74	672	683		
	Middle	1.66	1.69	652	664		
	Late	1.60	1.63	628	640		
11	Early	1.54	1.58	605	621		
	Middle	1.49	1.53	585	601		
	Late	1.43	1.59	562	624		
12	Early	1.38	1.46	542	573		
	Middle	1.33	1.43	522	562		
	Late	1.27	1.40	499	550	389	499
1	Early	1.22	1.40	479	550		
	Middle	1.17	1.35	459	530		
	Late	1.12	1.33	440	522		
2	Early	1.08	1.33	424	522		
	Middle	1.04	1.32	408	518		
	Late	0.99	1.27	389	499		
3	Early	1.18	1.52	463	597		
	Middle	1.08	1.44	424	566		
	Late	1.15	1.52	452	597		
4	Early	1.33	1.70	522	668		

(4) Irrigable area estimation based on actual water intake volume (Lower Moshi)

1) The data of water intake volume from headwork are averaged by the period data in which one month is divided into three (hereinafter “the period”) (**Fig. 2.26**)
2) In the case of the water intake volume of sub-LOMIA being available, the sub-LOMIA data are used.

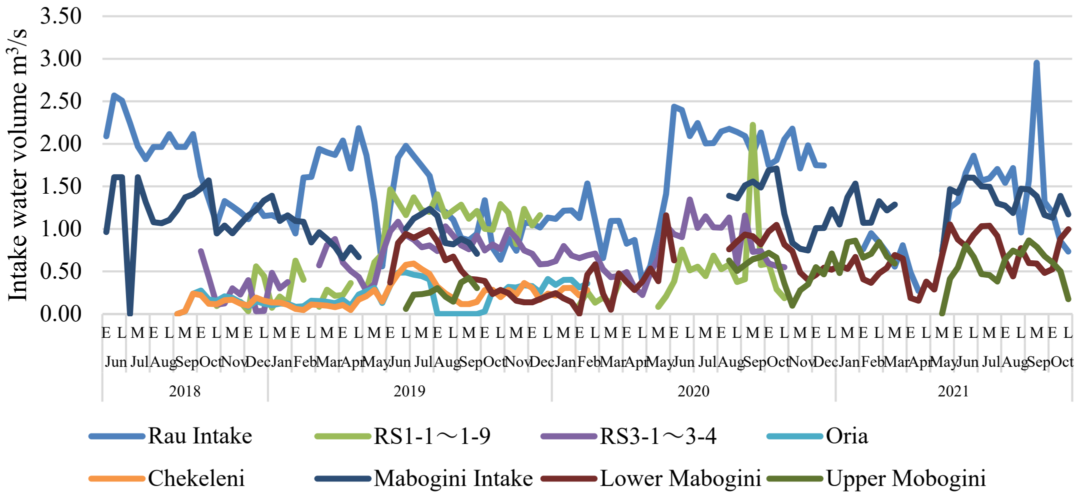


Fig. 2.26 Water intake volume by 10 days periods

3) Actual irrigation area data by irrigation block is organized by the period.
4) Actual irrigation area data by sub-LOMIA (or headwork) are organized by the period (**Fig. 2.27**).

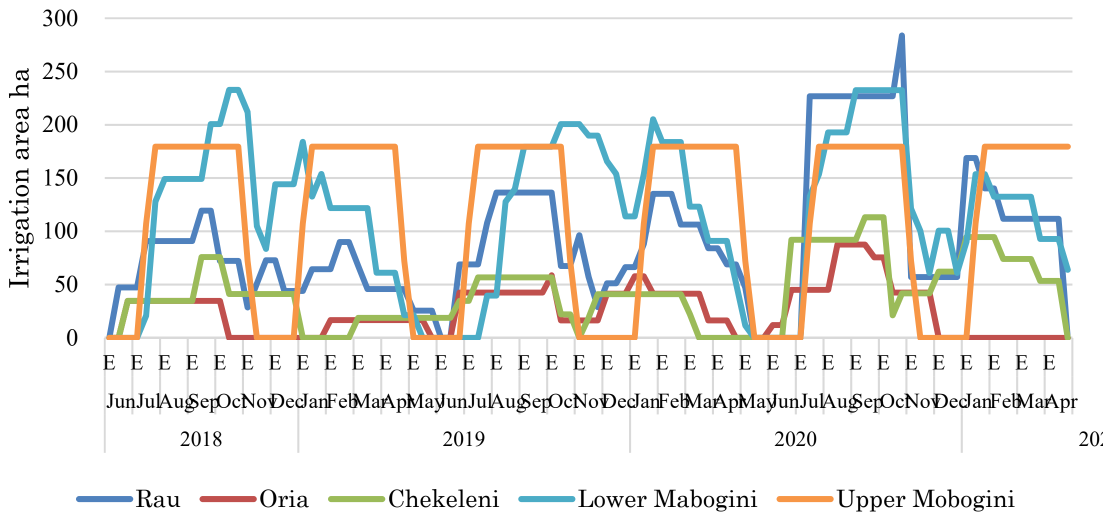


Fig. 2.27 Actual irrigation area by the period(June 2018 to October 2021)

5) Actual irrigation intensity (mm/d) is calculated by dividing water intake volume by irrigation area (**Fig. 2.28**).

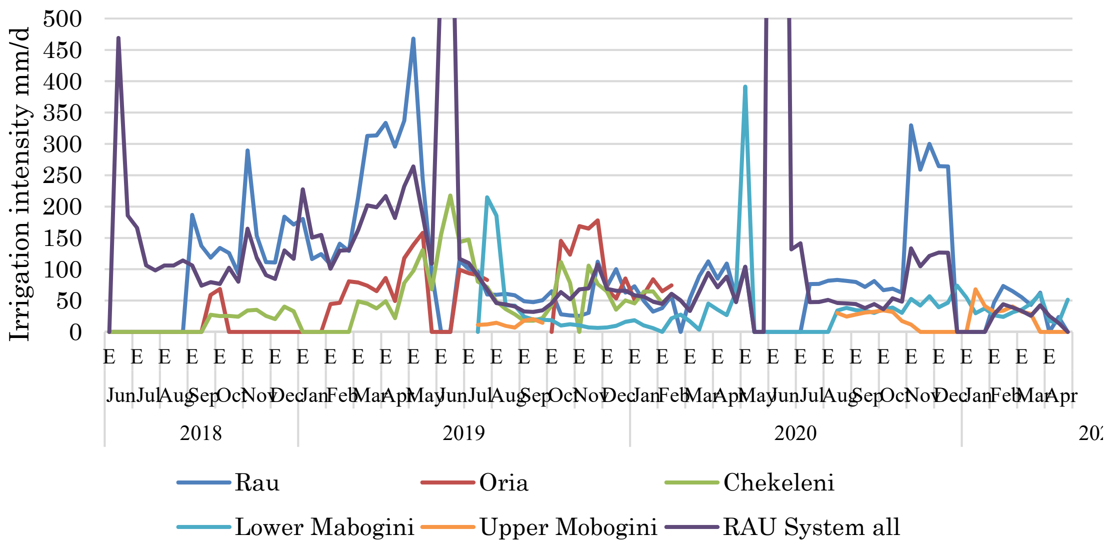


Fig. 2.28 Actual irrigation intensity by sub-LOMIA by the period (June 2018 to October 2021)

6) In the case of WRPD of 11 mm/d (measured) and irrigation efficiency (including water conveyance loss) of 50%, block WRPD is 22 mm/d (green line in **Fig. 2.29**). The water volume (intensity) above the green line is excess irrigation water.

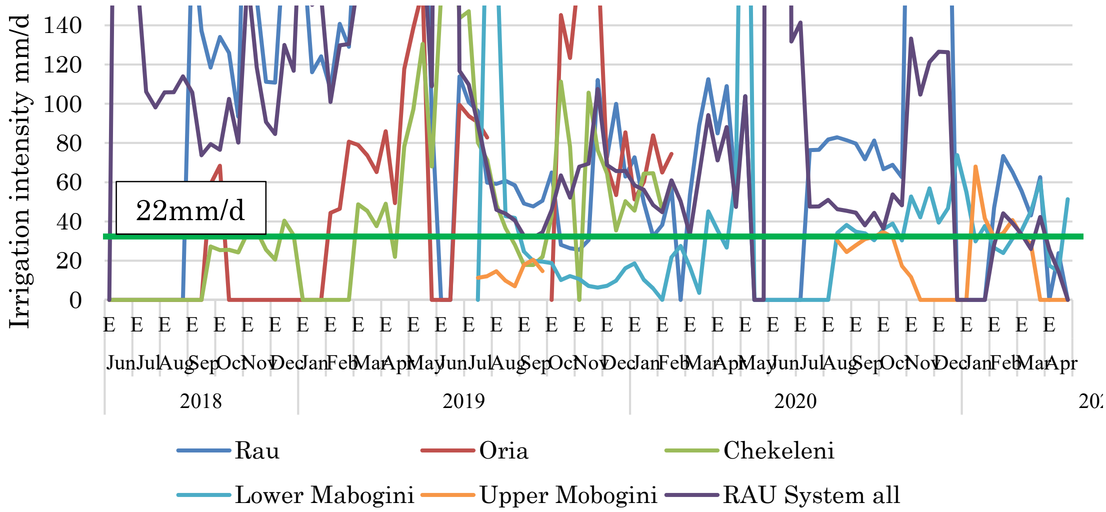


Fig. 2.29 Actual irrigation intensity by sub-LOMIA by the period (June 2018 to Obtober 2021) expansion

7) Excess irrigation water volume (m^3/d) is obtained by multiplying excess water intensity (mm/d) and the block area. Additional irrigable area can be determined by dividing excess water volume (m^3/d) by block irrigation water (22 mm/d).

8) Additional irrigable area of the period can be determined by averaging the data for before and after the period (**Fig. 2.30**).

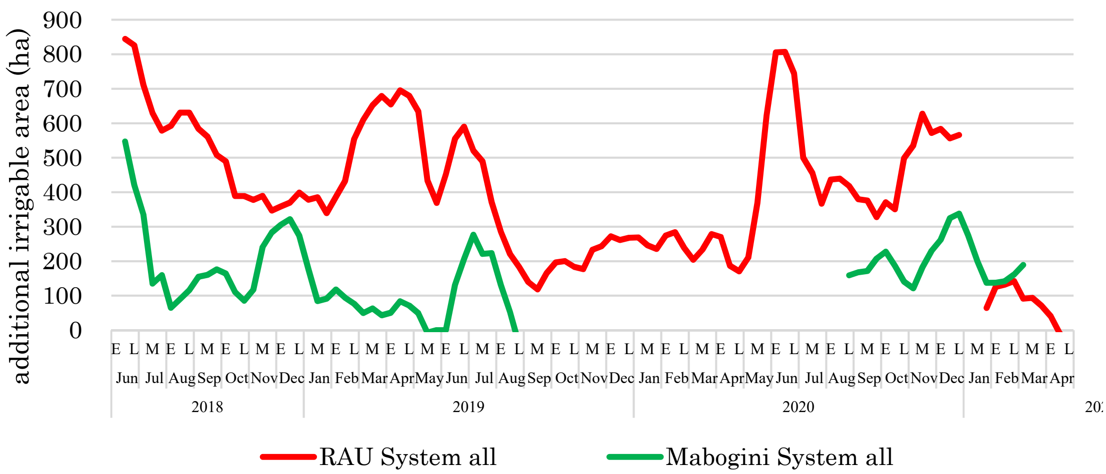


Fig. 2.30 Additional irrigable area by sub-LOMIA

9) Additional irrigable area of the irrigation period is obtained using minimum additional irrigable area of the period in the 110 consecutive days (irrigation period). Additional irrigable area in the irrigation period by water system is shown in **Fig. 2.31**.

