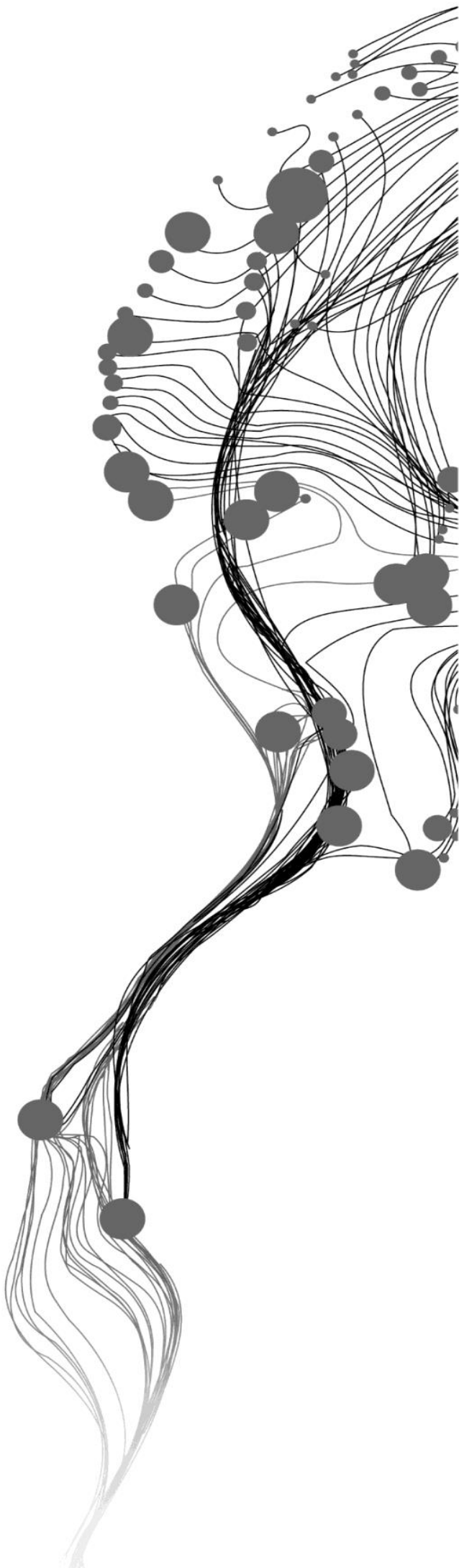


SATELLITE-BASED IRRIGATION PERFORMANCE ASSESSMENT– A CASE STUDY OF THE KPONG IRRIGATION SCHEME (KIS), GHANA

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Abstract

Water, a valuable asset needs to be harnessed and well-managed to ensure it is not depleted for the future generations, especially in this era of climate change. In the area of agriculture, Water Use Efficiency have been regarded as a measure towards agricultural water productivity and savings. This concept is extended into Irrigation Performance Indicators. These indicators are used as benchmarks towards effective and efficient use of water resources. Remote Sensing presents an opportunity with varying spatial and temporal scale for assessing these indicators.

WaPOR, a portal that utilizes remotely sensed data provides relevant information on water and biomass status for solutions towards sustainable agricultural land and water productivity. These datasets are used in the estimation of performance indicators such as uniformity, beneficial fraction, adequacy, and relative water deficit. This research uses WaPOR datasets and methodology to determine the efficiency in the water distribution and the delivery of irrigated water on the KIS scheme at the field level for farmers pre and post rehabilitation.

Aside the WaPOR methodology, stakeholder survey was conducted to establish a link between satellite analysis and ground truth conditions. These were done through survey questionnaires and stakeholder feedback. The CropSAR approach was used to determine the Start of Season (SOS) and End of Season (EOS). A time-series analysis was used to ascertain the precipitation patterns within the study area.

Findings revealed that depending on access to market and the rice seed variety, the SOS and EOS differ from farmer to farmer. However based on satellite interpretation and validation, the SOS and EOS used in this assessment were June to October for the major season and November to March for the minor season. The seasonal distribution of rainfall within the scheme shows varying trends which should be taken into consideration in the scheme's plans for the seasons.

The performance indicators generally show a fairly uniform scheme but with adequate distribution, though some areas had less than 60% in distribution even after the rehabilitation. The beneficial consumption seems good which could be attributed to better management practices. However, there were uncertainties with the outcome of the water productivity. This is largely due to the discrepancies between the WaPOR yield and the yield from the stakeholder survey. In view of this, identifying bright spots and productivity gaps could not be assessed.

This research discusses the limitations associated with the outcomes; and recommended for investments in improving open-access dataset and portals that supports studies in agricultural water productivity. Also, the scheme is recommended to modernize through expanding the lined canals, automation, land development, and adoption of the Alternative Wetting and Drying method.

Keywords: *Water Use Efficiency, Irrigation Performance Assessment, Uniformity, Adequacy, Efficiency, Relative Water Deficit, Land and Water Productivity, Phenology, Stakeholders, Precipitation*

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Abbreviations and Acronyms

AETI/ETc	Actual Evapotranspiration and Interception
AOT	Above Ground Biomass over Total Biomass Production
AWD	Alternate Wetting and Drying
BF	Beneficial Fraction
CMI	Climate Moisture Index
CRIB	Centre of Expertise in Big Geodata Science
CV	Coefficient of Variation
EOS	End of Season
ET	Evapotranspiration
Eto/RET	Reference Evapotranspiration
ETp	Potential Evapotranspiration
FAO	Food and Agriculture Organisation
fAPAR	Fraction of Absorbed Photosynthetically Active Radiation
fCOVER	Fraction of Vegetation Cover
GCM	Global Circulation Models
GEL	Golden Exotic Limited
GIDA	Ghana Irrigation Development Authority
GMET	Ghana Meteorological Agency
HI	Harvest Index
ISC	Irrigation Service Charge
JICA	Japanese International Cooperation Agency
Kc	Crop Coefficient
KIS	Kpong Irrigation Scheme
LOS	Length of Season
LST	Land Surface Temperature
LUE	Light Use Efficiency
MASAPS	Project for Enhancing Market-Based Agriculture through Smallholder farmers and private sector linkages
MODIS	Moderate Resolution Imaging Spectroradiometer
MoFA	Ministry of Food and Agriculture, Ghana
NDVI	Normalized Difference Vegetation Index
NICFI	Norway's International Climate and Forest Initiative
NPP	Net Primary Production
QGIS	Quantum GIS
SAR	Synthetic Aperture Radar
SD	Standard Deviation
SEB	Surface Energy Balance
SEBAL	Surface Energy Balance Algorithm for Land
SOS	Start of Season
SRES	Special Report on Emissions Scenarios
SSEB	Simplified Surface Energy Balance
T	Transpiration
TAHMO	Trans-African Hydro-Meteorological Observatory
VI	Vegetation Index
VRA	Volta River Authority
WaPOR	Water Productivity Open-access Portal
WPb	Biomass Water Productivity

WPy	Yield Water Productivity
WRC	Water Resources Commission
WUA	Water Users' Association
WUE	Water Use Efficiency

1.0. Introduction

1.1. Background

Global food security is a major concern to climate change considering the ever-increasing population with similar threats to available water resources, hydropower and even to human health. Water availability emerges as one of the limiting constraints to crop production and food security amid climate variability exerted as an influential force to year-to-year crop production (Y. Kang et al., 2009; Magadza, 2000).

The future availability of water supplies is largely dependent on climate change, as it the most important physical driver apart from other drivers of change such as demographic and economic drivers (Schnellhuber et al., 2006). This may largely affect changes in the volume and timing of river flow and groundwater recharge (Schnellhuber et al., 2006). This is true for dams and reservoirs as the impacts of climate change leads to uncertainties in their water balance. To prevent water scarcity and promote conditions of abundance or even supply, dams and reservoirs are constructed to store and manage water resources (Bhadoriya et al., 2020) for both upstream (hydropower, utilities, etc) and downstream (irrigation, aquaculture, etc) users. However, under unfavourable conditions such as climate change, the future of these resources may be uncertain as it may be difficult to meet conflicting interests in both demand and supply (Bhadoriya et al., 2020).

The Volta Lake, Ghana, on which the Kpong Multipurpose dam for hydropower and irrigation is built, is considered one of the most important surface waters in West Africa serving as a major socio-economic benefit. However, in 1983, 1998 and 2006, the lake suffered hydrological drought affecting the economic growth of both upstream and downstream users (Bekoe & Logah, 2013; Ndehedehe et al., 2017). The decline in water level resulted from negative trends in rainfall (Ndehedehe et al., 2017; Owusu et al., 2008). Extreme events of climate could have adverse effects on socio-economic growth.

As irrigation competes with another critical use such as hydropower generation, there is difficulty in the trade-offs. An example is told of the Blue Nile Basin, as drier conditions lead to a larger water storage for hydropower while irrigation suffers the most from the disregard to crop water requirement (World Bank Group, 2016). This indeed calls for innovative approaches to address the constraints on water resources to effectively bridge the gap between demand and supply for a sustainable future. This can be done by ensuring that water management actions are taken to ensure sustainable allocation and efficient use of water resources.

Ensuring food security is of paramount importance for a sustainable world, and one crucial aspect that can contribute to safeguarding Ghana's food security is irrigation. However, the existing irrigation infrastructure in Ghana remains underutilized, highlighting the urgent need to harness its full potential. It is imperative to assess the efficiency and effectiveness of these irrigation systems in optimizing the utilization of scarce water resources, particularly in the context of an ever-changing climate regime. Unfortunately, many of the irrigation schemes and projects in Ghana, especially, the Kpong Irrigation Scheme (KIS), lack comprehensive scientific data that could provide insights into their performance. This dearth of scientific data makes it challenging to substantiate critical factors such as crop productivity and appropriate irrigation scheduling with empirical evidence for future reference, informed decisions and policy-making processes.

1.2. Research Problem

There is growing competition as well as a scarcity of land and water resources (Chukalla et al., 2022). To determine how much water resources are available, climatic parameters such as precipitation and air temperature remain critical components of the hydrological cycle. These also are important factors in determining evapotranspiration and irrigation requirements (Ashaley et al., 2020; Kumi M, 2015; Parr et al., 2016).

Based on scenarios, Alcamo et al., (2007) have shown that changes in climatic patterns particularly temperature and precipitation could have an adverse impact on global water availability, therefore leading to water stress due to increased/growing water withdrawals. While precipitation changes could raise or lower the volume of river runoff, as temperature intensifies, evapotranspiration would increase reducing surface runoff. An increase in annual runoff may inadvertently lead to extremely high and damaging runoff events.

This has been evident in the recent Akosombo dam spillage due to excessive runoffs due to above-normal rainfall within the Volta basin displacing lives and destroying properties including farms (Ghana Business News, 2023a, 2023b). Previous investigations into the basin which includes the Kpong dam reservoir for both Irrigation (KIS) and hydropower reveal that there is high variability in the temporal and spatial distribution of rainfall leading to high variability in streamflow (Amisigo et al., 2015).

Agriculture is the leading cause of reduction in water withdrawals (Alcamo et al., 2007). Based on the Ghana Dry modelling scenario, there will be great pressure on crop productivity as water demand will be high in response to climate change which calls for prudent water resources management for increased productivity. The Ghana Dry scenario is a future climate scenario generated with two projections from the Global Circulation Models/Special Report on Emissions Scenarios (GCM/SRES) combining with the lowest and highest climate moisture index (CMI) for Ghana (Amisigo et al., 2015).

Ashaley et al. (2020) in similar research on the Kpong Irrigation Scheme (KIS) referred to similar trends in precipitation and rainfall as alluded by Amisigo et al. (2015) for areas within Accra and Tema. Using Regional Climate Models (RCMs), Ashaley et al. (2020) concluded that the decrease and increase in precipitation and temperature respectively will greatly affect the irrigation scheme likely in the long term.

The Volta River Authority (VRA) is the institution in charge of managing the operational water level of the Kpong dam for hydropower generation and for other end users such as KIS. In reviewing the condition and status of the KIS for rehabilitation, the consultant, BRL Ingenerie had a consultation discourse with VRA on the water balance of the dam. VRA established that the dam has enough storage to satisfy the water balance and crop water requirements of KIS (BRLI, n.d.-b). The section of the consultant's preliminary design report under consideration does not present scientific evidence supporting the claim made by VRA. This presents uncertainties regarding the water balance for both the dam reservoir and scheme and for the near future, particularly in the context of ongoing climate change events (Amisigo et al., 2015; Ashaley et al., 2020; Ndehedehe et al., 2017).

Taking into account the savannah-like characteristics of the KIS and its environs, significant losses in its water resources have been observed. Factors such as seepage, siltation, evaporation, lack of land levelling, among others, have impeded the scheme from operating at its optimum efficiency. The KIS has also faced difficulties of distributing water to the far end of the canal which has affected farming activities for a certain period.

Also, as part of the consultant's review of KIS, survey questionnaires administered to stakeholders especially farmers revealed challenges of the scheme aside from physical evidence of challenges pertaining to infrastructure. With regards to water management, farmers complaint about the inadequate and uneven supply of water, waterlogging on part of the field, undulating or unlevelled farms, the inability of the canal to supply water to certain parts of the field due to siltation, seepage, and poor drainage network etc. Other challenges had to do with the lack of credit facilities, lack of machinery, poor road network and the like (BRLI, n.d.-a).

Due to these challenges, the scheme embarked on a rehabilitation program (Ministry of Food and Agriculture, 2023) by re-designing the canal and drainage systems. The rehabilitation efforts were to ensure the optimal utilization of water to serve as a climate-resilient measure and improvement on the overall performance of the scheme. The project chose to rehabilitate the scheme with minimal maintenance after careful consideration of options pointed out by the consultant after the review of the scheme's status, (Peysson, 2017). The objective was to ensure optimal use of water and improved efficiency.

In order to meet the objectives of the program, it is crucial to conduct a thorough assessment of the scheme's performance subsequent to the implementation of the rehabilitation program. Such an assessment is indispensable for ensuring the long-term sustainability of the irrigation scheme and effectively guiding future strategies and actions. By conducting a comprehensive performance evaluation, it could be possible to address inefficiencies by identifying areas for improvement. This could enhance the scheme's overall productivity, contributing to the broader goal of achieving food security through efficient use of water resources which this study seeks to address.