Rau system: 855ha(2018), 635ha(2019), 850ha(2020),

Mabogini system: 149ha(2018), 43ha(2019) ,121ha(2020)

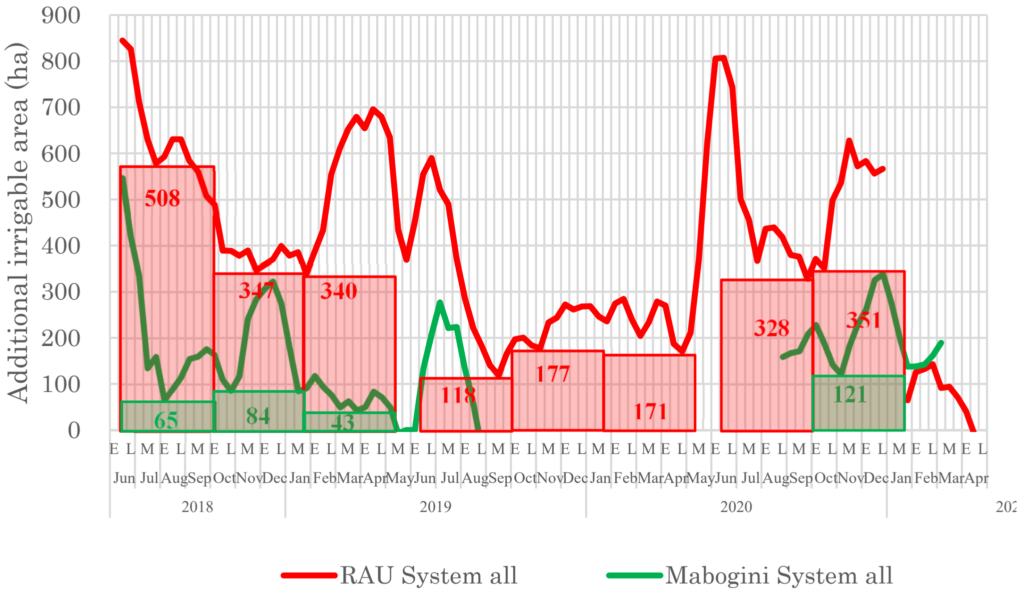


Fig. 2.31 Additional irrigable area of the irrigation period by sub-LOMIA

10) As plot area is limited in reality, the additional irrigable area is a theoretical value. If the real blocks are allocated as additional irrigation plots, additional irrigable area is 609.17 ha (i.e. 39.67 + 569.5 ha) in 2019 and 357.5 ha (0 + 357.5) in 2020 (**Table. 2.7** and **Table. 2.8**).

River discharge estimation model (section 2.3) and appropriate water manage method should be considered in actual operation.

Table. 2.7 Additional irrigable area by block in Mabogini system

(○ is actual irrigation block, ◎ is additional one)

		2018	2019		2020		2021	2019		2020	
	area	2nd, 3rd	1st	2nd, 3rd	1st	2nd, 3rd	1st	actual	additional	actual	additional
MS1-1	21.24	○	○	○	○	○	○	42.48	0	42.48	0
MS1-2	20.21	○	○	○	○	○	○	40.42	0	40.42	0
MS1-3	21.52	○	○	○	○	○	○	43.04	0	43.04	0
MS2-1	20.80	○	○	○	○	○	○	41.6	0	41.6	0
MS2-2	27.31	○	○	○	○	○	○	54.62	0	54.62	0
MS2-3	24.17	○	○	○	○	○	○	48.34	0	48.34	0
MS3-1	17.64	○	○	○	○	○	○	35.28	0	35.28	0
MS3-2	26.65	○	○	○	○	○	○	53.3	0	53.3	0
MS4-1	20.85	○		○		○	◎	20.85	0	20.85	0
MS4-2	31.82	◎	○		○	○	○	31.82	0	63.64	0
MS5-1	39.67	○	◎	○	○		○	39.67	39.67	39.67	0
MS5-2	27.59	○		○		○	◎	27.59	0	27.59	0
MS5-3	28.89	◎			○	○	○	0	0	57.78	0
MS6-1	32.07	○			○	○	○	0	0	64.14	0
MS6-2	21.29	○	○	○		○		42.58	0	21.29	0
MS6-3	11.80	○		○	○	○	◎	11.8	0	23.6	0
MS7-1	39.63	○		○	○	○		39.63	0	79.26	0
MS7-2	39.82	○	○	○		○	◎	79.64	0	39.82	0
Upper Mabogini								359.08	0	359.08	0
Lower Mabogini								293.58	39.67	437.64	0

Table. 2.8 Additional irrigable area by block in Rau system

(○ is actual irrigation block, ◎ is additional one)

		2018	2019		2020		2021	2019		2020	
	area	2nd, 3rd	1st	2nd, 3rd	1st	2nd, 3rd	1st	actual	additional	actual	additional
RS1-1	15.18	○	◎	○	○	○	○	15.18	15.18	30.36	0
RS1-2	28.82	◎	◎		○	○	○	0	28.82	57.64	0
RS1-3	28.45	○	◎	○		○		28.45	28.45	28.45	0
RS1-4	25.56	◎	○		◎	○	○	25.56	0	25.56	25.56
RS1-5	22.35	◎	○		○	○	◎	22.35	0	44.7	0
RS1-6	21.87	○	◎	○		○	○	21.87	21.87	21.87	0
RS1-7	21.78	◎	○		○	○	◎	21.78	0	43.56	0
RS1-8	10.88	◎	◎	○	○	○	◎	10.88	10.88	21.76	0
RS1-9	10.81	◎	◎	○	○	○	◎	10.81	10.81	21.62	0
RS3-1	20.28	◎	○			○	○	20.28	0	20.28	0
RS3-2	23.81	◎	◎	○		○	◎	23.81	23.81	23.81	0
RS3-3	28.63	○					○	0	0	0	0
RS3-4	25.41	○	◎	○	○	○	◎	25.41	25.41	50.82	0
RS4-1	34.78	◎	◎	○		◎	○	34.78	34.78	0	34.78
RS4-2	13.54	○	◎	◎		◎		0	27.08	0	13.54
RS4-3A	20.56	○			◎	○		0	0	20.555	20.555
RS4-3B	20.56	○			◎	◎	○	0	0	0	41.11
RS4-4	29.80	◎	◎	◎	◎	○		0	59.6	29.8	29.8
RS4-5	22.27	◎	◎	◎	○	○		0	44.54	44.54	0
RS4-6	18.80	◎	◎	◎		○		0	37.6	18.8	0
RS4-7	22.06	◎	◎		◎	◎		0	22.06	0	44.12
RS4-8	18.75	◎	◎			◎	○	0	18.75	0	18.75
RS4A-1A	21.17	◎	◎		◎	○		0	21.17	21.17	21.17
RS4A-1B	21.17	○	◎		◎	○		0	21.17	21.17	21.17
RS8-2A	25.20	○	◎		○	◎	◎	0	25.2	25.2	25.2
RS8-2B	12.05	◎	◎	◎		○	◎	0	24.1	12.05	0
RS8-3A	16.71	◎	◎	○	◎	○	◎	16.705	16.705	16.705	16.705
RS8-3B	16.71	◎	○		◎	○	◎	16.705	0	16.705	16.705
RS8-4A	16.33	◎	◎	○	○	○	◎	16.33	16.33	32.66	0
RS8-4B	16.33	◎	◎		○	○	◎	0	16.33	32.66	0
PilotA	9.45	◎	◎		◎	◎	◎	0	9.45	0	18.9
PilotB	9.45	○	◎	○	◎	○		9.45	9.45	9.45	9.45
Total											
Rau								226.4	165.2	390.4	25.6
Chekeleni								34.8	286.8	156.0	245.0
Oria								59.2	117.6	145.4	87.0
Total								320.4	569.5	691.9	357.5

3. Canal surface overlay method

3.1. Necessity and effect

Concrete canal surfaces become rougher with aging deterioration and water flow declines.
Canal water spills or necessary volume of water does not flow in some places (**Pic. 3.1**).
Canal water flow improves if canal roughness is lowered.

- Canal water flow condition is expressed by the roughness coefficient (n). The smaller is n, the more easily water flows.
- The n of a concrete canal is around 0.011–0.020 and for an earth canal is 0.014–0.030.
- Normal canal water velocity is expressed by the Manning formula using n:

$$V = n^{-1} R^{\frac{2}{3}} I^{\frac{1}{2}}$$

$$R = {}^{A}/_{S}$$

where V is water flow velocity (m/s), R is hydraulic radius (m), I is hydraulic gradient, A is flow area (m^2), and S is wetted perimeter (m).

Pic. 3.1 Water spilled condition

- In case that you want to eliminate back water effect by culvert, it is better to use gradually varied flow for estimating *n* (**Fig. 3.1**).

For gradually varied flow, the formula below is used:

$$-i + \frac{\partial h}{\partial x} + \frac{\partial}{\partial x}\left(\frac{v^2}{2g}\right) + \frac{n^2 v^2}{R^{\frac{4}{3}}} = 0$$

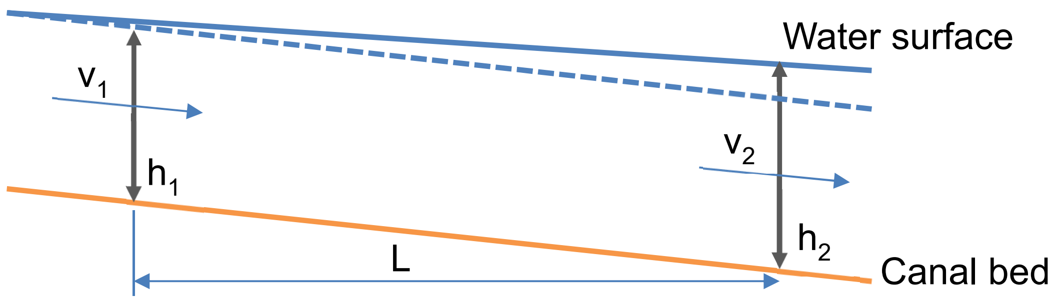


Fig. 3.1 Image of a gradually Flow

where i is position head gradient (canal bed gradient), $\frac{\partial h}{\partial x}$ is water head gradient ($(h_2 - h_1)/L$), and $\frac{\partial}{\partial x}\left(\frac{v^2}{2g}\right)$ is velocity head gradient ($(v_2 - v_1)/L$).

- If canal wall condition is deteriorating, *n* increases and water flow gets worse. If the volume of water is constant, water depth increases. If water depth is constant, volume of water flow decreases.

- When *n* of a canal wall improves (i.e. is lowered):

(1) if the same volume of water flows, water depth decreases and the canal shoulder is protected (**Fig. 3.2**).

(2) if the same depth of water flows, more water can flow and irrigation area increases (**Fig. 3.3**).

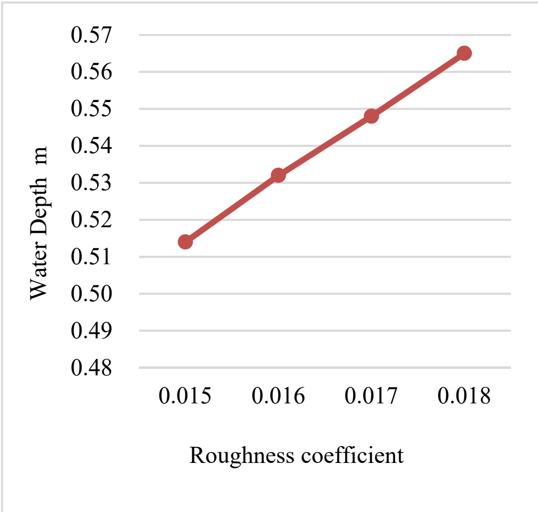


Fig. 3.2 Relation between roughness coefficient and water depth (water volume is constant)

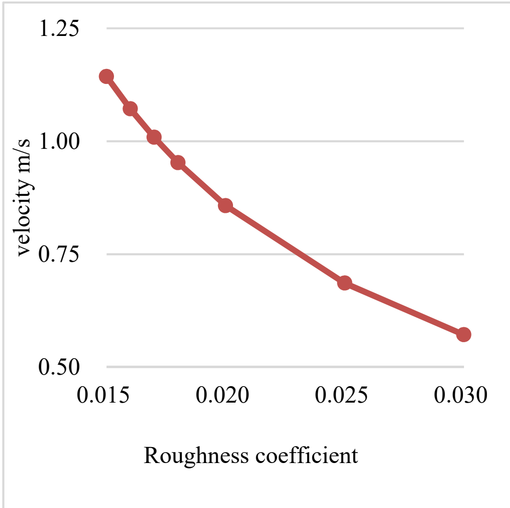


Fig. 3.3 Relation between roughness coefficient and velocity (water depth is constant)

3.2. Selection of open canal repair method

Canal surface overlay method is selected
Organic surface overlay method is selected from above method.