The capabilities of Remote Sensing technology provide opportunities to monitor key indicators that serve as drivers of change on these schemes which can immensely support farmers, managers, and key stakeholders in their decision-making process. This is to ensure that there is optimal allocation of water that improves irrigation efficiency and enhance overall yield of farmers (Sawadogo et al., 2020). Remote Sensing (RS) data provides assessment options based on production and actual water consumption allowing for water that is abstracted by crops under irrigation with limited field information (Chukalla et al., 2022).

A theory of change as detailed in *figure1* introduces multiple pathways for testing water use efficiency of KIS amidst climate change. Based on the multiple pathways, the study opts for exploring the water productivity and water-use efficiency, yield of the field and their implication at the field level of the scheme. This is for performance assessment on the optimal use of water for decision-making process. This is considered a widely promoted approach towards food and water security (Safi et al., 2022). Assessing irrigation performance downstream is seen as a preferred option as this serves as a check on the general health of the scheme comparing spatial and temporal performances leading to improving productivity (Chukalla et al., 2022). With the number of major stakeholders involved, farmers will be considered with a keen interest in the exploration process as they suffer great losses in terms of yield when water is not well managed.

The research uses remote sensing applications to determine the efficiency in the water distribution and the delivery of irrigated water on the scheme at the field level for farmers pre and post rehabilitation. The WaPOR methodology protocol (IHE Delft, 2020), coupled with field surveys to correlate estimated values to ground conditions at the Kpong Rice Irrigation Scheme, Ghana, was adopted. The data components of WaPOR are derived from available remote sensing satellite and other data sources for assessing the uniformity/equity, adequacy, efficiency, relative water deficit, land and water productivity.

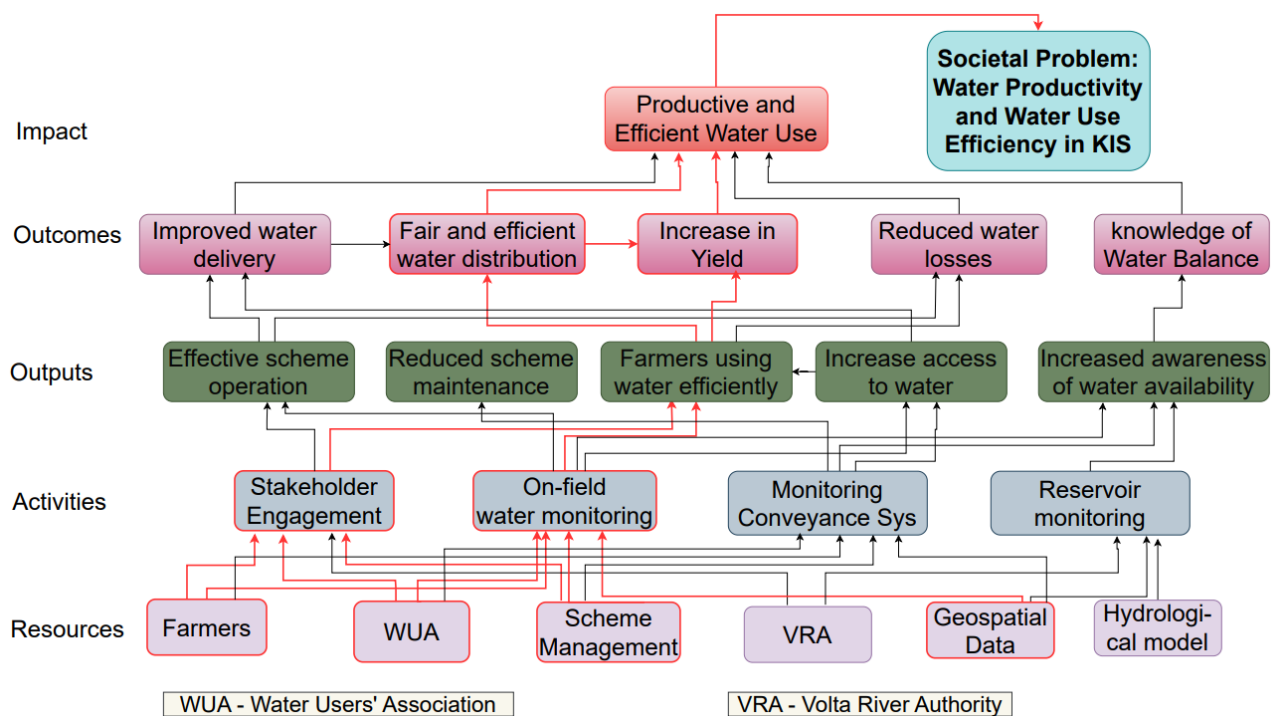


Figure 1: Theory of Change showing multipath ways with selected pathways for study in red

1.3. Research Objectives

The primary aim of this study is to evaluate the land and water productivity in the rehabilitated irrigation scheme and identify areas that require improvement. The study has the following specific objectives with research questions:

1.3.1. Sub-objectives

- To assess stakeholder perceptions of the rehabilitated system's performance in comparison to past performance.
- To evaluate the scheme's capability to efficiently supply crops with the required amount of water employing the use of Irrigation Performance Indicators such as Uniformity, Adequacy, Efficiency, and Relative Water Deficit; and Land/Water Productivity
- To identify and assess productivity gaps and bright spots within the scheme.

1.4. Research Questions

To achieve the research objectives, the following questions are derived.

- How do stakeholders perceive the current infrastructure design on the efficient water supply to the field compared to the past design in terms of uniformity and adequacy of flow?
- How has the rehabilitated scheme impacted the crop yield?
- How can the water productivity and water use efficiency of the scheme be assessed?
- Can productivity gaps be observed after rehabilitation? What are the causes of these gaps?

2.0. Literature Review

2.1. Water Use Efficiency (WUE): Definition and framework

Agricultural water savings have been regarded as an effective measure towards water use efficiency (Deng et al., 2006; Hu et al., 2010; S. Kang et al., 2008; Liu et al., 2020). Within the irrigation sub-sector water use efficiency for on-field application is defined by comparing the water depth beneficially used by crops and the total water depth supplied to the field (Pereira et al., 2012). It is important to note that the evaluation of irrigation water efficiency has undergone significant evolution, progressing from conventional assessments based on irrigation efficiencies to more contemporary approaches centered around performance indicators.

This shift has ultimately led to the adoption of a comprehensive water accounting framework. Farmers' yield, income and farm water management are largely dependent on the quality/quantity of water delivered to the field (Clemmens, 2006; Pereira et al., 2012), and how uniformly they are distributed. It is to be noted that in an application field that is not uniformly distributed, efficiency is highly reduced which affects yields (Pereira et al., 2012).

2.1.2. Inputs for WUE Computations

To accurately calculate these performance indicators, a diverse set of data elements must be considered. These include precise measurements of discharge, the specific water requirements for crop irrigation, effective rainfall data, actual evapotranspiration rates, the extent of the irrigated area, cropping intensity levels, crop yield metrics, and other pertinent factors that bear relevance to the analysis. By incorporating these multifaceted components into the assessment process, a more comprehensive understanding of irrigation water efficiency and its associated dynamics can be achieved (Bort et al., 2005).

2.1.3. Lack of Technical Know-How in WUE Assessment

The availability of irrigation water management information on farmer fields is rarely collected by farm managers or farmers and is mostly unreliable or not easily accessible when collected (Bastiaanssen & Bos, 1999). This could probably be due to their lack of technical know-how or possibly lack of understanding of the kind of indicators to look out for in such an assessment. This is especially attributed to a country like Ghana. Thus, the need to introduce novel approaches to existing practices.

2.2. Remote Sensing (RS) WUE Indicators

Remote sensing presents an opportunity where satellite data can be harnessed for such purpose. Remotely sensed data have been useful in Earth Observation (EO) and monitoring, particularly in areas like agriculture, hydrology, land use land cover, forestry, etc. Their systematic collection and wide system produce some level of objectivity and can be analysed at different scales (Bastiaanssen et al., 2000; Zwart & Leclert, 2010). Land surface information is readily available with varying spatial and temporal scales at varying degrees of accuracy.

In the case of irrigation and water use efficiency, remotely sensed data are used to estimate crop evapotranspiration, crop mapping, biomass, quantification of water storage etc. in combination with other datasets from local or regional offices (Bastiaanssen & Bos, 1999). However, data requirements as inputs for obtaining the aforementioned outputs are high and are not readily accessible (Sawadogo et al., 2020). Without requisite knowledge and expertise, processing such data is quite difficult and time-consuming.

2.2.1. Overview of RS Applications

In this section, we will therefore analyse different approaches researchers have adopted using satellite remote sensing in accessing water use efficiency and discuss their limitations. There are several approaches that have been adopted by scientists for the estimation of actual evapotranspiration (ET) and water productivity. These include the Vegetation Index (VI)-based method, the Surface Energy Balance (SEB) method, etc. These are discussed further in the subsequent paragraphs.

In the VI-based method, a relationship between the crop coefficient (K_c) and VI is developed. The ET is calculated based on the Food and Agriculture Organization (FAO) approach by Reyes-González et al. (2018). It utilized the Normalized Difference Vegetation Index (NDVI) to determine the K_c and crop ET, which makes it largely dependent on crop maps for estimation. With a slightly different approach, Er-Raki et al. (2010) employed additional parameters, including the crop cover fraction and the soil evaporation, to establish a relationship with the K_c of a wheat crop. These methods avoid complex processes of parameter estimation. The derived ET maps are, however, derived on a regional scale hence, it may require modification and validation of the relationship in different settings (Cai & Sharma, 2010).

The Surface Energy Balance (SEB) method also presents a different framework in ET estimations. Unlike the VI-based method, the SEB methods are not dependent on land use in ET estimates but rather combines physical and empirical modules for parameterization on a large scale. This is useful in areas where there are constraints in getting ground-based information, (Cai & Sharma, 2010). The outputs from these models require field or in-situ data for validation else their interpretation becomes complex.

Bandara (2006), for instance, leveraged the Surface Energy Balance Algorithm for Land (SEBAL) model to determine the evaporative depletion of water at different stages of crop growth in Sri Lanka. Results from the wet season indicated poor performance in depleted fraction, very high drainage ratio, excess water in terms of delivery performance and adequacy. These were devoid of field validation and the uncertainty of results to conditions on the ground.

In Cai & Sharma, (2010) research, the Simplified Surface Energy Balance (SSEB) was used for crop water consumption estimates. The model used was devoid of the complex land surface processes and biophysical parameters. The advantage is that it can be used everywhere. It does not need field calibration for new applications. The model thus takes calculated ETo from conventional approaches such as Hargreaves' equation and easily accessible data for its calculations. This approach is usually applicable to large-scale areas.

In another research, Sawadogo et al. (2020) in Burkina Faso provided insights into the spatio-temporal patterns of the irrigation performance of the Kou Valley irrigation scheme (KVIS) utilising the pySEBAL (python version of SEBAL) model for the performance assessment. Indicators focussed on included relative evapotranspiration, depleted fraction, uniformity, and crop water productivity. The research outcome indicated spatially different crop areas on their level of water stress. However, these analyses were based on the dry season without their complementing wet season. Satellite imageries from the tropics, for example Ghana, Burkina Faso, Togo, Benin, etc., are usually cloud-covered and therefore using this model in accessing such areas especially the wet season might be challenging hence Sawadogo et al. (2020) probable resolve to analysing the dry seasons.

Water Productivity through Open access of Remotely sensed derived data (WaPOR) portal created by FAO provides relevant information on water and biomass status for solutions towards sustainable agricultural land and water productivity. These are continuous near-real time data of different levels per location. The portal combines datasets of actual evaporation, transpiration, and interception (AETI), net primary production, land use (land cover classification), phenology, climate (precipitation and reference evapotranspiration (RET)) and water productivity layers, etc for land and water productivity assessment. 21 countries including Ghana make up the level 2 database of WaPOR with a 100m spatial resolution (FAO, 2020a). These datasets are used in the estimation of performance indicators such as uniformity, beneficial fraction, adequacy, and relative water deficit (IHE Delft, 2020).

With areas such as Africa, the Near East and surrounding regions, in-situ observation infrastructure are very limited making it difficult to independently ensure validation and quality-control. Hence, cross validation to other available reference datasets are used. They are also compared to simulated models (FAO, 2020b). Though with this setback, Weerasinghe et al. (2020) conclude in their research that WaPOR products produce low bias in ET estimations and a good spatial distribution of ET patterns for Africa. The estimates produced, however, should be linked to a good number of observations in specific locations for accuracy assessment.

CROPWAT is a decision support tool developed by FAO for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. All calculations are based on FAO 33 and 56. The simple computer-based program is used when local data are not available. Without complex parameterisation, the programme utilises standard FAO crop and soil data. The climatic parameters could be selected from over 5,000 stations worldwide from CLIMWAT (CROPWAT climate database platform) ranging from 1971 – 2000 (FAO, 2024a, 2024b).

Although not a remote sensing platform, CROPWAT could be used as a check on ET estimates based on satellite data. However, for a more accurate prediction pertaining to ground conditions the crop coefficients (Kc) would require calibration or adjustment to guarantee efficient agricultural water management (Vozhehova et al., 2018). Again, with the era of climate change, it should be plausible to adjust the climatic parameters to reflect current trends for better and accurate estimations.

From the models discussed in this section, the SEB approach is usually for assessing large-scale areas and utilises complex parameters unlike the VI-based method that avoids the parameterisation complexities in producing ET estimates. They are not mostly calibrated with ground information; the focus is usually on utilising remotely sensed data (Van Der Tol & Parodi, 2012). The pySEBAL model for example makes use of Landsat imagery, varying weather datasets, soil datasets for its analysis. Whiles access to data is a challenge, there are also difficulty to achieve good results especially for areas in the tropics where heavy cloud-cover seems to be a problem in most optical satellite imageries.