- The main canal repair methods follow (Irrigation Facilities Manual, MAFF Japan): surface treatment, crack repair, cross-section repair, and joint repair methods.
- When there are cracks in or large damage to the canal wall, joint damage and consequently water leaking from the canal, crack repair, cross-section repair, and joint repair methods can be adopted.
- As the object of this study is to improve water flow, the surface

treatment method is considered.

- Surface treatment methods comprise the surface overlay and surface impregnation methods. Because there are few cases of use of surface impregnation in agricultural canals in Japan, the surface overlay method is adopted.

- The surface overlay method comprises inorganic overlay, organic overlay, panel, and sheet methods.

- As a crack following function is low, the inorganic method is not considered (also, material is not readily available).

- Also, the panel and sheet methods are not considered as the necessary materials are not readily available.

- Thus, the organic surface overlay method is recommended as materials are easily available and construction is simple.

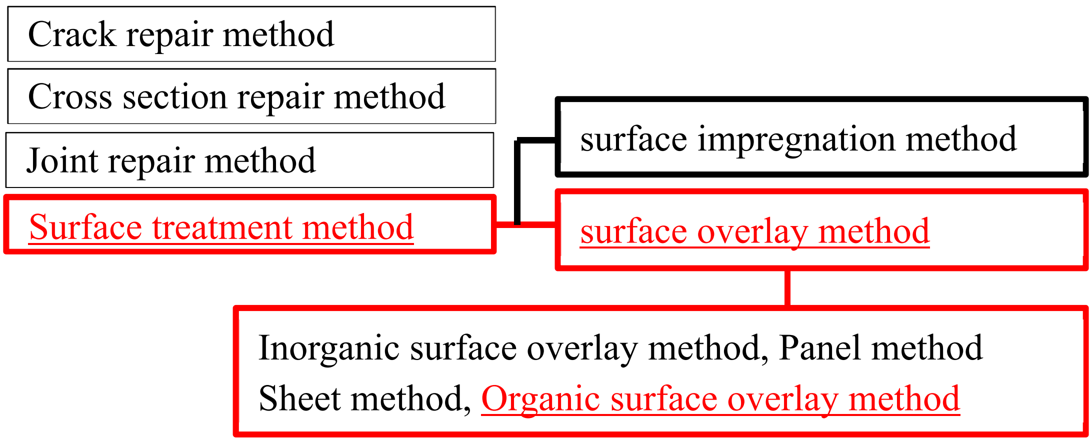


Fig. 3.4 Open repairing method

3.3. Organic overlay material

Organic overlay materials are used for exterior painting.
There are several types including acryl resin, epoxy resin, and polyurethane resin, all with similar effects (as of 2021).

- Organic overlay materials are often used for exterior painting – for example, painting walls as used in many houses in Tanzania – and so are easy to get.
- The resins from major production companies that are available in Tanzania local sites are acrylic resin, epoxy resin, and polyurethane resin. They all show similar performance (as of 2021).

3.4. Construction procedures

(1) Canal surface clearing
(2) Surface preparation
(3) Primer treatment
(4) Primer coating
(5) Top coating

(1) Canal surface clearing

The canal must be cleared of grasses and gravel before starting work (**Pic. 3.2**).

Pic. 3.2 Canal surface clearing (by removing weeds and debris)

(2) Surface preparation

The debris (or deteriorated particles) of the canal surface should be cleared before implementing surface overlay. Clearing should be implemented using a high-pressure washer machine. Although using a high-pressure washer (pressure 50–150 MPa) for clearing is common, if it is hard to get such a machine, a high-pressure washer (around 10 MPa) as normally used for car washing can be used (**Pic. 3.3**).

Pic. 3.3 Canal surface washing (by high pressure washer)

(3) Primer treatment

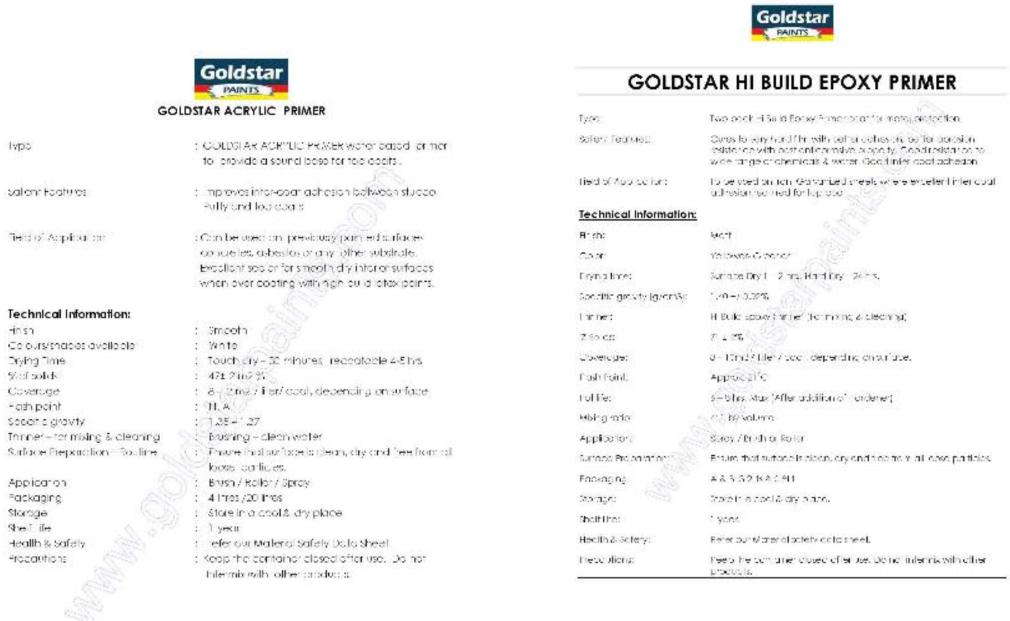
The object of the primer treatment is to remove the deteriorated part of structure for the overlay material to stick to the structure. Deteriorated parts or rough surfaces are sealed with mortar (**Pic. 3.4**).

Pic. 3.4 Primer Treatment (sealing by mortar)

(4) Primer coating (sealer coating)

The object of primer coating is to increase adhesion between the coating surface and the top coat. The primer must be coated after the surface of the canal is well dried (surface moisture content less than 5%).

Acryl resin and epoxy resin is used for the primer. The product that the production company suggests for primer use is used as the primer material. Coating volume is the standard described in the production catalog (**Pic. 3.5**). Coating is implemented by brush, roller, or spray (**Pic. 3.6** and **Pic. 3.7**).



GOLDSTAR ACRYLIC PRIMER

Type	: GOLDSTAR ACRYLIC PRIMER water based primer to provide a sound base for top coats.
Salient Features	: Improves inter-coat adhesion between stucco Putty and top coats
Field of Application	: Can be used on previously painted surfaces, concretes, asbestos or any other substrate. Excellent sealer for smooth dry interior surfaces when over coating with high build latex paints.

Technical Information:

Finish	: Smooth
Colours/shades available	: White
Drying Time	: Touch dry – 30 minutes, recoatable 4-5 hrs
% of solids	: [illegible]
Coverage	: 8 - 12 m2 / liter/ coat, depending on surface
Flash point	: N. A
Specific gravity	: 1.25 – 1.27
Thinner – for mixing & cleaning	: Brushing – clean water
Surface Preparation – Routine	: Ensure that surface is clean, dry and free from all loose particles.
Application	: Brush / Roller / Spray
Packaging	: 4 litres /20 litres
Storage	: Store in a cool & dry place
Shelf life	: 1 year
Health & Safety	: Refer our Material Safety Data Sheet
Precautions	: Keep the container closed after use. Do not intermix with other products.

GOLDSTAR HI BUILD EPOXY PRIMER

Type:	Two pack Hi Build Epoxy Primer [illegible] for metal protection.
Salient Features:	[illegible]
Field of Application:	[illegible]

Technical Information:

Finish:	Matt
Color:	[illegible]
Drying time:	Surface Dry 1 – 2 hrs, Hard Dry – 24 hrs.
Specific gravity (g/cm3):	[illegible]
Thinner:	[illegible]
% Solids:	[illegible]
Coverage:	[illegible] depending on surface.
Flash Point:	Approx 21°C
Pot life:	[illegible] hrs. Max (After addition of hardener)
Mixing ratio:	[illegible]
Application:	Spray / Brush or Roller
Surface Preparation:	Ensure that surface is clean, dry and free from all loose particles.
Packaging:	[illegible]
Storage:	Store in a cool & dry place.
Shelf life:	1 year
Health & Safety:	Refer our Material safety data sheet.
Precautions:	Keep the container closed after use. Do not intermix with other products.

Pic. 3.5 Catalog samples of acrylic and epoxy primers

Pic. 3.6 Primer application by spray gun

Pic. 3.7 Completion of primer application

(5) Top coating

Top coating is implemented after the primer is well dried (hard dry in the catalog). Materials for the top coating are acryl resin, epoxy resin, polyurethane resin, or others. There is no significant performance difference in the variety (as of 2021). The resin is selected according to availability and price (**Pic. 3.8**). Coating is implemented by brush, roller, or spray.

GOLDSTAR ROOF GUARD ACRYLIC PAINT

Type:	Goldstar Roof Guard Acrylic Paint is a versatile emulsion based roof paint on asbestos, corrugated iron sheets and cement roof tiles
Salient Features:	Easy application with brush / roller, fast drying, flexible & durable
Field of Application:	Can be applied on all types of roofs of concrete, tiles, corrugated iron sheets, etc. after proper surface preparation.

Technical Information:

Finish:	Matt
Colours / shades available:	White, Green, Blue, Red
Drying Time:	Touch dry – 30 minutes, hard dry 4 hrs, re-coat be 4 hrs
% of solids:	53 ± 2%
Coverage:	10 – 14 m2 / liter / coat, depending on surface
Flash point:	Non-Flammable
Specific gravity:	1.21 – 1.23
Thinner – for mixing & cleaning:	Clean water if required
Surface Preparation – Routine:	Surface should be clean, dry and any loose powder should be removed and appropriate primer should be applied.
Application:	Roller / Brush
Packaging:	4 Litres / 20 Litres
Storage:	Store in a cool & dry place
Shelf life:	1 year
Health & Safety:	Refer our Material Safety Data Sheet
Precautions:	Keep the container closed after use. Do not intermix with other Products.

GOLDSTAR INDUSTRIAL EPOXY ENAMEL

Type:	[illegible]
Salient Features:	[illegible]
Field of application:	[illegible]

Technical Information:

Finish	Smooth Glossy
Color	[illegible]
Drying time:	[illegible]
Specific gravity:	[illegible]
Thinner:	Industrial Epoxy Thinner (for mixing & cleaning)
% Solids:	[illegible]
Coverage:	[illegible] / liter / coat, depending on surface.
Flash Point:	Approx. 21°C
Pot life:	[illegible]
Mixing ratio:	[illegible]
Application:	[illegible]
Surface Preparation:	[illegible]
Packaging:	[illegible]
Storage:	[illegible]
Shelf life:	[illegible]
Health & Safety:	[illegible]
Precautions:	[illegible]

Pic. 3.8 Catalog sample of acrylic and epoxy top coats

Pic. 3.9 Completion status (left, acryl resin, right: epoxy resin)

3.5. Maintenance

Algae emerge soon after using the canal and canal functions get worse.
Algae should be removed without damaging the canal surface.

- In the Lower Moshi case, algae emerged on the surface of the canal after 3 months (**Pic. 3.10**);
- Water flow was disturbed by the algae;
- The *n* deteriorated: 0.0155→0.0181;
- Soft-blade tools like a squeegee (blade is urethane and does not damage resin, **Pic. 3.11)** are recommended to remove algae (50 m, 1 h/two men, **Pic. 3.12,** and **Pic. 3.13**) so that the canal surface is not damaged by removal work.

Pic. 3.10 Algae emerging situation

Pic. 3.11 Squeegee

Pic. 3.12 Removal of algae

Pic. 3.13 After removal of algae

3.6. Effect

Roughness coefficient decrease by 14%
Internal rate of return is more than 20%.

The roughness coefficient decreases 14% before and after introducing the canal surface overlay (**Table. 3.1**).

In the case of the same cross-section as Lower Moshi and 0.6 m of water depth, water flow volume increases by 16%.

In the case of the necessary water volume at the plot of 20 mm (WRPD 11 mm + loss), the additional irrigable area increases by 29.8 ha.

In the case of a service life of longer than 2 years and construction length shorter than 4,000 m, IRR is more than 20% (i.e. feasible) (maintenance twice per year and maintenance cost 8.9 USD/100 m from experiment results).

Table. 3.1 Change of roughness coefficient and cost before/after construction (Lower Moshi case)

	Before const.	After const.	Decrease rate	Cost (USD/m)
RS1-7	0.0184	0.0155	0.84	6
MS7-1 AA	0.0170	0.0148	0.87	6
MS7-1 EE	0.0139	0.0121	0.87	12
average	0.0164	0.0141	0.86	

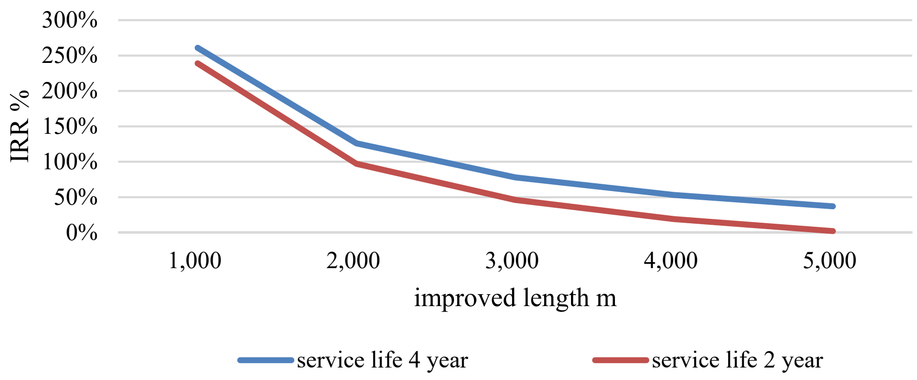


Fig. 3.5 Relationship between construction length and IRR

4. Earth canal leakage measure

4.1. Necessity, effect

Volume of earth canal (tertiary canal) leakage differs greatly depending on location and soil type. If the leakage volume is large, water use efficiency improves greatly by introducing measures to reduce water leakage.

- The volume of earth canal leakage is 109 mm/h in the dry season (**Fig. 4.1**), and 27 mm/h in the puddling season (**Fig. 4.2**) in Lower Moshi; these values are equivalent to 26.2 and 6.5 mm, respectively, in terms of WRPD at adjacent plots.
- Large amounts of leakage from downward movement are not observed. Most leakage is assumed to be generated from the sides of canals (**Fig. 4.3**).
- A leakage measure only applying to side of a canal is technically difficult. Earth canal leakage measures shall be applied in all aspects of a canal for higher effectiveness.

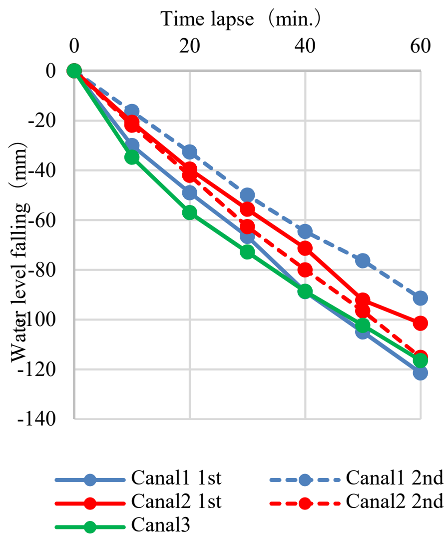


Fig. 4.1 Results of earth canal infiltration test in the dry season

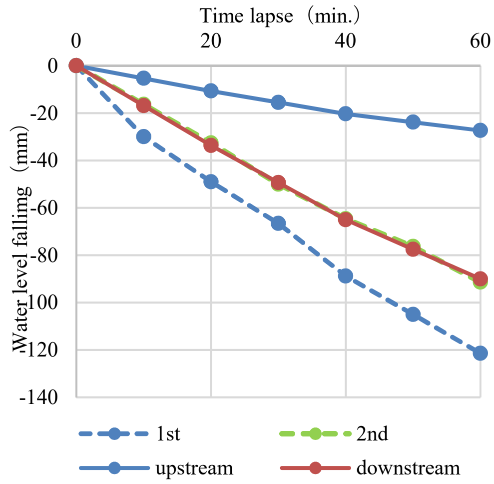


Fig. 4.2 Results of earth canal infiltration test in the puddling season (canal 1)

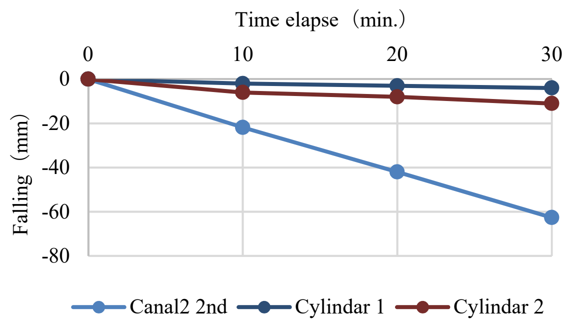


Fig. 4.3 Results of cylinder intake rate test

4.2. Type of measures

There are four types of earth canal leakage measures:
1) Concrete lining
2) Mortar lining (Masonry lining)
3) Geomembrane sheet lining
4) Polyethylene sheet lining

- Actual construction cost (direct cost) of four measures at the Lower Moshi Irrigation Scheme are shown in Table 1.
- The cost of polyethylene sheet lining is about 10% of the other measures. However, because polyethylene sheets are very vulnerable, they must be changed every cultivation season.
- The IRRs of each measure are more than 10%, in cases where the measures are introduced, and the leakage indicated above section stops. As the real long-term interest rate is 17% (JICA, 2017), if the other measures except for polyethylene sheet are applied, careful decisions are needed.

Table. 4.1 Direct Cost of earth canal leakage measure

	Length (m)	Price (USD)	unit price (USD/m)	IRR (%)
1) Concrete lining	90	4,416	49.1	12
2) Masonry lining	90	3,415	37.9	14
3) Geomembrane sheet lining	90	4,322	48.0	13
4) Polyethylene sheet lining	90	361	4.0	-

・Thickness of concrete lining is 7cm but if this is not easy to achieve, implement 14cm

・Service life and maintenance

Concrete lining – 20years (maintenance cost of 25% of initial cost every 5years)

Mortar lining – 20years (maintenance cost of 25% of initial cost every 3years)

Geomembrane sheet lining – 20years but cattle should not be allowed in the scheme otherwise it will not last for 20years (maintenance cost of 25% of initial cost every 5years)

Polyethylene sheet lining – one season (i.e. 0.5year).

4.3. Point to remember

- New polyethylene sheet needs to be laid every cultivation season and disposing of waste polyethylene sheets must be considered.
- Available water volume downstream increases as leakage decreases with the introduction of earth canal leakage measures. Thus, farmers adjacent to the improved earth canals do not receive a direct benefit, although most ordinary maintenance of tertiary canals is performed by these adjacent farmers. A way of cost sharing should be determined before introducing the measures.

4.4. Materials and Construction procedure

Construction procedure of polyethylene sheet lining is explained here.
Other measures: refer to a TANCAID manual or similar.

(1) Materials, tools, and cost breakdown

(a) Materials

-Polyethylene sheet for engineering work (roll)

-Nails

-Soil is sometimes needed to maintain canal shape at Lower Moshi for ease of laying polyethylene.

(b) Tools

-Shovel (for canal clearing)

-Knife or scissors (for cutting polyethylene sheet)

-Hammer

-Tape measure (reference).

(c) Cost breakdown.

Table. 4.2 Cost breakdown of Polyethylene sheet lining (USD: 3 interval(90m))

		Qt.	Unit	Unit price	Amount	Remark
1	Site clearance	180	m2	0.2	36	90m*2m
2	excavation (trimming)	45	m3	1.56	70	90m*0.5m^3/m
3	Polyethylene sheet	90	m	0.67	60	
4	Labor	7.2	person	8.89	64	50 m/ 4 persons
5	Materials	1	unit	12	12	20% of polyethylene sheet
6	supervise (engineer)	1.8	day	26.67	48	1 person/50m
7	Driver	1.8	day	22.22	40	
8	Fuel	17	L	1.11	17	6km/Litter, 25 km, One way
9	contingency	10	%	136	14	
	Total				361	

(2) Implementation procedure

(a) Procedure 1: canal clearing

Canals are cleared. It is necessary to carefully remove sharp objects, such as plastics and wood chips, from the canal surfaces as polyethylene sheets are laid there (**Pic. 4.1)**.

(b) Procedure 2: Cutting sheet

Because polyethylene sheets for civil construction are cylinder-shaped, they are cut open before use. Polyethylene sheets are sold in rolls typically placed with one end on the ground at local markets. Therefore, one end of the rolls is often deteriorated by rubbing, and so the deteriorated end of the sheet is cut (**Pic. 4.2)**.

Pic. 4.1 Elimination of garbage in a canal

Pic. 4.2 Polyethylene sheet cutting

(c) Procedure 3: temporary laying of sheets

The sheets are laid on the canals. The sheets are temporarily laid with an extra 1 m in length. This is because both ends of the canal require some extra room for end treatments and, due to uneven canal surfaces, when the canal is flooded after sheet installation, the sheets are pressed to the ground, making the required sheet length longer than that required for a flat surface (**Pic. 4.3)**.

(d) Procedure 4: Laying of sheet

The sheets are laid while being trodden on from above by the people who lay them, so that the sheets are pressed to the canal bed (**Pic. 4.4**). Both sides of the sheets are fixed using long nails (5 cm or longer) (**Pic. 4.5**). Because polyethylene sheets are not strong against tensile force, the parts of the sheet where nails are used are reinforced by double-folding, pasting a vinyl tape on them, or other means. Also, if holes are found in sheets during laying, they are sealed using vinyl tape (**Pic. 4.6)**.

Pic. 4.3 Temporary placement (Temporarily place a margin (about 1 m) in the diversion work)

Pic. 4.4 Placement (stepping on the bottom of canal for fitting canal shape)

Pic. 4.5 Striking a peg or nail

Pic. 4.6 Repair of a sheet

(e) Procedure 5: Terminal treatment

Both ends of the canals are either a concrete division work or a Hume pipe. Terminal treatments are carried out in accordance with the type of canal end. For the upstream end, poor end-treatments can result in water passing under the sheet, thus the leakage measure will not work. Therefore, particular care is required with terminal treatments on the upstream end (**Pic. 4.7**). In contrast, the downstream end of the sheets does not receive much water force and requires only simple treatments such as placing of rocks.

(f) Procedure 6: confirmation

After completing the laying of polyethylene sheet lining, water is allowed to flow into the canal to check for problems such as leakage (**Pic. 4.8**).

Careful confirmation is required especially at the place where terminal treatment is applied.

Pic. 4.7 Terminal treatment

Pic. 4.8 Completion status

5. Renewal of Division box

5.1. Necessity

Leakage occurs when a division box deteriorates, and water flows to a sub-block where irrigation is not necessary as useless water. If a division box is renewed, useless water decreases and water use efficiency improves.

- Deterioration of division boxes in Lower Moshi is severe, as they have not been renewed since the beginning of construction in 1987 (**Pic. 5.1**and **Pic. 5.2**)
- If there is leakage in a division box, water can flow to blocks where irrigation is not allocated on that day.
- If there is leakage in a division box, water management is not implemented effectively (necessary plots cannot be irrigated), and unused water is drained out of the scheme through drainage canals.
- Leakage from a division box is classified into leakage from gates and leakage from surrounding area. Thus, renewal of a division box is classified into two types: (1) exchange the board for a new one and (2) exchange the whole division box.
- Measure should be selected according to the leakage situation.

Pic. 5.1 Deterioration situation of division box

Pic. 5.2 Division box deterioration situation is explained by user

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5.2. Necessity of renewal (initial condition study)

Necessity of renewal of division box is decided by measuring leakage from a division box.

Necessity of renewal of a division box (i.e. renewal of only the board or of the whole diversion box) is decided by measuring leakage from a division box. If the benefit of renewal exceeds the cost of renewal, the division box should be renewed. The benefit is estimated by measuring leakage from a box.