The WaPOR platform deals with the complexities that comes with parameterisation and produces already processed outputs that are readily usable for analysis. These outputs are mostly cross validated and seem to produce less bias in ET estimates as reviewed by Weerasinghe et al., (2020). However, it is advisable to validate for local areas. CROPWAT, not a remote sensing programme, could be used as a validation tool for satellite-based ET estimates. However, calibration of Kc and climate parameters could fine-tune estimates for better interpretation.

3.0. Methodology

3.1. Study Area

The size of Kpong Irrigation Scheme (KIS), constructed in 1965, is 4081 hectares. Over 2000 hectares is dedicated to rice irrigation for smallholder farmers while 2000 hectares is developed for commercial agriculture for banana production managed by Golden Exotic Limited (GEL). The focus of this research will be based on rice production.

The scheme is located along the right bank of the Volta River as shown in *figure 2*. Its primary beneficiary towns are Akuse and Asutsuare in the Shai Osudoku District of the Greater-Accra Region, Ghana. The KIS obtains its water supply from the Volta River through the Kpong Hydro-Electric Power Dam at Akuse. Priority is given to power generation. The canal take-off is below the powerhouse with a total discharge of 7.2m³/s allocated to the scheme. This is distributed amongst the rice part of the scheme, GEL and other areas such as fish farms, factories, cattles, etc (BRLI, n.d.-b; Tinsley, 2009).

The climate in KIS is the savannah type. The cropping calendar ranges from February/March to August/September for the major season (supplementary irrigation) and September to February/March as the minor season (mainly irrigation). The scheme has a bimodal pattern of rainfall. According to Peysson (2017), the mean average of rainfall ranges from 762.5mm to 1,220mm. The temperature ranges from 30° to 37°. KIS has a relatively flat topography with altitudes ranging between 5m and 14m

The key infrastructure of the scheme includes a main canal, branch/supply canals, distributary canals, drainages, night storage reservoirs, weirs, siphons and road networks. Within the rice scheme are fish farms. The rice scheme is mainly under gravity for water distribution. The conveyance system is faced with challenges of overgrowth of aquatic weeds, cattle, crocodile, and rodent invasion leading to seepage preventing water from reaching the scheme's tail end. Other challenges of the conveyance system include siltation and evaporation. On the irrigable areas, farmers complaints of uneven land levels, inadequate water supply, waterlogging, amongst others (Peysson, 2017). Previous studies suggest that the average yield was between 6 and 7 tonnes/ha/season (Tinsley, 2009). The yields are not the same currently. From *table 1*, provides a breakdown of the yield from 2019 to 2023.

Table 1: Yield data from 2019 - 2023, source: Kpong Irrigation Scheme

YEAR	TOTAL AREA	TOTAL AREA	AV. PADDY YIELD
	AVAILABLE(HA)	CROPPED (HA)	(T/HA)
2019-MAJOR	1,988	1,840	5
2019-MINOR	1,950	1,599	4.5
2020-MAJOR	1043	962	5.5
2020MINOR	1,043	955	5.5
2021-MAJOR	1,056	1,042	6
2021-MINOR	2,190	1,904	4.8
2022-MAJOR	2140	2000	6
2022-MINOR	2047	1,901	5.2
2023-MAJOR	2,160	2,050	6

Rehabilitation works were carried out between the period of 2019-2021 to modernize the conveyance system to ensure optimal water use. This has been classified as phase I of the project. The scope of phase I for rehabilitation work included desilting, reshaping, and sectional lining of the main and secondary canals,

converting the lateral system from an open channel to closed conduit pipes, reshaping the night storage reservoirs, desilting, and reshaping drainage networks. Phase II is yet to commence. This would include automation at major head works of canals and complete lining of the main canal.

Reiterating the focus of this study, the rehabilitated scheme needs to be tested for optimal water use of water on farmer fields to ascertain fair and adequate distribution.

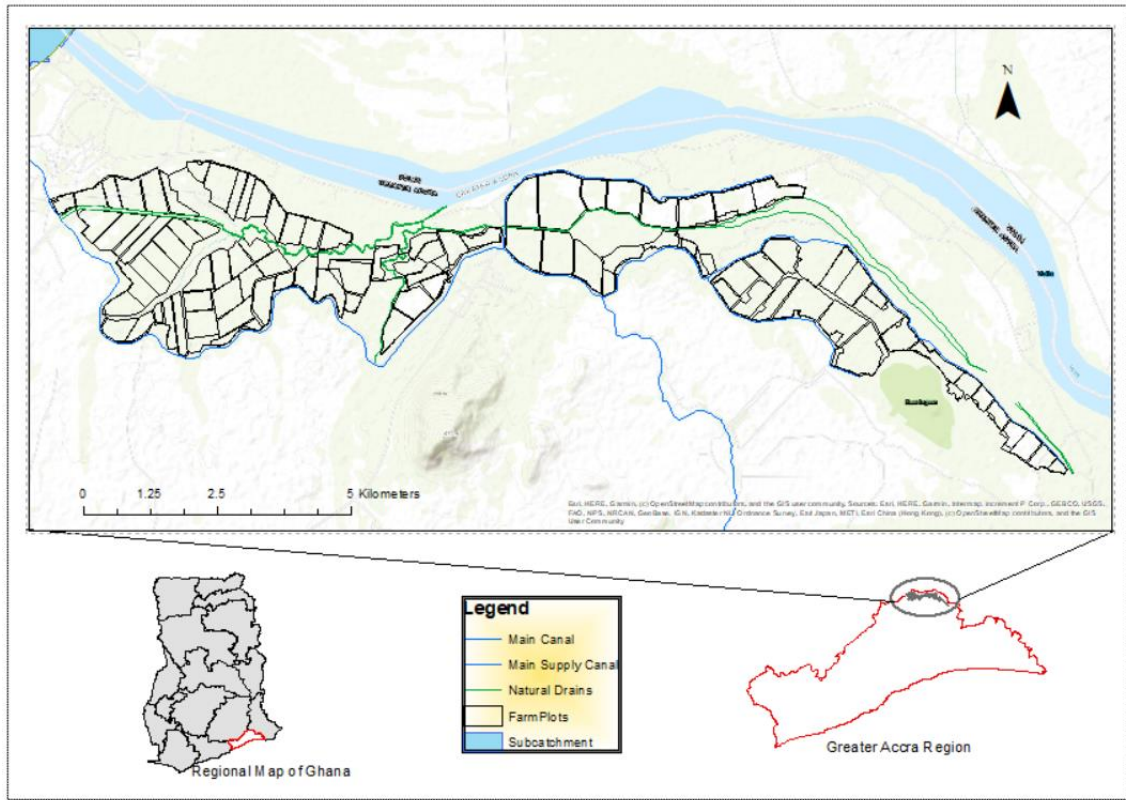


Figure 2: Schematic boundary of the Kpong Irrigation Scheme

3.2. Method

The flowchart in *figure 3* below represents the methods or approaches used for the analysis of the water productivity and water use efficiency at the KIS. The components presented in this flowchart form an interconnected link that contribute to the overall objectives of this study. They consist of input datasets gathered from stakeholder surveys including Start of Season and End of Season (SOS/EOS) and yield information, WaPOR datasets including default parameters from FAO and Precipitation data for analysis. Satellite-based SOS/EOS are also factored as inputs for the analysis of the WaPOR data.

The stakeholder surveys are important components to establish ground-truth conditions. They were used as validation for the outputs from the WaPOR analysis. These were done applying ethical principles to ensure that stakeholder participation was anonymous and confidential. Refer to *Appendix 8.3.3* on the ethical considerations applied in the research. The WaPOR analysis provides insights into optimal water distribution and water-use efficiency. Aside being validated with stakeholder survey, they are compared to the rainfall patterns within the area and literatures to ensure coherence and identify gaps where necessary for possible recommendations.

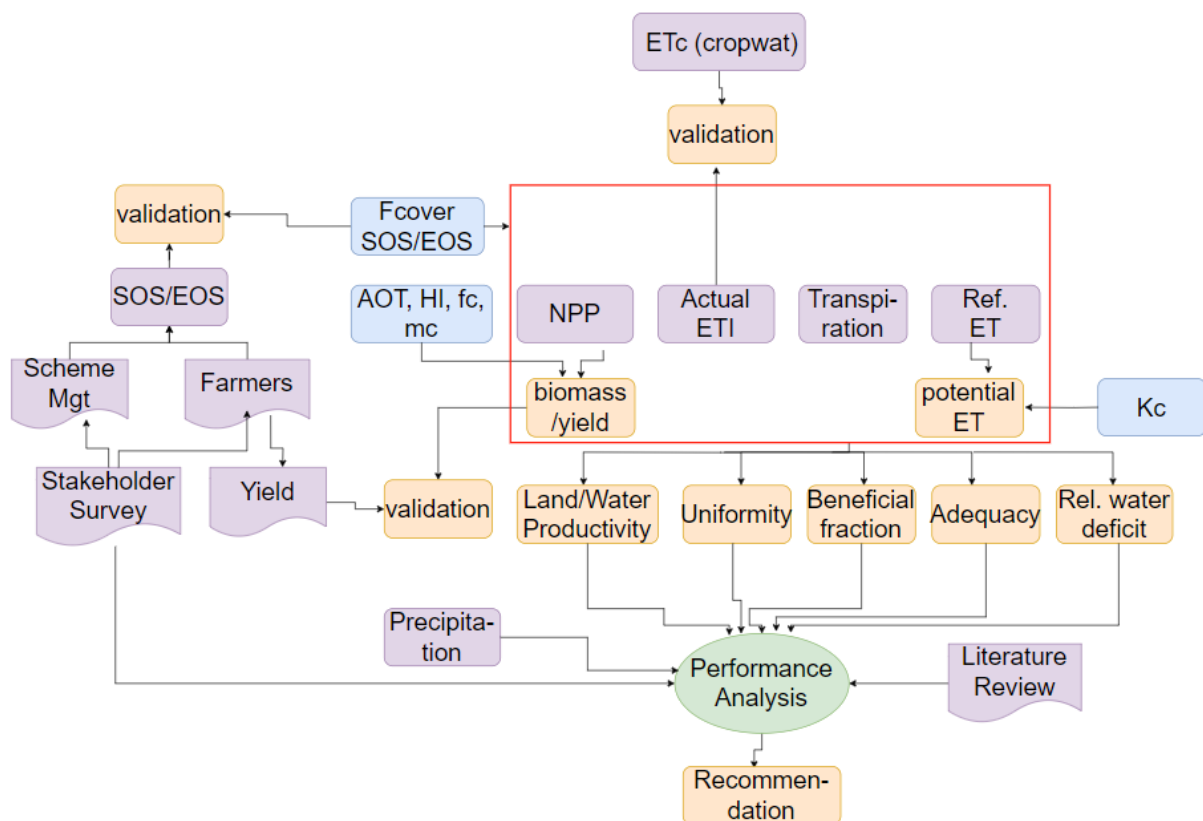


Figure 3: Flowchart of Methodology

3.2.1. Field Survey

For this study, stakeholders are key to unraveling the situation at KIS to gain firsthand information of what has been done and the impact this has had on the scheme especially with the rehabilitation works. The stakeholders of KIS includes the smallholder farmers, GEL, fish farmers, cattle ranchers, the Scheme Management operating under the Ghana Irrigation Development Authority (GIDA), GIDA itself, Water Users' Association (WUA), Volta River Authority (VRA), Ministry of Food and Agriculture (MoFA), Water Resources Commission (WRC), the community. The stakeholders that directly contribute to the rice scheme were interviewed. They included the smallholder farmers, the WUA, and the Scheme Management. These are based on their importance, that is, how they are affected by the scheme, and their level of influence. The following approaches were adopted for data collection.

- i. Designed Questionnaire and stakeholders' feedback: Based on major stakeholder influence and importance, survey questionnaires were designed to obtain relevant information on the scheme's performance amidst before and after rehabilitation. Key irrigation on-field performance indicators including adequacy and uniformity of water, yield performance, land and water productivity were baseline survey questions for stakeholders. *Appendices 8.1 and 8.2* provide information on stakeholder's importance and influence, and design questionnaires respectively. Information collected were used for both qualitative and quantitative analysis.
- ii. Participation of this survey was voluntary, and stakeholders were made aware of that. Methods used to obtain information included online video interviews, WhatsApp calls and field visits/interviews particularly with the farmers.

- iii. GPS location: Some fields were identified to be having problems before the rehabilitation. These boundaries were delineated serving as a guide to conducting the survey. A single point coordinate of these delineated fields was taken. These were considered in the analyses of the phenology (SOS/EOS) and irrigation performance before and after the rehabilitation.

3.2.2. Precipitation

According to Peysson (2017), the KIS has a bimodal rainfall pattern with the major raining season starting from April to July and the minor from September to November. This has had influence on the major cropping calendar of KIS. A time-series analysis was done to ascertain the precipitation patterns within the study area.

3.2.3. Phenology (SOS and EOS)

The different stages of crop growth and development is known as Crop phenology. In improving agricultural productivity, the phenology becomes crucial in the production and estimation of crop yield (Gobin et al., 2023). It also gives better understanding of phenological variations by analysing the timing and duration of the growing season (Ganeva et al., 2023).

To better model phenology there are methods that could be adopted. NDVI from optical satellite images could determine the phenology of KIS. The NICFI PlanetScope has the capability of providing NDVI values in determining the SOS and EOS with minimal interference of cloud. These imageries are monthly produced since September 2020 and provide sharp and less detailed analysis of the SOS and EOS of the scheme. The information before September 2020, the period preceding rehabilitation, is limited. Before 2020, the data was produced at 6-month time-step. Based on these limitations, the CropSAR model is adopted for the SOS and EOS.

The model uses Sentinel-1 radar data to enhance Sentinel-2 using a deep learning model that combines per image spatial encoding/decoding. These temporal blocks are then gap-filled to generate spatial/temporal time-series. The FCOVER, an output of the CropSAR 2D, is used as a proxy in determining the SOS and EOS of KIS (TERRASCOPE EOPLAZA, 2024). The FCOVER is an indicator of the surface phenology which represents the fraction of ground covered by green vegetation. It is also used to quantify the spatial extent of photosynthetically active vegetation (Diack et al., 2024). The CropSAR model generates time-series data starting from 2019 (VITO, 2021). The period used for this analysis was from 1st January 2019 to 21st March 2023.