The procedures to measure leakage from a division box follow:

(1) The case of using original wood board/stop log

❖ Close all gates of division box with original wood board (**Pic. 5.3**)

❖ Measure depth of division box (**Pic. 5.4**)

❖ Raise water level until water depth reaches 80% of maximum depth of division box (**Pic. 5.5**)

❖ Measure water depth decrease rate as follows:

- Decide the measuring interval
- Measure elapsed time with a stopwatch
- Record decreasing depth against time
- Repeat the above steps until no decrease in depth

Pic. 5.3 Gate closing

Pic. 5.4 Measuring the depth

Pic. 5.5 Water tapping

(2) The case of using new wood board/stop log

❖ Close all gates of division box with new wood board/stop log (**Pic. 5.6**)

❖ Measure depth of division box

❖ Raise water level until depth reaches 80% of maximum depth **(Pic. 5.7**)

❖ Measure water decrease rate as follows:

- Decide the timing interval in seconds or minutes
- Measure elapsed time with a stopwatch
- Record decreasing depth against time
- Repeat the above steps until no decrease in depth

Pic. 5.6 Closing by new board

Pic. 5.7 Water tapping

5.3. Removal of an existing box

An existing division box should be removed either by demolition or other suitable method, and the concrete waste treated appropriately. The removal procedures follow:

- Check levels before starting work (**Pic. 5.8**)
- Dig out the structure by removing the surrounding soil (**Pic. 5.9**)
- Remove the excavated soil/materials and place them properly

- Remove the excavated soil/materials and place them appropriately
- Remove existing division box using a crane or winch or demolish the structure using suitable tools (**Pic. 5.10~Pic. 5.13**)
- Treat the removed division box by either storing (if removed by crane) or appropriately disposing of waste (if demolished).

Pic. 5.8 Level check

Pic. 5.9 Excavation

Pic. 5.10 Removal-1

Pic. 5.11 Removal-2

Pic. 5.12 Removal-3

Pic. 5.13 Demolish

5.4. Materials and construction Procedures

Work should be implemented in accordance with Site Handbook (NIRC).

(1) Communication with stakeholders

Before carrying out any assignment on construction in any irrigation scheme, there should be good preparation which includes communicating with coordinators or scheme managers, irrigators' organization, village government, farmers, and all other necessary stakeholders **(Pic. 5.14** and **Pic. 5.15**). The main aim of meeting with the mentioned stakeholders is to create awareness and common understanding of what is going to happen. Also, this gives a good chance for experts to understand the existing situation in the location/irrigation scheme.


Pic. 5.14 Explanation-1


Pic. 5.15 Explanation-2

(2) Materials and Tools

Cement,	Aggregate,	Clean sand as per BS 8110
Shovel,	Hoe,	Hammer
Timber,	Nails,	Plywood
Spade,	BRC mesh,	Spirit level

- Concrete is Class A
- Compressive strength (28 days) is 255 kg/cm^2, aggregate size is 20 mm, and water/cement 50%
- Concrete thickness is 7 cm
- Anchor
- Concrete anchors should be installed on the top of the division box, and are used to connect the division box and the metal weir plate.

The cross-section of the new division box is the same as the previous one. The concrete thickness of the division box side wall can be changed to 10 cm instead of 7 cm, for ease of construction, as it is very difficult to maintain 7 cm for in situ construction.

(3) Construction Procedures

1) Preparation

- ❖ Check and confirm levels before starting new division box construction (**Pic. 5.16**)

2) Excavation

- ❖ Excavate to structure, so that formwork can be easily placed
- ❖ Trim or reshape the excavated area ready to construct the new structure (**Pic. 5.17**)

3) Bottom slab work for a division box

- ❖ Fabricate formwork to put in the area
- ❖ Cut, place, and arrange BRC mesh as per structure design (**Pic. 5.18**)
- ❖ Mix mass concrete and pour it onto the base about 10–15 cm thick (**Pic. 5.19-Pic. 5.20**)
- ❖ Leave the base concrete to set for about 24 h before implementing the next task
- ❖ Cure the base structure with sufficient clean water.

Pic. 5.16 Level work

Pic. 5.17 Excavation

Pic. 5.18 Bar arrangement

Pic. 5.19 Concreate work-1

4) Lateral wall work of a division box

- ❖ Fabricate and fix formwork as per structure design (**Pic. 5.21**)
- ❖ Mix concrete by mixer or hand
- ❖ Cast the concrete to formwork (use all possible ways to vibrate the concrete for good compaction) (**Pic. 5.22-Pic. 5.23**)
- ❖ Leave concrete to set for at least 48 h before removing formwork
- ❖ Cure the structure for more than 5 days
- ❖ Backfill, compact well, and shape the surrounding of the structure (**Pic. 5.24-Pic. 5.25**)

Pic. 5.20 Concrete work-2

Pic. 5.21 Formwork

Pic. 5.22 Concrete casting

Pic. 5.23 Concrete work-3

Pic. 5.24 Concrete casting

Pic. 5.25 Concrete casting

5.5. Effectiveness

- Results of current leakage measurement of division boxes at Lower Moshi are shown in (**Table. 5.1**).
- Leakage change by board renewal is 4.5 m^3/h (54 m^3/12 h) → 3.6 m^3/h (43 m^3/12 h);
- 11 m^3/12 h of leakage saved by board renewal – equivalent to irrigation water volume of 540 m^2 (WRPD is 20 mm);
- Cost is 374 USD per division box, income from paddy rice cultivation is 1,350 USD/ha;
- Where irrigation is implemented at both the sub-block belonging to a division box and downstream sub-blocks, even if there is leakage from the division box, there is no water loss as a whole block;
- Where irrigation is not implemented at a sub-block belonging to a division box, and irrigation is implemented at a downstream block, one gate of the division box is closed. Thus, leakage from the box occurs (and vice versa);
- **Fig. 5.1** shows a block schematic diagram of MS5-1. The numbers are plot numbers and beige-colored parts indicate a canal. The colored rectangle indicates a division box. The numbers colored green indicate the plot where irrigation was implemented on 23 August 2020;
- **Fig. 5.2** shows the estimated leakage volume based on **Fig. 5.1**. Here, 6 h is necessary to irrigate one plot and irrigation of multiple plots is not implemented at the same earth canal block up to 4 irrigation plots (least leakage condition). Leakage volume is estimated under conditions that leakage from a division box would occur when the canal is not used (red colored time zone);
- Leakage volume by day is calculated from leakage volume of one division box of 4.5 m^3/h (**Fig. 5.2** is the sample of 23 August 2020, and leakage is 270 m^3). The average leakage is 53.6 m^3/d (**Table. 5.2**);.
- When there are four division boxes in one block, the cost for the four boxes is 1,496 USD. If all four boxes are renewed, 53.6 m^3/d is saved and an additional 0.267 ha (53.6/0.02) can be irrigated. The renewal increases income by 360 USD;

- If service life of a division box is 10 years, IRR is 28%.

Table. 5.1 Result of division box leakage test

	Original board		New board	
	water level decrease cm/min	Leakage volume m3/h	water level decrease cm/min	Leakage volume m3/h
Division box1	not ponding	-	2.2	3.0
Division box 2	3.5	4.7	3.0	4.1
Division box 3	3.8	5.1	2.9	3.9
Division box 4	2.8	3.8	2.1	2.8
Ave		4.5		3.6

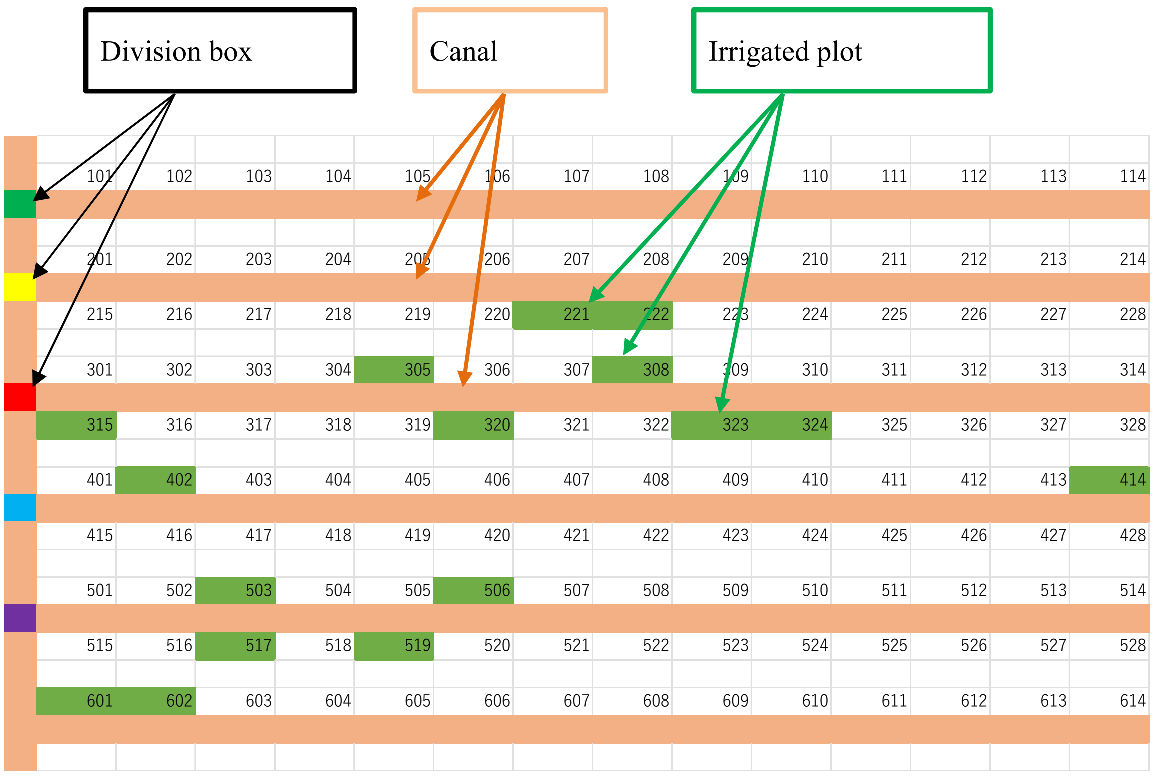

Fig. 5.1 Schematic diagram of MS5-1

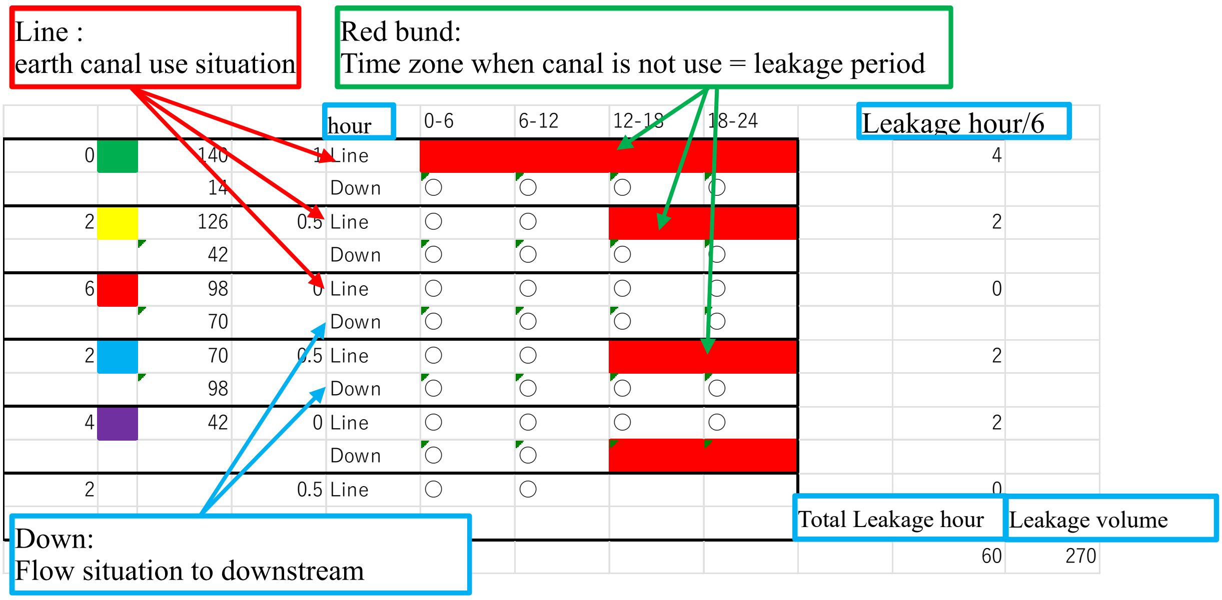

Fig. 5.2 Estimation sample of leakage volume and leakage time zone (23 Agugust 2020)

Table. 5.2 Trial calculation of leakage volume from a division box

date	Leakage volume		date	Leakage volume	
21-Aug	81	m^3	28-Aug	243	m^3
22-Aug	297	m^3	29-Aug	162	m^3
23-Aug	270	m^3	30-Aug	297	m^3
24-Aug	432	m^3	31-Aug	378	m^3
25-Aug	270	m^3	1-Sep	324	m^3
26-Aug	216	m^3	2-Sep	216	m^3
27-Aug	297	m^3			
Average (whole block)				268	m^3/d
Number of division boxes				5	places
Leakage per one division box				53.6	m^3/d

6. Plot leakage measure

6.1. Necessity, effectiveness

(1) Ordinary irrigation period (from transplanting to harvesting)

The smaller is plot leakage volume, the more the necessary irrigation water volume decreases.
Thus, irrigable area increases by the same volume of water.
Also, applied fertilizer lost without any use by plants decreases, and effective fertilizer use improves.

- Water consumption volume in a plot is called “WRPD”, and consists of evaporation, plant absorption volume, and water leakage from the sides or bottom of a plot;
- Average WRPD in the Lower Moshi Irrigation Scheme is 11 mm (simple average from 21 blocks);
- WRPD ranges within 8–20 mm by block and plant growing stage;
- WRPD differs for plots in the same block. Value of large WRPD plots is around 30 mm;
- When water leakage measures are implemented at a plot where leakage volume is large, both WRPD and necessary irrigation water volume will decrease;
- For example, when water leakage measures are implemented at a plot where leakage volume is large (WRPD is 30 mm), and WRPD is improved to 25 mm, necessary irrigation water volume decreases by 5 mm;
- If WRPD is 11 mm (i.e. normal plot) and water leakage measures are implemented in 1 ha, then irrigable area increases by 5/11 ha.

(2) Paddling period

In cases of plot leakage being small, puddling water volume decreases.
Puddling possible area increases by the same amount of water volume.

- Generally, because paddy soil is dry before puddling, much water is needed to be enough for puddling (i.e. submerging a paddy field).
- The volume of water that infiltrates deep under the hard pan before reaching submergence is a large proportion of the puddling water volume.
- The average deep-infiltration water volume is 180 mm in the Lower Moshi Irrigation Scheme. The deep infiltration water velocity is 0.05–0.06 m/h.
- The volume of deep-infiltration water decreases with compaction of the hard pan.
- The relationship between deep-infiltration water velocity and leakage volume is assumed to be as expressed in **Table. 6.1**.
- Leakage volume by plot (0.3 ha) is 900 m^3 in the case of deep-infiltration water velocity of 0.06 m/h, and the leakage volume decreases to 58 m^3 if deep-infiltration water velocity is improved to 0.01 m/h.

Table. 6.1 The leakage volume till full submerge(3,000㎡) by deep infiltration water velocity

	observe	Deep infiltration water velocity (m/h)					
		0.01	0.02	0.03	0.04	0.05	0.06
Time to fully submerge (hours)		3.7	4.0	4.5	5.0	5.9	7.7
Intake water volume (m^3)	1,268	778	848	942	1,066	1,257	1,621
Submerge water volume (m^3)	281	281	281	281	281	281	281
Water volume in Plough layer (m^3)	440	440	440	440	440	440	440
Leakage water volume under hard pan (m^3)	547	58	127	222	345	537	900

6.2. Crush and compaction method

Generally, a hard pan (impermeable layer) is formed by tread pressure of a tractor or plowing.
Crush and compaction method is used in soil that is difficult to compact using only pressure from above, e.g. a volcanic ash soil.

- Lower Moshi Irrigation Scheme is located at the foothills of Kilimanjaro Mountain and is assumed to include volcanic ash soil.
- Volcanic soil has high permeability, and the structure generates a strong supporting force such that compaction does not destroy the structure and decrease porosity (Yamazaki, 1971).
- Thus, using a crush and compaction method that destroys the porous structure (Iwate Univ., 1986) should be considered.
- The crush and compaction method is effective for volcanic ash soil but expensive. Thus, trial construction to confirm its effectiveness is desirable before using this method.

6.3. Construction procedures

(1) Topsoil treatment
(2) Hard pan crush
(3) Compaction
(4) Top soil return

(1) Topsoil treatment

Crush and compaction method aims to crush and compact the hardpan. Topsoil above the hardpan should be removed and temporarily stored. It is expensive to move the soil a long distance. So, topsoil treatment should be implemented on half of a plot, and the removed soil temporarily stored on the other half (**Fig. 6.1**).

A bulldozer is used for topsoil treatment. If the capacity (rating output) of the bulldozer is small, it takes a long time to implement topsoil treatment, and if the topsoil is hard, the bulldozer cannot remove it. Using as large a rating output as possible (D5 (Caterpillar) is used at Lower Moshi) is recommended. Thickness of topsoil is determined by prospect excavation (the thickness of Lower Moshi is 20 cm).

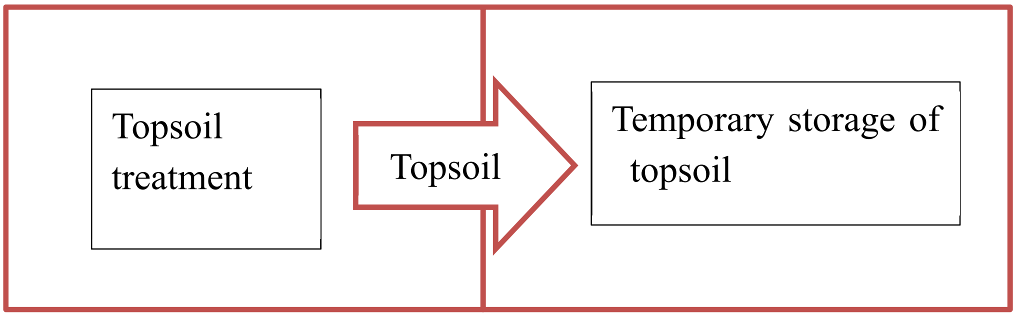

Fig. 6.1 Temporary storage of topsoil

(2) Hardpan crush by tractor

Normally hardpans are crushed using a disk plow; however, if the hardpan is particularly hard, it is penetrated with the ripper of a bulldozer.

Disk plows are common for farmers, as they are used for plowing plots and the cost is low. Bulldozers are not normally used by farmers but for road construction and the cost of bulldozers is much higher than for a tractor and disk plow. Thus, disk plows are often more easily available.

The timing is better immediately after harvesting rather than immediately before puddling, as a small amount of water remains and the hardpan is not as hard at this time.

Pic. 6.1 Bulldozer (D5)

Pic. 6.2 Topsoil treatment

Pic. 6.3 Disk plough

Pic. 6.4 Crush situation

Pic. 6.5 Too hard for disk plough

Pic. 6.6 Crush by ripper

(3) Compaction by bulldozer tracks

After crushing a hardpan, the soil is compacted by the bulldozer tracks. The construction time varies according to the amount of compaction needed, and as construction time rises so does the cost. Thus, compaction times of are determined by determining the relationship between compaction passes and the decrease in leakage volume.

Table. 6.2 shows the result of experimental construction at Lower Moshi. There was no significant difference in WRPD between one compaction pass and three passes. So, one compaction pass was selected.

It should be noted that it is better to implement compaction near optimum water content (i.e. water content to maximize compaction density). The value of optimum water content is about 22% in Lower Moshi (**Fig. 6.2**). As the value of optimum water content changes with the soil, it is desirable to determine the value in advance by soil compaction test (ASTM D1557, BS1377).

Table. 6.2 WRPD after crush and compaction method

Compaction times		before	1 day after	2 day after	3 day after
1 time	N type	26.5	30	13	14
	Plot		32	16	16
2 times	N type	27	20	12	10
	Plot		23	13	10
3 times	N type	17.5	30	10	13
	plot		25	18	13

Pic. 6.7 Compaction by caterpillar

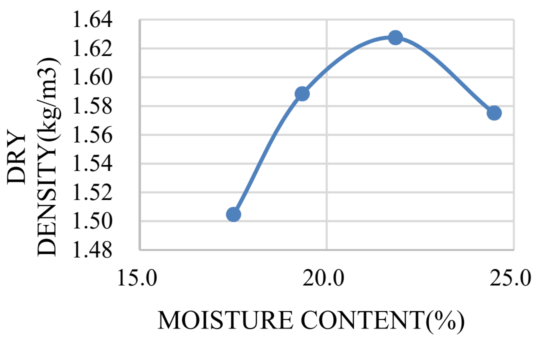

Fig. 6.2 Compaction curve (Lower Moshi)

(4) Topsoil return

After finishing compaction, topsoil is returned from temporary storage by bulldozer. After finishing returning of the soil, the crush and compaction method is implemented where the soil had been temporarily stored.

6.4. Effectiveness

The result of a verification experiment at farmers' plots in Lower Moshi is described below. The verification experiment was implemented at five consecutive plots. Both end plots were control plots.

Average WRPD of the plots where the crush and compaction method were implemented (409–413) decreased by 5.0 mm (29%) from 17.0 to 12.0 mm **Table. 6.3**. However, the WRPD of unconstructed plots increased slightly from 15.5 to 18.0 mm.

The leakage volume decreased by 29% for plots in which leakage was not high.

Because average WRPD is 11.3 mm in Lower Moshi, the crush and compaction method increased the irrigable area by 44% (5.0/11.3).

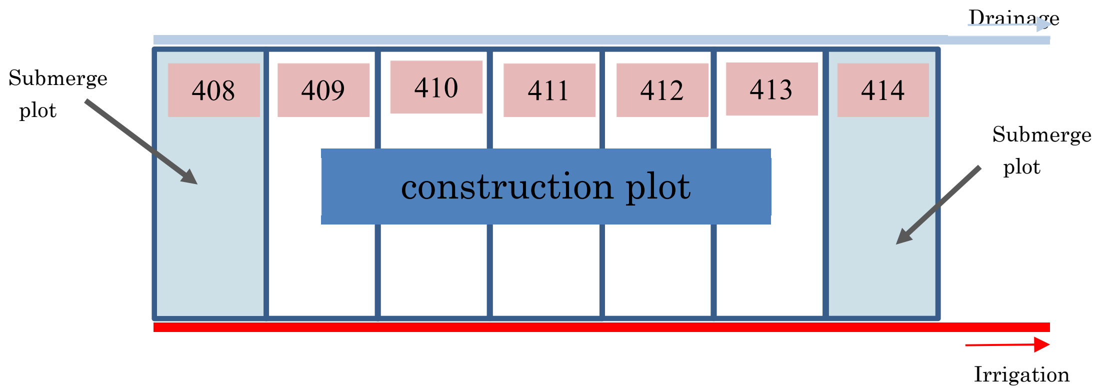

Fig. 6.3 Plot image of the test (center plot is largest leakage)

Table. 6.3 Result of verification experiment of crush and compaction test (Lower Moshi)

	409	410	411	412	413	Ave.	408	414	Ave.
Before	22	17	15	14	17	17.0	13	18	15.5
After*	13	11	12	12	12	12.0	18	18	18.0

* Without first day

6.5. Cost effectiveness

Cost effectiveness for Lower Moshi follows:

・Mean of WRPD improvement by crush and compaction method was 5.0 mm (17.0→12.0 mm/d);

・Mean WRPD of Lower Moshi was 11.3 mm;

・0.44 ha (5.0/11.3) can be additionally irrigated by using saved water by implementing crush and compaction method in 1 ha;

・Cost for trial construction was 5,888 USD/ha (2019 prices(**Table. 6.4**));

・Income from paddy rice cultivation was 1,350 USD/ha (2019 prices);

・The IRR was 10.0% (service life of 20 years). Determining feasibility requires considering the long-term interest rate of the government at design time and the service life. Because deterioration of earth works by aging is small, if the service life is 100 years (standard of MAFF, Japan), the IRR would be 11.6%. The real interest rate of Tanzania is 8.2% (Chapter 1), making the measure feasible.