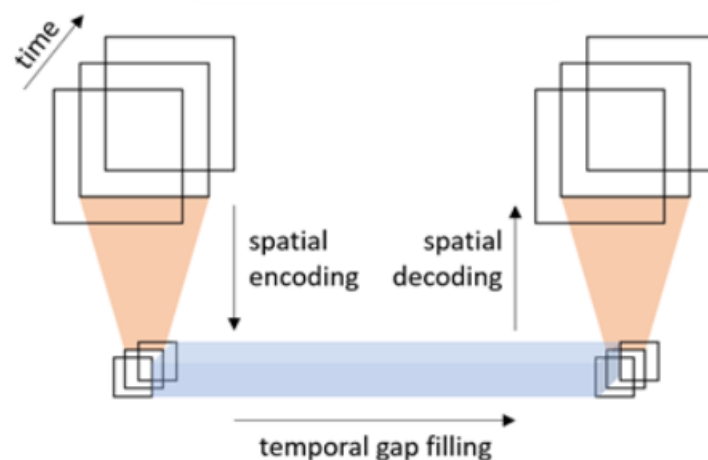


Figure 4: CropSAR spatial encoding and decoding

According to KIS, the rice scheme is made of 2 sections, Section A and Section B. For this FCOVER methodology, Section B is sub-divided into B1 and B2, refer to *figure 5*. In all, 3 Section will be used to generate the time series phenological data. In each section, 3 field boundaries are used for the analysis. These boundaries correspond to areas where the field survey was conducted.

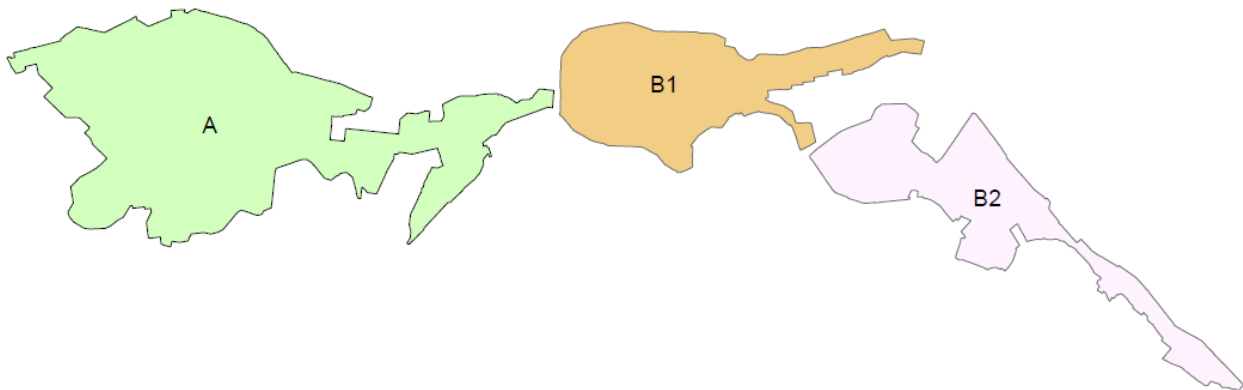


Figure 5: KIS scheme sub-divided into 3 sections for SOS and EOS analysis.

3.2.4. Irrigation Performance Assessment (IPA)

Water Productivity through Open access Remotely sensed data (WaPOR) provides cost-effective support to irrigation performance assessment to identify possible pathways to improve performance. Data components used for this assessment was based on the FAO WaPOR v.2.1 platform and v.3 for the 2023 minor season (FAO, 2020).

Periods considered for this assessment were from 2017 – 2019 before rehabilitation and 2021 – 2023 after rehabilitation respectively. These periods were of keen interest as farming within the scheme were active before farming ceased in late 2019 and 2020 respectively for civil works on the scheme. The relevance of these periods was to help with the comparative analyses of water use on-field and yield performance.

Based on the WaPOR methodology, input datasets such as reference evapotranspiration (RET), transpiration (T), actual evapotranspiration (AETI), and net primary production (NPP) served as major inputs. These are already derived dekadal datasets from WaPOR and are readily available for Ghana at level 2 at 100m resolution. The dekadal datasets were aggregated over the entire cropping season considering the Start and End of Season (SOS and EOS) (IHE Delft, 2020).

The reference evapotranspiration (RET) is a hypothetical reference crop with an assumed height of 0.12m, a fixed surface resistance of $70sm^{-1}$, and an albedo of 0.23. This simulates the behaviour of a well-watered grass surface (FAO, n.d.-b). The estimation of RET is based on solar radiation and climatic data. By applying the crop coefficient (K_c), RET can be used to estimate potential ET. The actual evapotranspiration is the sum of evaporation from the soil, transpiration, and interception on the plant. The sum of these three parameters is used to quantify water consumption and in combination with biomass or yield, the water productivity can be derived. The NPP indicates the conversion of carbon dioxide into biomass driven by photosynthesis (FAO, 2020a).

As this project delved into farmers' interests as major stakeholders, on-field performance indicators were analysed as outcomes of the spatio-temporal analysis. Key performance indicators such as Uniformity and Adequacy were looked at with keen interest. As well, the efficiency and relative water deficits based on the aforementioned input parameters were measured. The outcome for every cropping season for the farmer's

interest is yield. A comparative analysis over the stipulated years of the land and water productivity were checked.

The assessment of the Irrigation Performance of KIS were based on the methodology of IHE Delft (2020), however, the processing of datasets was done on the CRIB (<https://www.itc.nl/about-itc/centres-of-expertise/big-geodata/>) with QGIS. The model builder in QGIS was used to optimize the processing of data for the outcomes of the indicators. *Figure 6* illustrates the workflow. ETp was precalculated with RET before serving as an input algorithm for the data processing. The Coefficient of Variation were derived afterwards using AETI statistics from the model builder.

Presentation of the maps were done with ArcGIS. For our key stakeholders, the farmer and scheme management, this assessment would be of value to them. The farmer’s interest is to maximise their fields for increased yield while the scheme management looks out for productivity in water use and sustainability.

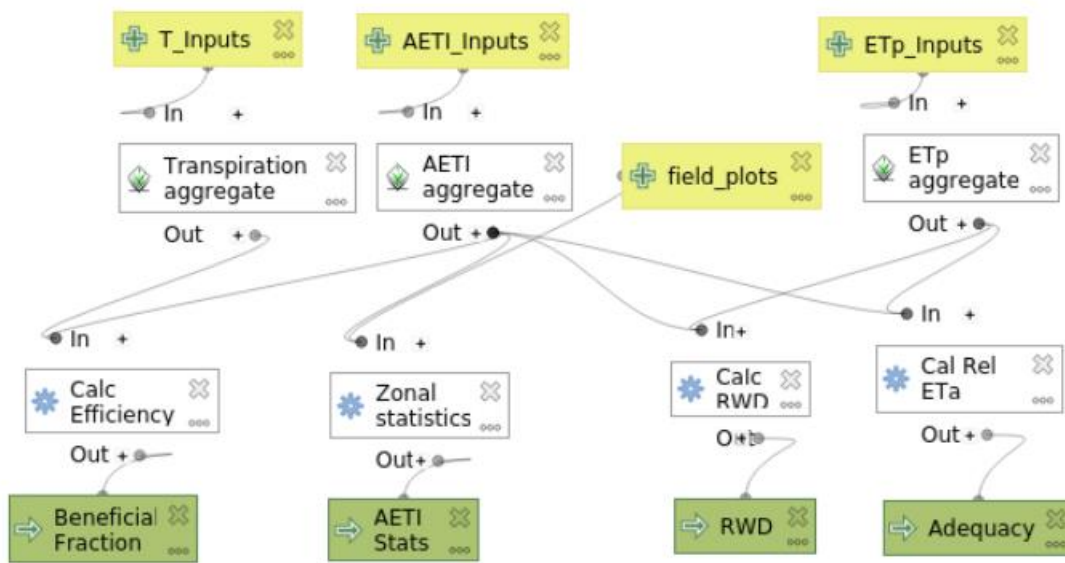


Figure 6: Workflow for Irrigation Performance Analysis

3.2.4.1. Uniformity/Equity

One of the key determinants of the quality and success of irrigation is Uniformity. Irrigable areas need high humidity conditions. This can be achieved when uniformity is high (Jobbágy et al., 2021). When the irrigated water is even or spatially homogeneous on the field of application it is said to be uniform. Equity measures the water evenly to different users, for example farmers, in the tertiary unit (IHE Delft, 2020).

There are methods to evaluate the quality of irrigation. This includes coefficient of uniformity, coefficient of non-uniformity, degree of uniformity and coefficient of variation (Jobbágy et al., 2021). For satellite remote sensing, a key indicator of uniformity/equity is the actual evapotranspiration (ET) of pixel values of the field. The coefficient of variation (CV) was taken from the seasonal actual ET. The CV was measured by the quotient of the standard deviation of the depth of the irrigation water applied to the average depth infiltrated (López-Mata et al., 2010).

A CV between 0 – 10% reflects a uniformly distributed water, CV between 10% - 25% represents fair distribution while CV greater than 25% is poor uniformity (IHE Delft, 2020)

$$CV_{(ET)} = \frac{\text{Standard Deviation (SD)}}{\text{mean } (\sigma)} * 100\% \quad \text{eqn 1}$$

The field sizes of the KIS are between 0.5 – 1 hectare (ha). The resolution of the AETI datasets from WaPOR L2 is 100m. This was resampled with a PlanetScope image at 4.77m (PlanetScope, n.d.) with the nearest neighbour resampling technique. A zonal statistics of the AETI was calculated by super-imposing the rice field boundaries on the aggregated AETI raster datasets to estimate the mean and standard deviation. These are then used to calculate the CV per field.

3.2.4.2. Adequacy

Also referred to as Relative ET, it measures the quantity of water and how much it satisfies the water requirements of the crops on the field (IHE Delft, 2020) This reflects how adequate soil moisture is at the root zone for crop growth and improved yield (Karimi et al., 2019).

$$\text{Relative ET} = \frac{\text{seasonal actual ET}}{\text{seasonal potential ET}} \quad \text{eqn 2}$$

The potential ET is estimated as the product of average crop coefficient (K_c) and RET .

$$\text{potential ET} = \sum Kc * RET \quad \text{eqn 3}$$

The Kc values for KIS are derived from CropWAT and interpolated for individual months. *Appendix 8.5* shows the CropWAT values for both wet and dry season, however, *table 2* displays the author's interpolation for individual months.

Table 2: Interpolated Kc from CROPWAT

Wet Season (Major)		Dry Season (Minor)	
Month	Kc	Month	Kc
June	1.1	November	0.5
July	1.14	December	0.9
August	1.2	January	1.05
September	1.11	February	0.84
October	1.05	March	0.7

3.2.4.3. Efficiency

Beneficial consumption is the evaporated or transpired water for intended use. In order to optimize irrigation water supply, this needs to be maximised (Reinders, 2022). Therefore, Beneficial Fraction (BF) or Efficiency can be defined as the percentage of water consumed (transpired) by the crops compared to overall field water application or consumption (IHE Delft, 2020). This can be used to assess losses in the irrigation system. The degree of efficiency is influenced by climatic conditions, soil properties, etc.

$$BF = \frac{\text{seasonal Transpiration}}{\text{seasonal actual ET}} \quad \text{eqn 4}$$

3.2.4.4. Relative Water Deficit

This indicates the level of water shortage on the field. The actual ET is divided by the maximum ET which is the 99th percentile of the actual (IHE Delft, 2020).

$$RWD = 1 - \frac{\text{actual ET}}{ET_{max}} \quad \text{eqn 5}$$

For the purposes of this study the potential ET is considered as the ET_{max} .

3.2.5. Land and Water Productivity

This is to calculate the seasonal land and water productivity of the study area. It is expressed as kg/m³ or tonne/ha (IHE Delft, 2020).

$$Biomass (B) = AOT * f_c * \frac{NPP * 22.222}{1 - \theta} \quad \text{eqn 6}$$

$$Yield (Y) = HI * B \quad \text{eqn 7}$$

$$WP_y = \frac{Y}{actual ET} \quad \text{eqn 8}$$

$$WP_b = \frac{B}{actual ET} \quad \text{eqn 9}$$

AOT denotes the above-ground biomass over the total, f_c the correction factor for light use efficiency which is calculated by dividing the LUE of the crop by the LUE of a generic crop, θ as the moisture content, HI as the harvest index and WP as the land/water productivity. AOT, θ and HI for rice will be based on literature (IHE Delft, 2020). The *figure 7* shows the standardized input parameters recommended by FAO and used by WaPOR in the biomass estimation.

The screenshot shows a web interface for selecting input parameters. At the top, there are tabs for 'NATIONAL' and 'SUB-NATIONAL'. Below this, there are three main sections: 'PLACE', 'TIME PERIOD', and 'ADVANCED OPTIONS'. Under 'ADVANCED OPTIONS', there is a 'SELECT CROPS' dropdown menu with 'Rice' selected. Below this, there are four input fields: 'LUE (1 FOR C3, 1.8 FOR C4)' with a value of 1, 'HARVEST INDEX' with a value of 0.43 and a note 'Suggested range from 0.35 to 0.5', 'ABOVE GROUND OVER TOTAL BIOMASS' with a value of 0.75, and 'MOISTURE CONTENT RATIO' with a value of 0.15. There is also a link for 'Explanatory Notes'.

Figure 7: Standard input parameters by FAO

3.2.6. Validation

3.2.6.1. Phenology (SOS and EOS)

The time-series SOS and EOS analysis based on the FCOVER by CropSAR were compared with the time-series of NPP by WaPOR to establish a relationship. This was to establish the validity of the SOS and EOS results by CropSAR.

3.2.6.2. Yield

Yield data from the KIS scheme from the stipulated period were collected and used to validate the spatio-temporal yield assessment made from the WaPOR database.