Table. 6.4 Breakdown cost for crush and compaction method

Construction	Volume	Unit price	USD	5 plots
Bulldozer	20day	266.7	5334	D5 topsoil treatment 2 days, compaction 1 day, return soil 1 day
Operator	20day	22.2	444	
Fuel	1600L	1.1	1760	80kW×0.12L/hr×8hr=80 L/day
Tractor	5day	44.4	222	Heavy disk plough, including fuel, operator 1 day/plot
Labor	15man	4.4	66	assistant 1 man/day
Engineer	15day	26.7	401	
Government staff	5day	26.7	134	
Driver	15day	22.2	333	For government staff
Fuel for car	125L	1.1	138	6km/Litter, 25 km, One way
Total			8,832 5,888	/1.5ha /1ha

6.6. WRPD's influence to yield

Pic. 6.8 Experiment in KATC

In pot experiments in Kilimanjaro Agricultural Training Center (KATC), WRPD did not change yield significantly for the range of 10–30 mm/day (daily average through the crop season) shown in **Fig. 6.4 - Fig. 6.7**.

- The WRPDs above included underground penetration, evaporation, and transpiration but not rainfall. Applied rice varieties were NERICA and SARO5.
- Other than yield, no significant difference was observed in maturing ratio, panicle number, 1000 grain weight, and culm length.
- Thus, decreasing WRPD should increase regional total yield and irrigated area. In other words, the fixed irrigation water volume can be shared by more fields.

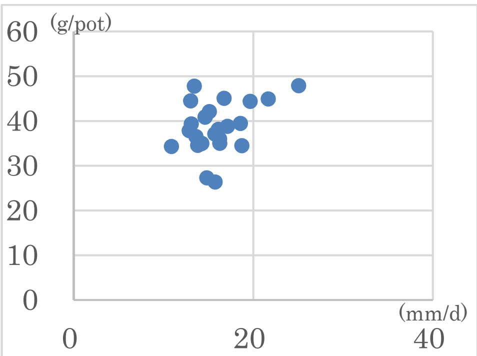

Fig. 6.4 2019(NERICA, 25pots)

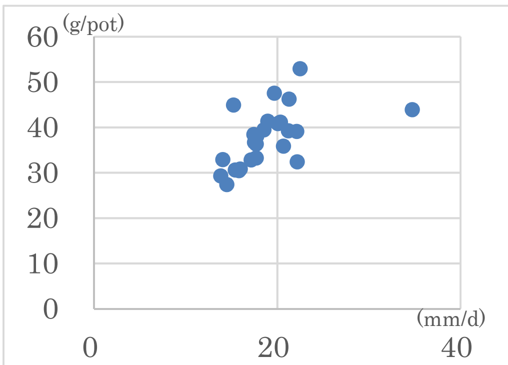

Fig. 6.5 2019(SARO5, 25pots)

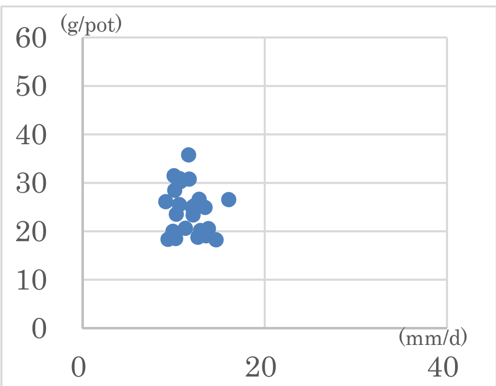

Fig. 6.6 2020(NERICA, 25pots)

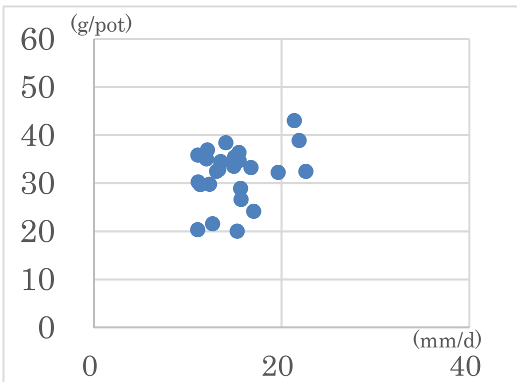

Fig. 6.7 2020(SARO5,25pots)

7. Water saving cultivation

7.1. Necessity and effect

Application of water saving cultivation to irrigated rice should improve agricultural water use efficiency.

- There are three ecosystems for rice cultivation: irrigated paddy, rainfed lowland, and upland. Irrigated paddy uses much more water than the others and the necessary water volume differs according to the growth period of the variety used (Water Requirement per Day in Moshi is estimated about 12.0mm/day at minimum).

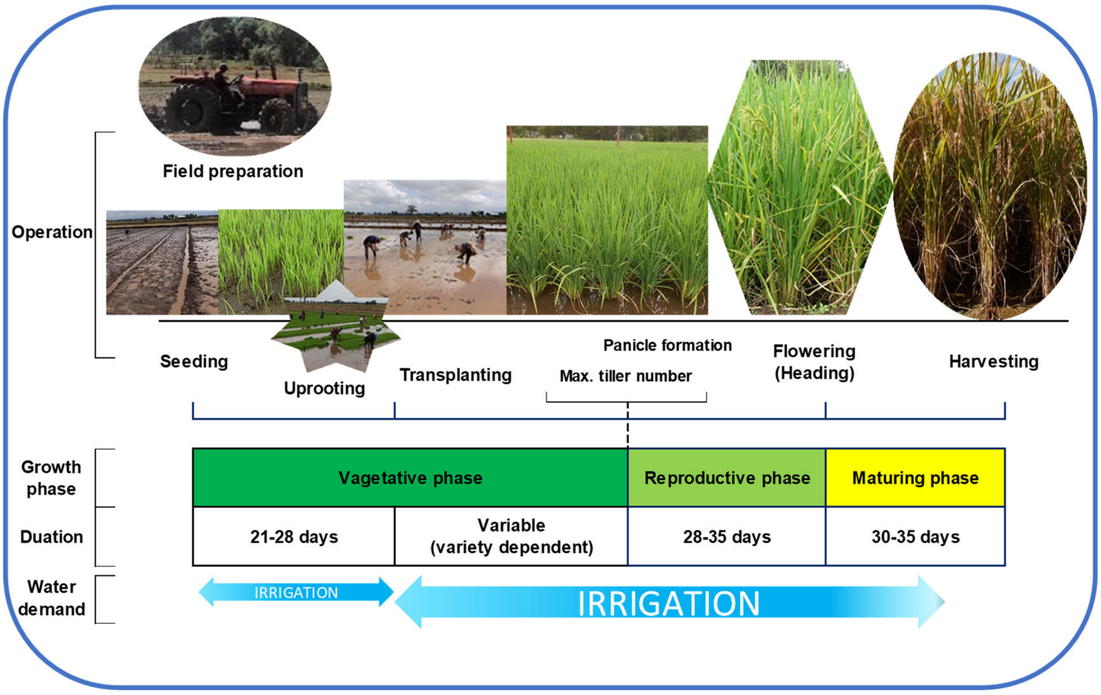

Fig. 7.1 Field operation, growth stage of rice plants and water requirement

- It is necessary to improve efficiency of water usage when water supply is reduced or when farmland area is expanded.
- There is a possibility that the efficiency of water use can be improved by introducing water-saving cultivation in irrigated paddy fields that require the most water.

7.2. Methods of water-saving cultivation

Following are some examples of water-saving methods applicable to irrigated paddy fields:

1) Convert irrigated paddy to upland rice field
2) Convert irrigated paddy to upland field for other crops such as maize and/or vegetables or others
3) Introduce **A**lternate **W**etting and **D**rying (AWD)

- Generally, when upland rice is cultivated in fields converted from irrigated paddy, the rice yield decreases.
- When irrigated paddy is converted to upland fields and supplemental irrigation is planned during cultivation of upland crops, it is necessary to consider the soil condition and quality of irrigation water. Growth inhibition of crops may occur due to quality of irrigation water.
- In addition, it is also necessary to introduce rotation cropping cultivation of upland fields because rice monocropping in upland fields causes severe growth problems unlike rice monocropping in irrigated paddy fields.
- When AWD is carried out in paddy fields, it may be possible to reduce the amount of irrigation water without yield penalty compared to conventional continuous flood irrigation.

7.3. Introduction of AWD to paddy field

Some field conditions are necessary for AWD to apply

- In the interval of irrigation during AWD treatment, water level gradually lowers and the field soil progressively dries out. Some types of soil easily crack in such cases, and these cracks can reach deeply and initiate water leakage. As the leakage increases, the irrigation frequency needs to be increased, resulting in no water-saving. Thus, soil type should be well considered.
- Upper and Lower Mabogini of the Moshi Irrigation Scheme in the Kilimanjaro District are close to each other and have similar soil components.
- The experiment at Upper Mabogini indicated that timings of irrigation at the water levels of both −7.5 and −15 cm were effective to save water. However, the results differed at Lower Mabogini.

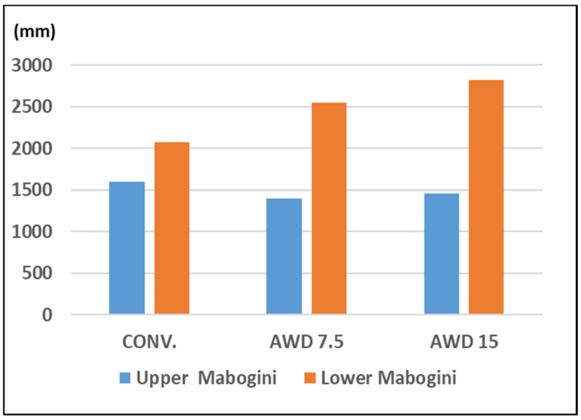

Fig. 7.2 Effect of AWD for water-saving

Conv: Continuous irrigation keeping water level above 0-5 cm from the soil surface.

ADW-7.5: Irrigate at field water level -7.5cm from the soil surface

AWD-15: Irrigate at field water level -15cm from the soil surface

- AWD is not applicable to heavy clay soil due to forming deep cracks during low water level. However, it significantly reduces irrigation water by about 10% under conditions such as at Upper Mabogini.

AWD is compatible with rice cultivation as shown in "Rice Cultivation Technology" (TANRICE, 2011)

- AWD is a post-transplanting operation. To maximize yield even in water-saving cultivation, the cultivation procedure should follow the manual for the" Rice Cultivation Technology".

Variety and AWD

- In the experiment at KATC using 18 varieties cultivated in Tanzania or in Africa, namely CHEREHANI, WAHIWAHI, AFRIHIKARI, IR 64, KILOMBERO, SUPA, IR 54, KOMBOKA, KAHOGO, KALAMATA, SATO 9, TXD 220, SATO 1, TXD 306, TXD 88, SATO 6, TXD 85, TXD 307, AWD did not show significant disadvantage in terms of yield.

7.4. Before starting AWD

Grow healthy and thick seedlings in nurseries

- Appropriate fertilizer application to the seed bed is necessary to grow healthy and thick seedlings. Sowing too many seeds causes fast elongation and softens tissues of the seedlings which can be easily broken. Keep in your mind to establish healthy nursery by following the manual for rice cultivation technology.
  Followings are extra tips to make uprooting of seedlings easier.
- When seedlings are grown in communal fields, it is necessary to keep the seed bed in a moist condition (and not allow drying out). Once dry, the mud gets harder and pulling seedlings causes root damage easily.

Healthy seedlings with roots have higher survival rates and produce new roots in a few days.

Pic. 7.1 Dried seed beds

Uprooting is difficult

- Care is necessary especially at the time when top-dressing is applied to the specific seedling bed. Irrigation is usually stopped and water is drained to avoid dissolving the fertilizer. To avoid drying of the nursery bed, constructing a simple levee between beds may help to maintain moisture of beds and efficiency of fertilizer applied.

Preparation of fields without leakage

- Fundamental maintenance of levee, such as filling ant nests, tunnels of other insects or rats, and cracks, should be done during field preparation.
- Agricultural engineering approaches, such as lining of earth canal, etc., are described in other sections.