3.2.6.3. Actual Evapotranspiration

The AETI of WaPOR was validated with the crop water requirements computed using RET and Kc values from the CROPWAT programme by FAO. This was to establish correlation between these outputs.

4.0. RESULTS

4.1. Field Survey Outcome

Field surveys are of importance in research to provide ground-level insights that enhances understanding and validation of other datasets. Field surveys cannot be done without stakeholders. They ascribe influence and importance to the subject matter. In the context of KIS, the scheme management and farmers were considered key for understanding the performance of the scheme. Respondents to the survey consisted of 14 scheme managers and 44 farmers, making a total of 58 voluntary contributors. The scheme managers comprise of Water/Agric Engineers, Agronomist and WUA Executives. The scheme boasts of having 3000 farmers.

The KIS rice scheme has been identified to be of 2 sections, that is, Section A and B. The rehabilitation that took place was a partial one which started in 2019 and ended in 2021, however, civil works started in the 1st quarter of 2020. Stakeholders classify the rehabilitation period as phase I of the project. Section B was mainly affected by the partial rehabilitation. Farmers left their farm fallow within this period. In addition, about 30% of section A was rehabilitated. They are, however, waiting for the commencement of the phase II of the rehabilitation which is likely to commence in the latter part of 2024. The outcome of the field survey are discussed based on the climate variability, SOS and EOS, water supply distribution, monitoring, and yield.

4.1.1. Climate Variability

Though KIS is an irrigation scheme, rainfall contributes to improving the yield of farmers in the major season. Most farmers wait on the rain during this period before they start to crop. However, there has been quiet a shift in climatic patterns in recent times. The rain shows up unexpectedly, sometimes before SOS, at other times at EOS. It has been reported that there are rain episodes during the maintenance period as well.

Farmers hesitate to start the major season with the hope of the rains coming on time only for them to realise that the cropping calendar is ending before they start to plant. Other instances are made about the rains not showing up during the panicle initiation stage where enough water is needed but rather came at the time of harvesting.

This challenge has been more eminent between the 2022 and 2023 cropping year even though this has been there for some time. Extreme rain events were experienced in 2023 which flooded some few fields (Ghana Business News, 2023b). This really had a toe on the quality of yield, decreasing their market value. There are claims that June, a major raining season is becoming drier in the area. More rains are rather experienced from July. Farmers explained that the scheme used to have a chart that indicates when rains are to be expected but due to changes in climatic patterns lately that provision is no more. Based on change in weather patterns, JICA in their Project for Enhancing Market-Based Agriculture through Smallholder farmers and private sector linkages (MASAPS) - Ghana, introduced the scheme to Alternate Wetting and Drying technology with field trials. According to the scheme management, the technology is such that there is no need for much water on the field. Water is only introduced when the field is getting dry. This could be a good way of water savings. However, farmers are yet to come to terms with this nouvelle approach. To them rice is a water loving plant, therefore more water is required on the field. More education and sensitization on the part of the scheme management is required to change the narrative.

There are two communities in which the scheme is located. These have different rainfall patterns. Akuse, the northern part of the scheme receives more rainfall than Asutsuare, the southern part. The scheme utilizes

climate information by the Ghana Meteorological Agency (GMET), Akuse, for their operations. Another station, the Trans-African Hydro-Meteorological Observatory (TAHMO) located at the Osudoku Senior High School, Asutsuare also provides climatic datasets, (TAHMO, n.d.), but this is likely unknown to the scheme management.

4.1.2. Start Of Season and End of Season (SOS and EOS)

From the survey, the scheme officially operates a double cropping from 2 seasons, namely the major and minor seasons for both before and after the rehabilitation. Information from some scheme managers revealed that due to water challenges before rehabilitation, some farmers only planted in the major season, abandoning their fields in the minor. But after the rehabilitation farmers are now doing both seasons. Other managers also confirmed that the scheme is trying to cultivate 5 seasons in 2 years but established that the success rate has been minimal since most of the variety of seeds used for planting are usually 4 months. This was not confirmed by the farmers during the survey. All the farmers responded to have 2 seasons, that is, major and minor. None confirmed to have planted 5 seasons in 2 years.

Though established as major and minor seasons, the key stakeholders had different perspectives of when these seasons start and end. Both stakeholders gave different dates for the major and minor seasons. Their cropping season is dependent on factors such as land preparation, the type of rice seed planted and access to market, etc. For the major season some reported March/April to August/September, April to September, April/May to August/September, May to September, etc., and the minor from October/November to February, November to March, to mention but a few. In correlating their views, it has been established that the major season is April – August/September and the minor, October – January/February with maintenance work in March. From the report, land preparation is factored into the seasonality dates. *Figures 8 and 9* shows a pie chart of the stakeholders’ response to SOS and EOS. *Appendix 8.4* shows the table with details of SOS and EOS together with yield data.

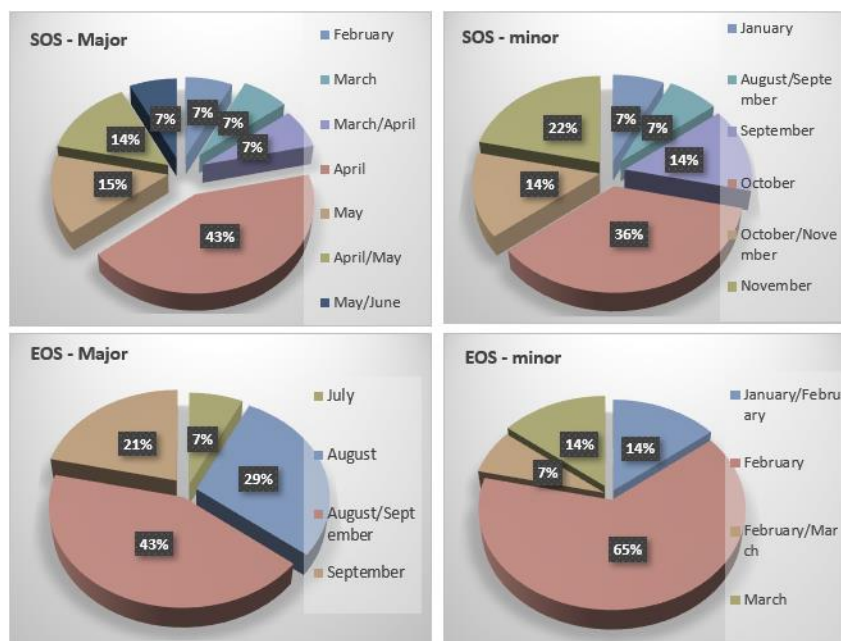


Figure 8: Scheme management; major: April – August/September, minor: October – February

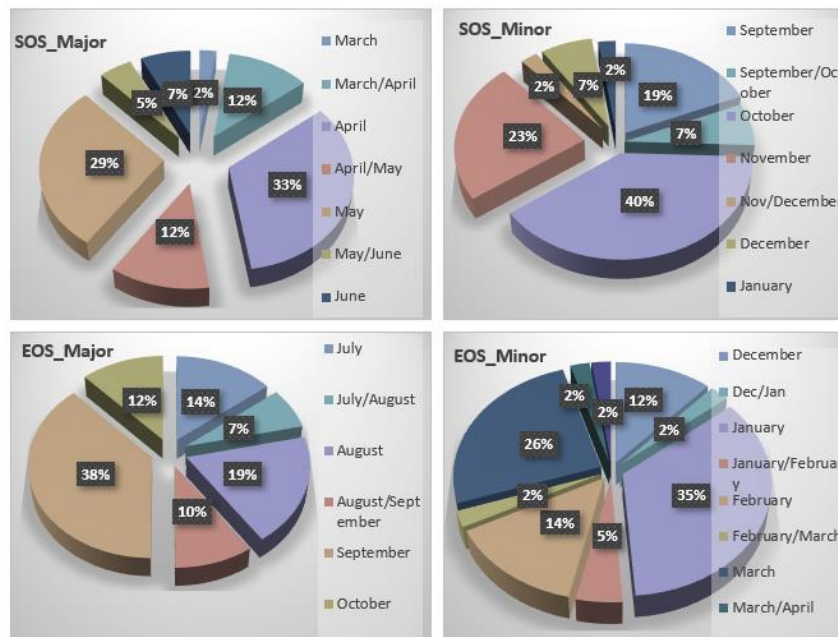


Figure 9: Farmers; major: April – August, minor: October – January/February

4.1.3. Water Supply and Distribution

4.1.3.1. Dilapidated Canal

Water has always been a challenge for farmers before rehabilitation. Both stakeholders attribute this to the canal not efficiently delivering water. The canal is unlined and out of shape. This is characterized by aquatic weeds growing within the channel, impeding flow in distribution and the tail-end of canal. Another challenge is siltation and cattle invasion distorting the shape of the canal. While velocity is expected to increase with the large volume of water from upstream, these challenges limit the flow and prevent the right amount of water to downstream users.

As the rehabilitation is expected to improve delivery, the canal continues to experience this challenge of impeded flow as it is yet to be lined. The presence of aquatic weeds continues to be a challenge even though the canal has been desilted during the phase I of rehabilitation. According to sources from the scheme, the scope of phase II includes fully lining both main and partially lined supply canals and the introduction of automated metering devices to control flow to check the efficiency of the system.

4.1.3.2. Lateral Leakages

Distribution channels like the laterals also faced huge challenges like leakages and seepage. Water that makes it through to the laterals are not sufficiently and efficiently distributed due to this challenge. As this was caused by rodents and crocodiles boring holes within the chamber, farmers' attitude also contributed to the cause. Some respondents claim about 40% of water go to waste.

The share in water rights usually lead frustrated farmers to block or shut other farmers' lateral to get access to water. This brings about water conflict on most field blocks and slows accessibility. Farmers complaints it takes 2-3 days and sometimes a week to have access to water. Some farmers would have to be on the field as early as 2am to have a share of water for their crops. Before rehabilitation, there was no proper

scheduling, and this exacerbated the conflict amongst farmers especially in the minor season. Based on these frustrations, some farmers choose to crop only in the major season and abandon farm in the minor. Others also illegally connect pipes to the main or supply canal or rely on other sources like the drain water from other field blocks upstream to receive a fair share of water.

The situation has been better after phase I of the rehabilitation. The laterals which are mainly open channels are converted to a closed conduit pipe. Hydrants are connected to these pipes to supply water to the field making it easier for irrigation to happen in a few hours. While some farmers seem to enjoy this new arrangement, especially those at the tail-end, other farmers seem to have a few concerns. The chambers installed are not sufficient. For instance, 2 blocks would have to rely on one chamber for water. Though schedules have been made for a fair share of water, it takes time for water to build up in the chambers for distribution. This causes a repeated cycle of water conflict amongst impatient farmers. Furthermore, other defects in design shows low chamber outlets that lead to overflowing of water leading to water inefficiency. Some respondents also claim leakages in the regulators which needs to be looked at in phase II.

4.1.3.3. Drain network

The drainage situation before rehabilitation has been poor. They were choked and highly infested by aquatic weed. The central part of the scheme is reported to be the scheme's lower section. They get flooded especially in the rainy season when the drain is not able to remove excess water. This disrupt farming activities in the major season and destroys yield as these are soaked reducing the quality of the crop output. It is also worth to mention that flooding of some fields occurs because of lagoon overflowing its banks during the rainy season.

The maintenance of drains and conveyance system are supposed to be a shared responsibility between farmers and the scheme. The scheme management are supposed to maintain the main canal and drain while the farmers under the leadership of the WUA the infield drains. However, these activities are not able to effectively take place as most farmers refuses to pay Irrigation Service Charge (ISC). Farmers claim not much is made from the farm to pay for ISC. Other challenges attributed to this is the lack of machinery.

Phase I of the rehabilitation programme included reshaping and desilting of drains. There is currently easy flow in the drains. The rate of ISC payment have also increased due to the programme. A component of these payments goes to the scheme and the WUA for the maintenance of these structures.

4.1.3.4. Uniformity and Adequacy

Historical records according to the survey revealed that section B of the scheme was under sugarcane cultivation until in the year 1997 where it was converted to a rice scheme. Others also indicated that initial plans for some part of section A was for the cultivation of cash crops. Based on these events, land preparation was not considered as crucial. This has had untold effect on water distribution within fields especially section B.

The level of most fields are uneven, preventing uniform distribution and difficulty in monitoring water level. Some parts become under-irrigated leading to stunted growth and low yield while other parts are over-irrigated. A programme introduced by JICA trained farmers into the introduction of chunking bunds to control supply and improve uniformity. However, farmers are yet to fully come to terms with this innovation even though supply has been improved after phase I of the rehabilitation.

4.1.4. Monitoring

The scheme has a Water Management Team and Water Bailiff from the WUA trained by the scheme who manage the day-to-day demand and supply of water on the field. With the rehabilitation in place, the key to control valve of pipe is managed by the WUA and the Bailiffs to ensure proper scheduling. Phase II is expected to install an automation system to monitor water use. The farmers do not know their irrigation requirement, however, there is an adopted strategy either by the stick, ruler, bunds or high point of field for uneven fields, in monitoring water level. There are training efforts to build the capacity of farmers on how to use water efficiently. This is done during their monthly meetings.

4.1.5. Yield

Generally, there are 3 varieties of rice grown in KIS. They include the Jasmine 85, Legon rice 1 and the AGRA rice. Most varieties grow within 110 – 120 days. This means that some farmers plant within 3.5 months while others 4 months. This is dependent on the seed type used. Some use certified seed while others uncertified seeds. Transplanting is mostly done in the major season while broadcasting for the minor season.

Over 50% of responses from the survey indicated that before the rehabilitation, the yield was between 3.5 – 4.5 tonnes/ha. There has been an improvement in yield after the rehabilitation. The survey indicates that the yield is now between 5 - 6 tonnes/ha after the rehabilitation. Over 60% of responses indicated that.