Making of bunds/levees

- For efficient utilization of irrigation water, proper bunding of paddy plots is needed.
- Temporary bunds are 30–40 cm high and 30–60 cm wide at the base;
- Permanent bunds are 40–50 cm high and 130–160 cm wide at the base;
- Bunds should be compacted to avoid cracks, prevent seepage during flooding, and make them strong.
- Narrowing the levee to expand the field area weakens the levee and causes it to easily break while walking on it and so leads to water leakage.
- It is strongly recommended to coat levees using softened mud before

final puddling if possible.

How to determine the desired level without instruments

- For uniformly sloping areas it is quite easy to level the ground without pegging. The soil in the higher areas is scraped to the lower areas until the soil surface is level. This can be achieved using equipment like rakes and hand hoes.
- After the first leveling, let water into the basin and see how it lies. The deeper areas should be filled with earth taken from higher ground.

Preparation of healthy seedlings for transplanting

- As described in the section on nurseries, healthy seedlings with roots have a higher survival rate and shorter time to produce new roots. New tillers also appear, giving an advantage in competition with weeds.
- Even highly skilled experts at transplanting, who can transplant very quickly, cannot eliminate damaged seedlings (seedlings without roots). Thus, preparing good seedlings is essential for a good start in water-saving cultivation.

Preparation of some tools (optional)

- It is easy to check water levels using a pipe with holes. The part with holes (5 mm dia.) should be buried underground with covering net. The depth depends on timing of irrigation during AWD treatment. If you plan to irrigate at field water level −7.5 cm from soil surface, 15 cm of underground part is enough.

- If suitable pipes are not available, PET bottles can be used. However, the bottles, as same as perforated pipe, used should be salvaged when irrigation is stopped in preparation for harvesting.

Pic. 7.2 Perforated pipe to be inserted in the paddy(left); Perforated pipe showing level of water below the soil surface in the paddy (center, right)

Pic. 7.3 How to install a perforated pipe

7.5. Starting AWD

> Start AWD after first top-dressing at 14 days after transplanting

- AWD should be started when seedling have produced new roots and settled well after transplanting. If recovery of rice seedling is delayed, in the cases that older seedlings or weak seedlings were transplanted and establishment delay, starting of AWD treatment should be postponed.
- Continuous irrigation prevents weed growth because water keeps the soil surface in an anaerobic condition. However, the soil surface is exposed to air periodically during AWD treatment and this allows weeds to grow. Thus, weed control is very important in the early period after transplanting.
- The first top-dressing is recommended at 14 days after transplanting and weeding is done before that. The AWD can be started after the first weeding and top-dressing.
- If a selective herbicide is applied to suppress weeds after transplanting, weeding before the first top-dressing may not be necessary.
- The first top-dressing should be applied under irrigated condition and the water should be kept in the field so that applied fertilizer is dissolved to irrigated water. The AWD can follow the water decrease (fertilizer moves to soil).

7.6. Operation during AWD treatment

> Timing of irrigation is determined by the position of water level

- Water level can be surveyed using a pipe with holes (see section 7.4) or even water in the ditch constructed in the field (option*).
  *A ditch saves time for spreading water to the whole area and does not affect yield.
  *Do not step in to ditch while conducting weeding or top-dressing operations.

Pic. 7.4 **Perforated** pipe set in the field to check water level (left) and ditch maker (right)

- Record the date, time of irrigation, other operations, and observation of field. The frequency of irrigation may change during the flowering period of rice plants because they consume a lot of water at this time.
- Stop irrigation a week before the expected harvesting date and prepare for the harvest.

Memo

Plants infected with RYMV

What is the source?

Rice Yellow Mottle Virus (RYMV) disease is widely observed in Africa. It is transmitted by insect and physical contact among infected and healthy plants. The most effective countermeasure is killing all residual plants in the previous season, by irrigating the field for a few days to germinate residual plants and spraying a nonselective herbicide. This may also reduce contamination of seed.

8. Water Management

8.1. Water management problems

The irrigation plan was not achieved. The problems were investigated from the aspect of water management. Recommendations should be made to improve the monitoring system for water distribution, improve the decision-making method for water management, and introduce participatory irrigation management (PIM) in the future.

Work summary

- Unachieved plans: since 1988, when the irrigation plan was reviewed, the irrigation plan of 1,500 ha was achieved for only two years, and the average irrigation area is only 920 ha. The full effect of irrigation facilities is not obtained.
- Excessive water intake: investigating the use of irrigation water in the Lower Moshi area showed excessive upstream water intake. Some paddy fields cannot be planted as originally planned, and water is being used inefficiently.
- Lack of coordination: water management is carried out by gatekeepers and watermen (who controls water in a irrigation block), but is not based on data. No adjustments are made among the gatekeepers.
- Water distribution: to maximize local production, it is necessary to distribute water as planned. If water resources are limited and cannot be allocated as planned, it is important to allocate them as evenly as possible. In the case of paddy fields, a water levy is collected based on the beneficiary area[3] (Satoh et al., 2007).
- Proposals: this chapter proposes establishment of a monitoring system for water distribution, improvement of water management

[3] Water levies in the Lower Moshi area vary slightly from block to block due to differences in the number of gates and canal lengths. Mahande area is based on area.

decision-making methods, and introduction of PIM in the future.

8.2. Central LOMIA shall monitor water distribution

Central LOMIA should establish a system to coordinate water use of the entire Lower Moshi.
Appoint a Water Master and monitor water distribution by the gatekeeper.

Improvement of organizational structure:

- In the Lower Moshi, five sub-LOMIAs currently operate independently. No meetings have been held for the five sub-LOMIA executives.
- The irrigation facilities of the main and secondary canals are operated by three gatekeepers. Information on water management is not exchanged, and irrigation water distributed greatly exceeds the planned amounts especially in upstream areas.
- Central LOMIA should be positioned as an organization that coordinates the water use among the five sub-LOMIAs. For local allocation, we propose setting up a water distribution coordinating committee in Central LOMIA and/or appointing a Water Master to handle the work.
- It is necessary to organize the water intake of the corporate farm (Usagara Farm). (Is it okay to take water if it is drainage, or should drainage be returned to the river? Need to check the rules and regulations.)

8.3. Water distribution information shall be opened

The water allocation is determined by JICA's plan, but the planned irrigation area has not been achieved.
To grasp the water distribution reliably, install water gauges at points such as diversion works so that water intake information can be shared.

(Disclosure of information)

- Since the upstream block is taking water with priority, the upstream side is irrigated more than necessary.
- We propose sharing information on water level in the canal so that we can confirm that water intake is appropriate.
- Currently, partial flumes are installed in several places, and the volume of water in the canal can be confirmed at these places; however, the volume of diversion cannot be confirmed. A new water gauge will be installed at the point of diversion work. The gatekeeper confirms the water level and implements water distribution.

(Reference)

- The National Irrigation Act (2013), Regulations (2015):

"64. Every irrigation scheme shall install water gauge at abstraction points and division structures in order to ensure…"

- In Egypt, farmers check the volume of water distributed by the water-level gauge.


Pic. 8.1 Example of water level gauge (Egypt)

8.4. Review of water allocation plan and reorganization of water management system

To increase the acreage, review of the water distribution plan is necessary. The water distribution plan should be decided by the consensus of the farmers (water users' association, WUA) with involvement of the government.
To realize the new water allocation plan, the water management system should be changed. The water management system seeks the optimal method through four processes: decision, operation, monitoring, and feedback.

(Future plan)

- Under the current regulations, the farmers (WUA) create an irrigation and planting plan based on a government-approved one. Farmers cannot change acreage without government approval.
- However, on the premise of government decision and approval, it is impossible to raise farmers' awareness of water saving, and as a result, it is difficult to realize efficient water use. To encourage farmers to save water, it is necessary to reflect the will of the farmers who are the users in the decision of the water distribution plan.
- For farmers, it is rational to decide the water allocation plan by themselves, but it is not easy to coordinate among regional representatives due to (regional/organizational) conflicts in water allocation. To prompt rational decisions by the farmers, the government engineers need to provide the necessary scientific, technical, and agricultural knowledge of hydrology, hydraulics, and cultivation. In addition, it is the role of the government to guide, advise, and monitor the discussions within the WUA so that discussions can be proceed rationally and the goals achieved. In this way, the water allocation plan is created with the involvement of both the government and the WUA.
- Operation of the facility needs to be directed toward the set plan. This will be done by the gatekeeper under guidance of the Water

Master, but specialized knowledge and skills are indispensable to ensure fairness between blocks and perform stable operations. Gatekeepers need to be trained as required (government should consider training gatekeepers).

- It is necessary for the WUA to monitor the water usage status (in addition to measuring the amount of water at the partial flume, install a gauge to check for excessive water intake). Furthermore, as a result of monitoring, the water distribution will be corrected, and adjustments of facilities made to make it appropriate.
- In summary, we propose to determine optimal water management by decisions, operation, monitoring, and feedback through the following four processes (**Fig. 8.1**).

1) Decision: determine water allocation goals and plans for when, where, and how to allocate available water.
2) Operation: distribute water according to the determined goals and plans (operation in a narrow sense).
3) Monitoring: monitor the actual water distribution operation and grasp and evaluate the result of water distribution.
4) Feedback: reflect the monitoring results in the operation process to correct and adjust the water distribution. In some cases, go back to the decision process and review the water allocation plan.

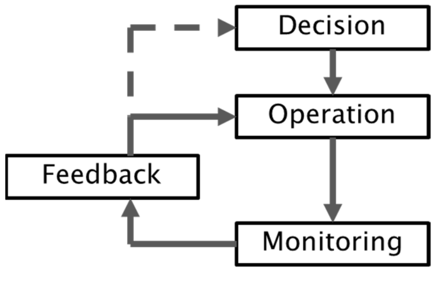

Fig. 8.1 Four processes of water management
(Satoh, et al. 2007)

8.5. Proposal for rotation irrigation trial

We propose a rotation irrigation trial as a new water management method to eliminate inequality in water distribution.

(Proposals)

- For the time being, we propose "rotation irrigation" for the entire Lower Moshi area as a water management method to be tried. Specifically, for example, rotation irrigation is carried out every three days in each area of the Mabogini River system (Upper and Lower Mabogini) and the Rau River system (Rau ya Kati, Oria, and Chekereni).
- This will eliminate regional or upstream/downstream inequality in water distribution.
- After trying this, this will be reviewed as appropriate using the above process (**Fig. 8.1**).

8.6. The importance of equal water distribution and proposals for the introduction of PIM

Participation in the water management of farmers who are water users is indispensable for efficient water use. Therefore, we propose the introduction of PIM in the future.

(Future goals)

- To distribute water resources fairly and make the irrigation system more productive and sustainable, the introduction of PIM, in which the beneficiary farmers themselves participate in management, is desirable.
- In PIM, the WUA is involved in all aspects such as water distribution planning, facility operation, and maintenance activities.
- In the actual introduction of PIM, the method is to have the farmers in the target area raise problems related to irrigation, check the site with everyone, decide the concrete methods of countermeasures by

consensus, and work on the actual problem solving. We will introduce a case study and use it as an alternative to the demonstration (see the references).

Egyptian case for PIM

Pic. 8.2 Discussion within farmers(at sites)

Pic. 8.3 Site inspection by Water User's Association(WUA)

Pic. 8.4 Farmers' discussion countermeasures

Pic. 8.5 Repaire work by WUA

Pic. 8.6 Before repair work

Pic. 8.7 After repair work

(References) Case Studies of Participatory Irrigation Management

・ Case of Asia (Thailand)

Onimaru, T., Satoh, M., Kawsard, K., Shioda, K. (2003): The Present Situation and Problems of the Establishment of Water Users' Organizations in the Chao Phraya Delta, Trans. of JSIDRE, 225, pp. 119–126

・ Case of Egypt

Shindo, S., Yamamoto, K. (2017): Strengthening Water Users' Organization Targeting for Participatory Irrigation Management in Egypt, Paddy and Water Environment, 15, pp. 773–785.

・ General

Satoh, M. et al. (2007): Principles and Methods for Participatory Irrigation Management and Role Sharing between Government and Farmers, The 4th Asian Regional Conference & 10th International Seminar on Participatory Irrigation Management.