The increase in yield has been attributed to increased access to water due to the partial lining of the canal and JICA's training programme in good agronomic practices and water management. This means that when the canals are fully rehabilitated the yield would be positively impacted. While most farmers have gained in yield from the rehabilitation, some few farmers had a reduction in yield. This is attributed to some defects in construction and flooding as previously mentioned in *section 4.1.3.2*. Other challenges that hindered yield increase include competition of rice with weeds (these are weeds that germinate like rice and are difficult to control), high cost in transplanting which causes some farmers to broadcast, the type of rice seed, uneven fields, diseases like brast, continuous cropping, to mention but a few.

Overall, the rehabilitation has served a good purpose and have achieved a great milestone even though there are minor defects with the construction. It is the hope of both the scheme management and the farmers for phase II to construct fully lined canals and address the defects. Additionally, they aim to see a modernize system during this period with the introduction of the automation for metering and monitoring of water use. Access to credit and market is beginning to be a challenge for farmers. It is important for measures to be put in place to help farmers market their produce for their economic prosperity.

4.2. Satellite Data Analysis

4.2.1. Precipitation

A time-series analysis was generated in Google Earth Engine (GEE) from daily CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) datasets. *Figure 10* presents daily precipitation data ranging from January 1990 to June 2024. From the figure, two seasons can be identified for each year, major and minor. The results show how climate change is eminent. There are different trends in precipitation patterns. There are seasons of very high peaks of rainfall like that of 2003 and 2019 respectively and likewise seasons with low precipitation output. There are also seasons of longer drought periods like the 1991/92 and 1994/95 seasons.

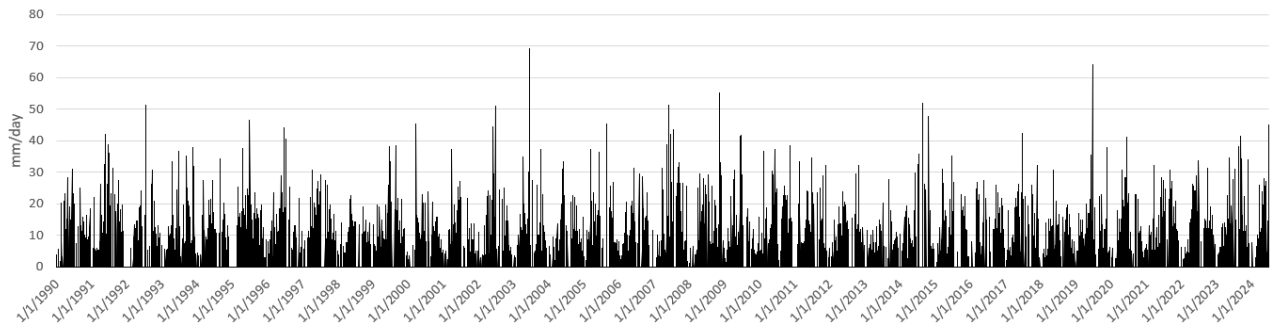


Figure 10: Precipitation time-series from 1990 to 2023

In the last few years, the precipitation pattern on the scheme have experienced a drastic change. The field survey suggested that rain shows up unexpectedly. Rains rather came in the months of July, August, September, and October and with high volumes. Usually, it is expected that the major rainy season ends in July while the minor starts in September. These are very evident in the above time-series.

The scheme has experienced above normal averages over certain periods on the scheme. *Figure 11* details the precipitation averages from 2017 to 2023 compared to the long-term average which spans from 1990 – 2016. The long-term average for the scheme indicated a 1,008.75mm rainfall with a standard deviation of 146.39mm. In comparison to the rainfall distribution within the period, there are indications of higher rainfall in 2017, 2019, 2021, 2022, and 2023 respectively. This is more prominent in the 2023 season.

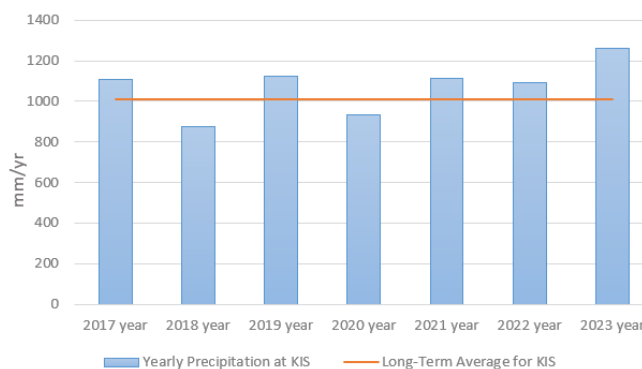


Figure 11: Comparison of Yearly to Long-Term Average Precipitation for KIS

4.2.2. SOS and EOS

4.2.2.1. NDVI

An NDVI time-series analysis of KIS using NICFI PlanetScope imagery were performed in GEE. *Figure 12* illustrates the outputs from the time-series. These are time-series from 2017 to 2024. As mentioned in the methodology, details of events before the rehabilitation could not be depicted due to the 6-month time-step in production and therefore the SOS and EOS for the region could not be determined.

However, the period after the rehabilitation showcases the SOS and EOS but with sharp trends. Attempts to smoothen with a larger window length destroys the trends. Nonetheless, based on visual interpretation the SOS and EOS can be assumed to be June to October for the major season with November to March as the minor season. These assumptions were based on the 2022 seasonal year as this was the year the scheme gained stability after the rehabilitation. There were no indications of 3-cropping season or 5 seasons for 2 years.

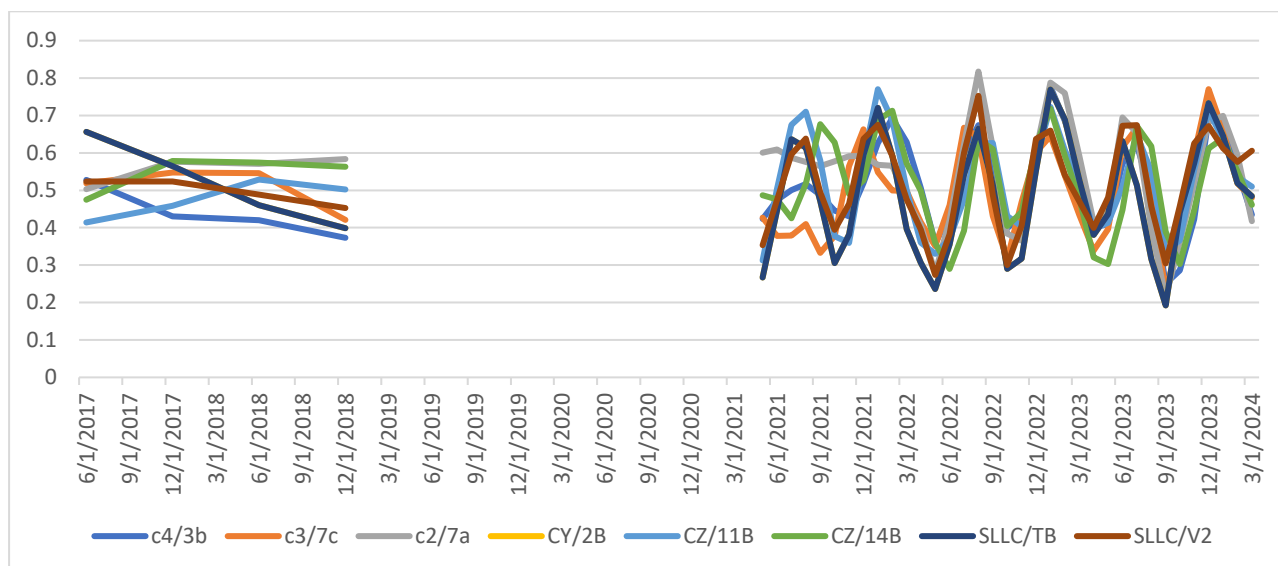


Figure 12: NDVI time-series for KIS

4.2.2.2. FCOVER

The CropSAR model produced 3 Fcover time-series outcomes from the 3 sections ranging from 1st January 2019 to 21st March 2023. The time-series starts from 2019 because CropSAR has been available since this period in filling gaps and reconstructing time-series (VITO, 2021). The year 2020 starting from March was not considered in the time-series generation. This represents the period of the rehabilitation. The time-series was smoothed with the Savitzky-Golay filter.

The field survey suggested that due to water challenges some farmers abandoned their fields during the minor season, hence cropping was done once for the seasonal year. Others also received their fair share of water between 2 – 3 days and sometimes a week, experiencing longer fallow periods and in effect affecting their production. This is evident in the 2019 seasonal year for all the 3 time-series. There are irregularities and variations. Based on this, the 2019 period could not be used to decide on the SOS and EOS.

Similarly, the 2021 cropping season also shows certain dynamics in the seasonality. In FCOVER_A, while some fields had a longer fallow period before starting the season, other fields started within the same period. This shows variations and an irregular turn of events. For FCOVER_B1, 2 field boundaries shows 2 seasons with a longer fallow period before the start of the 2022 cropping season while the other boundary shows 5 cropping seasons in 2 years, that is, from 2021 – 2022 seasonal years. This shows that there are tests by some farmers to produce in 5 seasons. However, the overlap of boundaries shows differences in cropping patterns. This can be attributed to defects experienced with the rehabilitated system, thereby affecting their cropping patterns, though some farmers may have had a good start after the rehabilitation to the extent of cropping 5 times in 2 years, but it is more likely that most farmers cropped within 2 seasons. The 2021 seasonal year of FCOVER_B2 also shows similar patterns like FCOVER_B1. There are events of 3 seasons in a year while others continue with 2 seasons with lower FCOVER in the minor season. The 2021 seasonal year could not be equally used as the SOS and EOS.

For 2022 and 2023 seasonal years, it can be established that all 3 time-series data show a regular and consistent cropping patterns. The variations in seasonality are very minimal, continues to show a certain trend within seasonal years, and more stationed seasonality from one year to the other. This could be as a result of recovery from the rehabilitation. Based on the 3 outputs as displayed in figures 13, 14, 15; the SOS

and EOS for the KIS scheme is June – October and November – March respectively, making the major and minor seasons This is exclusive of the land preparation period.

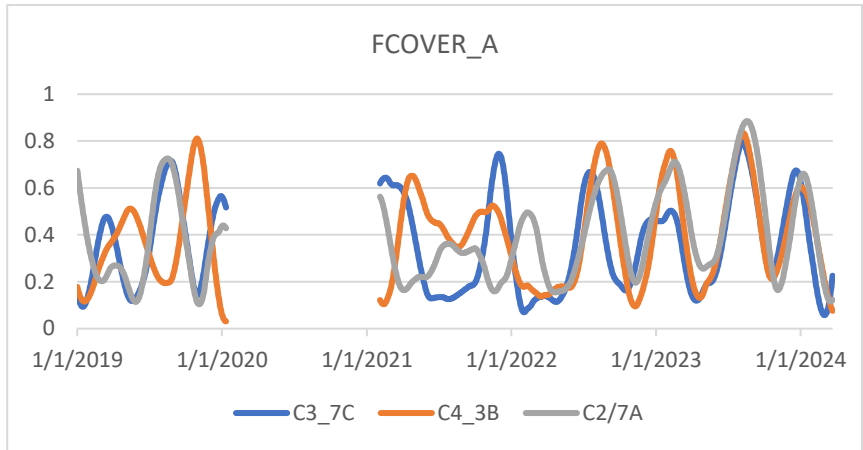


Figure 13: SOS and EOS for Section A

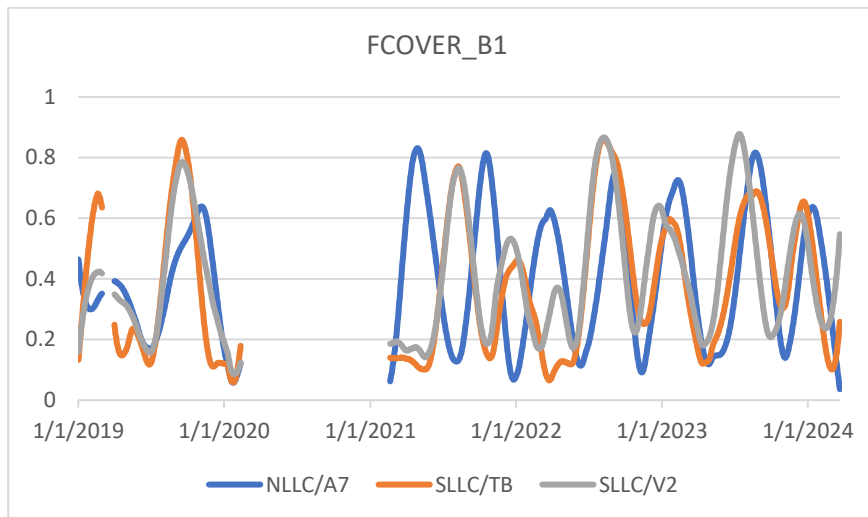


Figure 14: SOS and EOS for Section B1

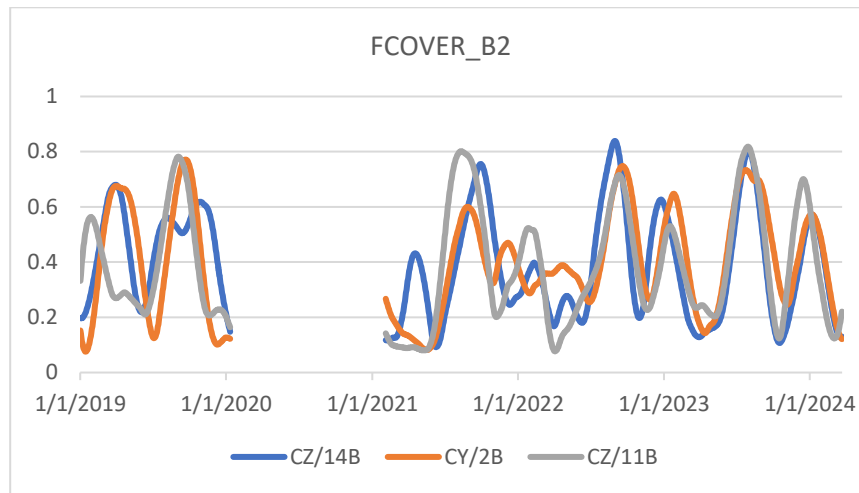


Figure 15: SOS and EOS for Section B2

4.2.3. Irrigation Performance Assessment

4.2.3.1. Uniformity

Figures 16 and 17 represents the extent of uniformity/equity in KIS. From figure 16, it is observed that the major season before rehabilitation shows that 60% of the fields are reflecting a good uniformity with the coefficient of variation ranging from 1% – 10%. About 40% of the fields are reflecting fair to poor distribution ranging from 10% – 30%. The minor season before rehabilitation shows that 50% of the fields are with good distribution with CV ranging from 1% – 10% and the other 50% with CV of 0% – 1%. This might be attributed to abandonment of fields in the minor season due to water challenges.

For distribution after rehabilitation, the seasonal years of 2021 and 2022 had over 70% of fields reflecting good distribution of water with CV ranging from greater than 1% – 10%. Few areas reflect a fair distribution pattern. The seasonal year of 2023, on the other hand, shows a different trend. About 50% – 60% of the field have good distribution while there are fair to poor distribution of water on about 40% of fields. Field areas with distribution of greater than 10% may have the challenge of uneven fields.

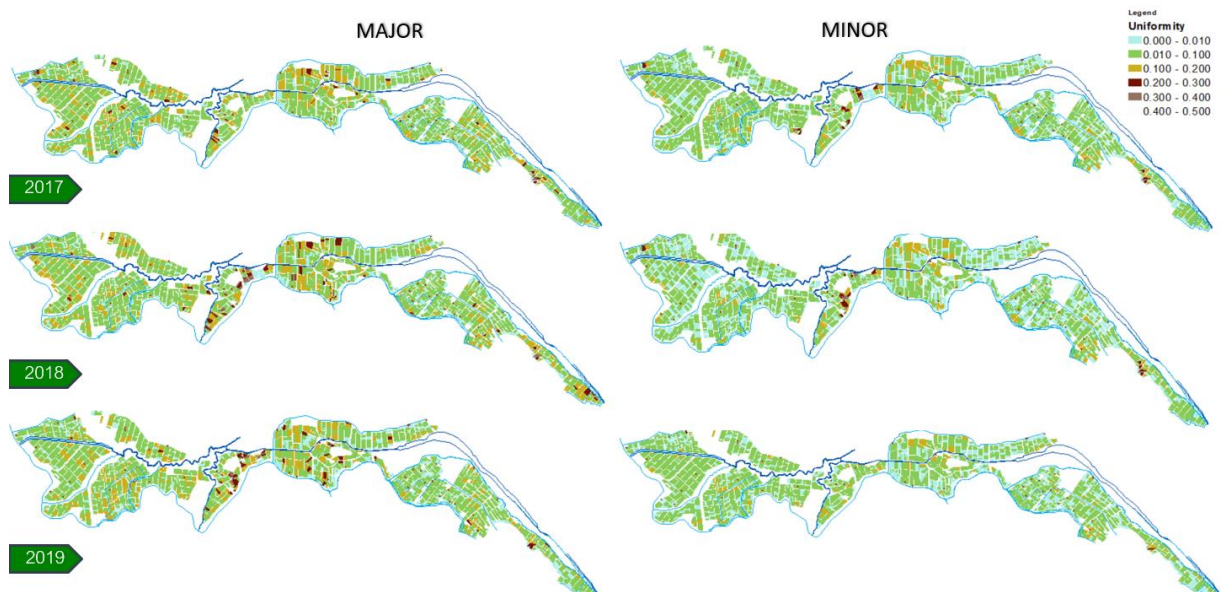


Figure 16: Uniformity before rehabilitation

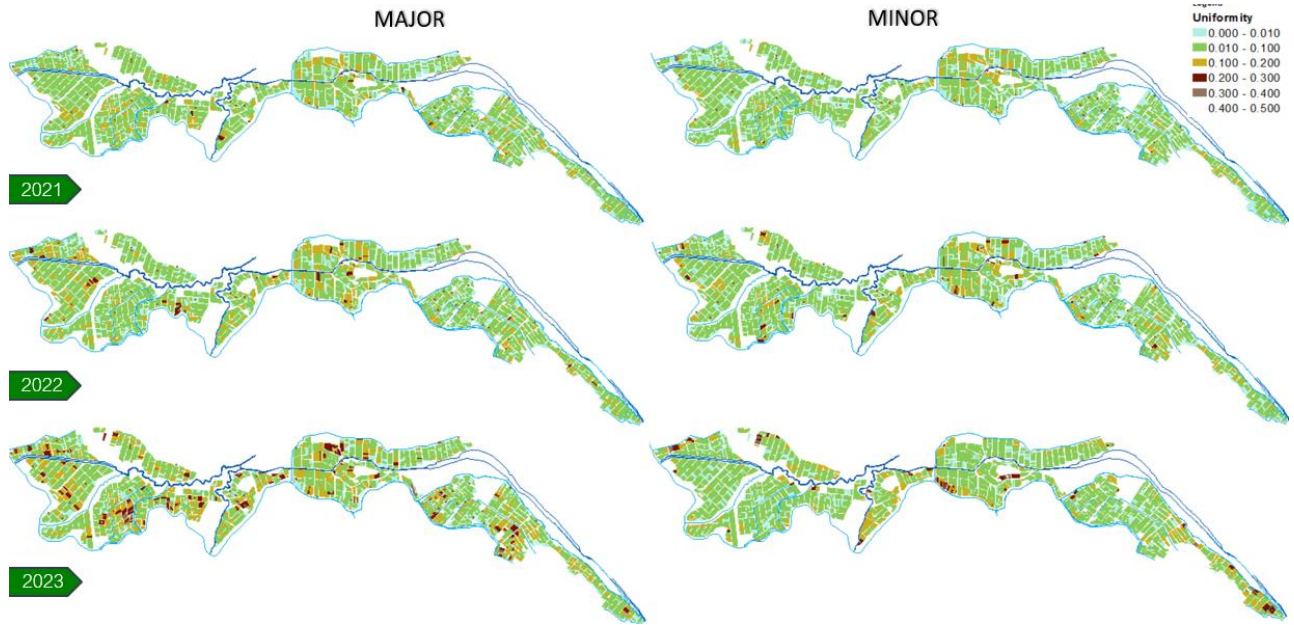


Figure 17: Uniformity after rehabilitation

4.2.3.2. Adequacy

The major seasons from 2017 to 2019 before the start of the rehabilitation experiences a relative ET between 40 – 80% while the minor seasons up to 100%. However, the 2019 minor season presented some distinctions. While the Section A of the scheme experienced up to 100% of relative ET, the Section B experienced between 40% to 80%. Areas that experienced equal or greater than 100% in relative ET are said to have received AETI equal to or higher than ETP.

Surprisingly, the major seasons after the rehabilitation didn't seem to have good sufficiency in water. The sufficiency rate throughout the major seasons showed a relative ET up to 60%. However, the minor seasons seemed to be proficiently using the modernised structures. The 2021 minor season showed a sufficiency between 60% - 100% while the minor season of 2022 showed a better relative ET of over 100%. The 2023 minor season majorly had a sufficiency up to 80%, however, there were few areas which had between 40% to 60%. This is especially vivid towards the tail-end of the scheme. This account might be as a result of some challenges within the area.

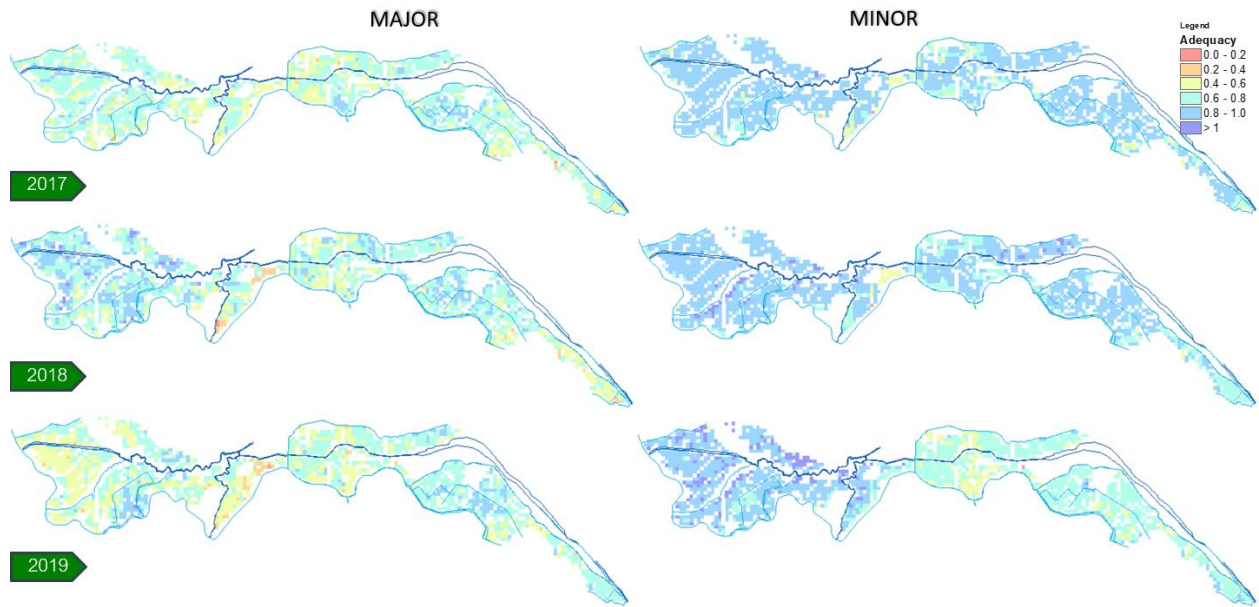


Figure 18: Relative ET before rehabilitation

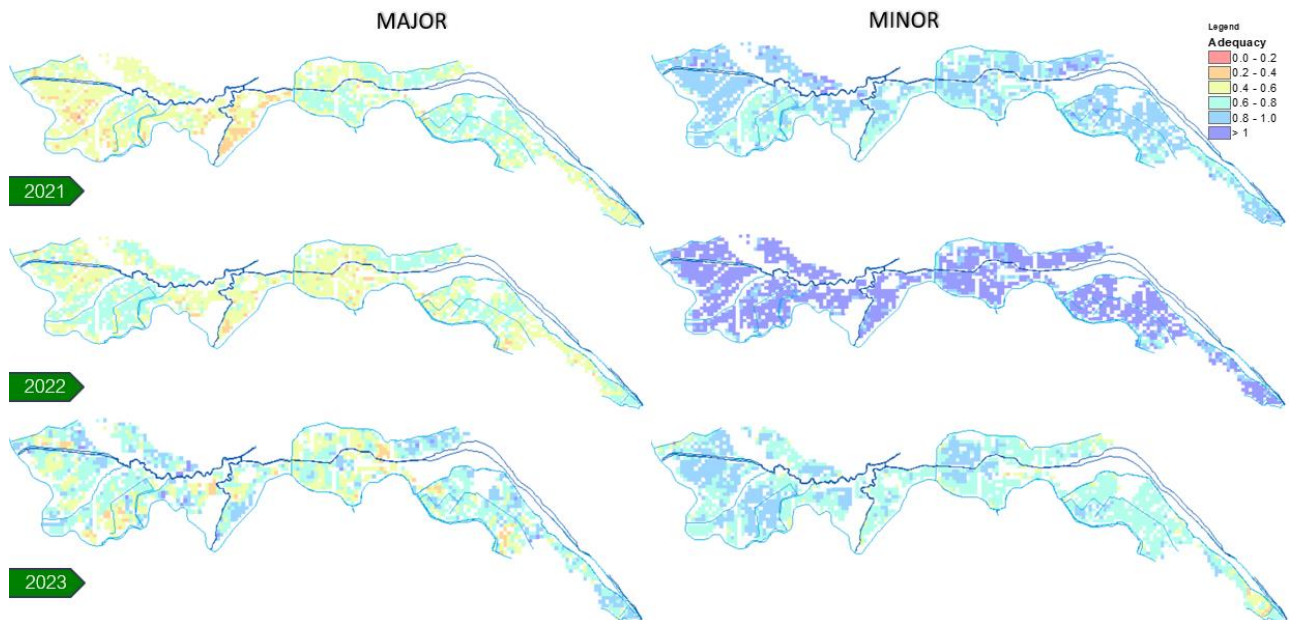


Figure 19: Relative ET after rehabilitation

4.2.3.3. Efficiency

Figures 20 and 21 shows the percentage of water consumed in KIS. Before rehabilitation, the scheme generally looked good in terms of water consumption with over 60%. However, the minor season of 2019 portrays a different trend. More than half the scheme area had low consumption levels with 40% even though the corresponding relative ET seems otherwise. This is typically identified with the Section B of the scheme. There are also areas with very low percentages (0% - 2%). From inspection, the red pixels at the central part of the scheme had pixel value of zero. These may be due to cloud coverage and can be nullified.

The 2021 major season after rehabilitation projected certain dynamics in the efficiency of water consumed. About two-thirds of Section A had an efficiency of less than 60% while the Section B part experienced an

efficiency of over 60%. However, the minor season for both sections of the same cropping year experienced an efficiency of over 60%; the same outputs for the 2022 cropping year and 2023 minor season. The 2023 major season on the other hand presents a different twist all together. The results as indicated in *figure 21* shows to very low efficiency of the scheme within the period for both Sections A and B.

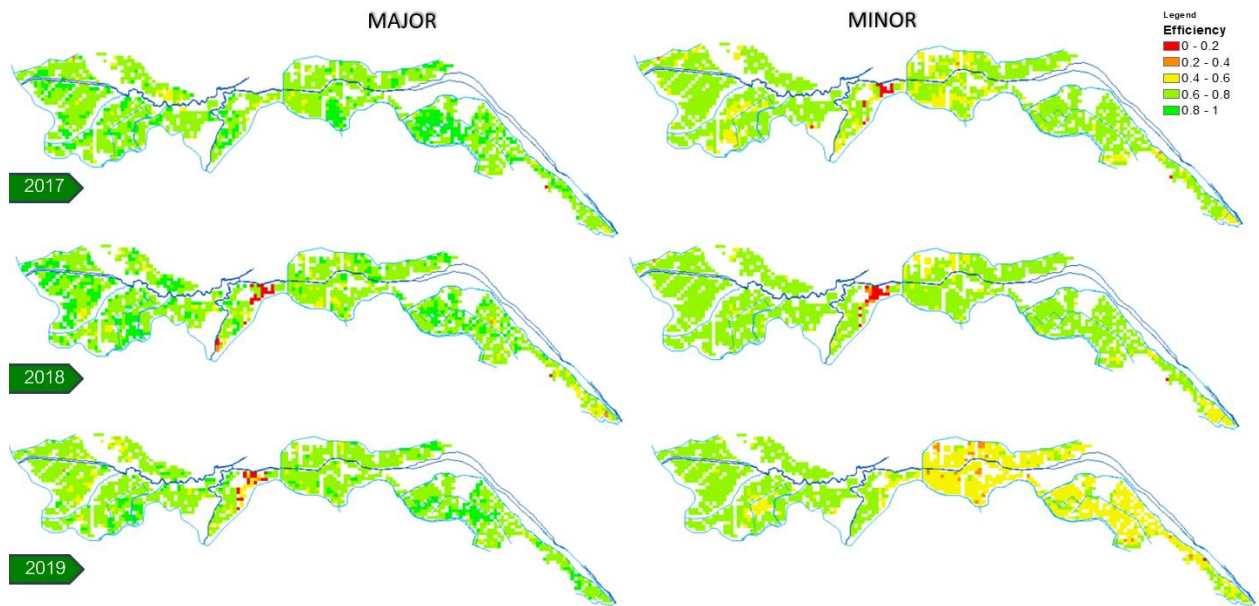


Figure 20: Irrigation Efficiency before rehabilitation

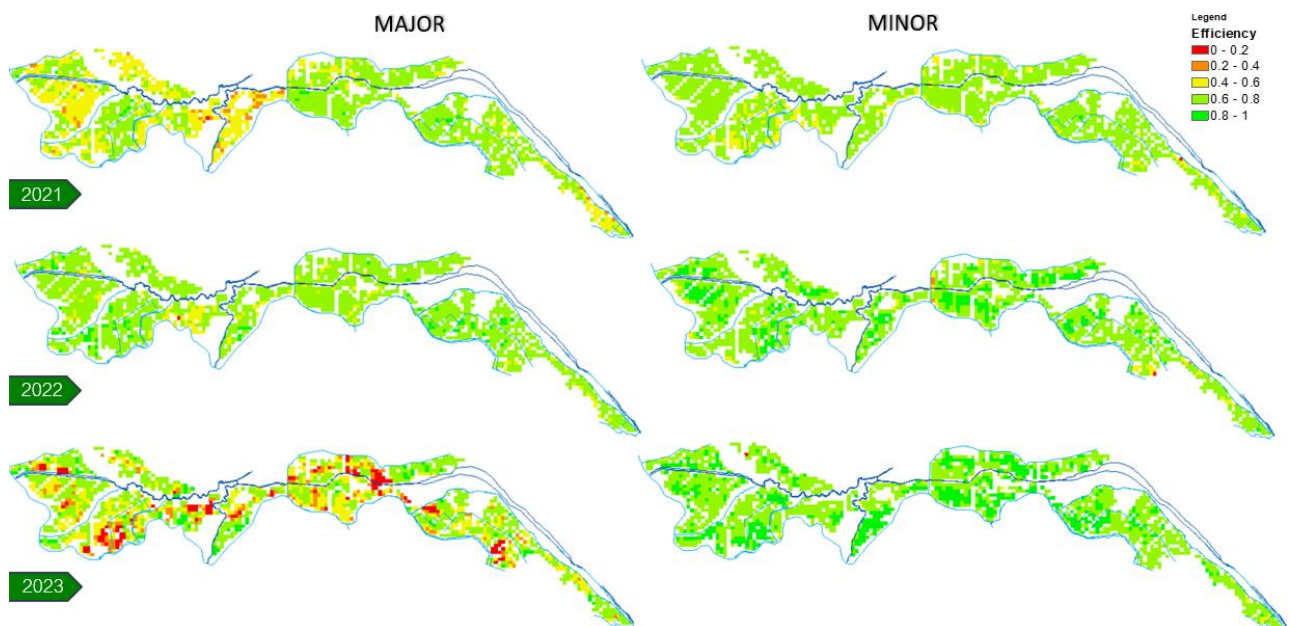


Figure 21: Irrigation Efficiency after rehabilitation

4.2.3.4. Relative Water Deficit

The major season according to the stakeholders, is the season that experiences massive precipitation which influences the cropping and serves as a yield booster. However, before the rehabilitation, the major seasons from 2017 to 2019 had up 40% in water deficit whiles the minor seasons with the specified periods had up

20% in water deficit. Interestingly, the minor season of 2019 showed some variations. While Section A experienced a deficit of up to 20%, Section B rather had a 40% deficit of water.

After the rehabilitation, it is expected that the relative water deficit becomes minimal. However, the major seasons within the period of 2021 – 2023 rather seemed worse compared to the water deficit of the major seasons before the rehabilitation. The scheme experiences up to 60% in water deficit. Nonetheless, the minor seasons within the period continue to experience a deficit of 20% except for 2023 minor season which is up to 40% in water deficit.

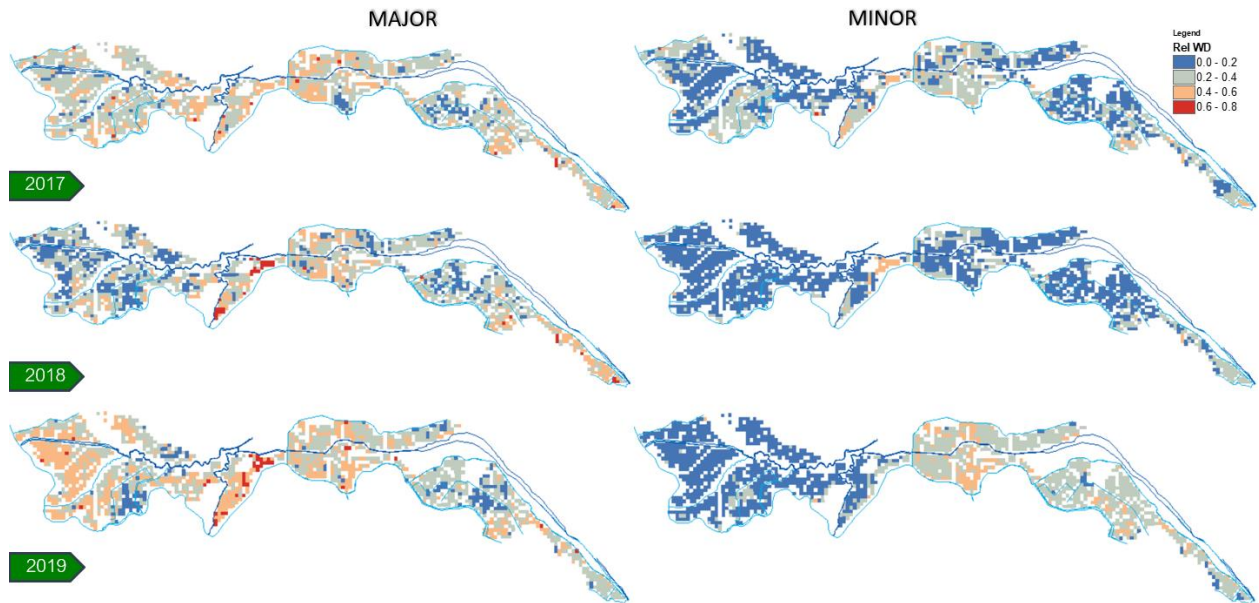


Figure 22: Relative Water Deficit before rehabilitation

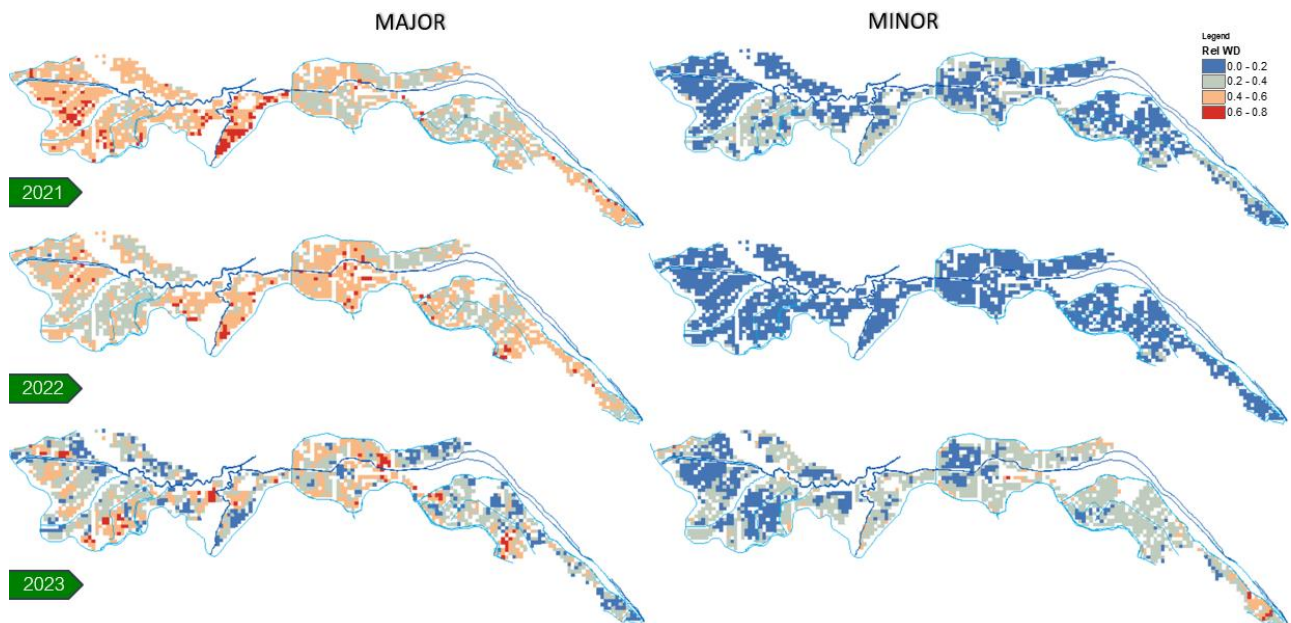


Figure 23: Relative Water Deficit after rehabilitation

4.2.4. Land and Water Productivity

4.2.4.1. Biomass

There is clear distinction in biomass between the major and minor seasons before rehabilitation. While the major seasons yielded between 4 – 6 tonnes/ha/season, the minor seasons yielded between 2 – 4 tonnes/ha/season.

After the rehabilitation, the 2021 major season struggled in biomass. From *figure 25*, Section A of 2021 major season had a reduction in biomass with an estimate between 2 – 4 tonnes/ha, however, the Section B part maintained a 4 - 6 tonnes/ha. The minor season for the seasonal year was no better with a biomass between 2- 6 tonnes/ha. The 2021 seasonal year showed some improvement. The major season had a biomass between 4- 8 tonnes/ha while the minor with majority of fields gaining 4- 6 tonnes/ha in biomass.

Due to the rehabilitation, the biomass of the 2022 seasonal year seems to have increased compared to the previous season. With such increase one would expect similar increase for 2023. However, the 2023 major season shows a major disparity in biomass compared to previous years. Majority of the areas in the 2023 major season had a biomass up to 4 tonnes/ha. It can be concluded that the scheme struggled during the season which in turn affected the biomass, hence the total yield.

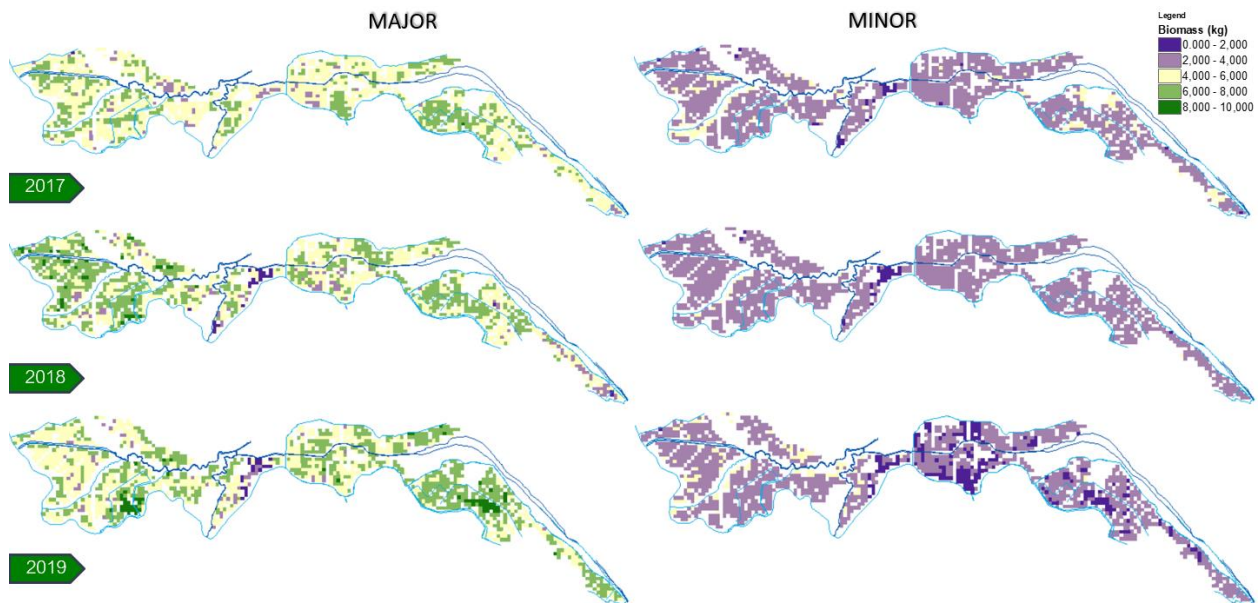


Figure 24: Biomass before rehabilitation

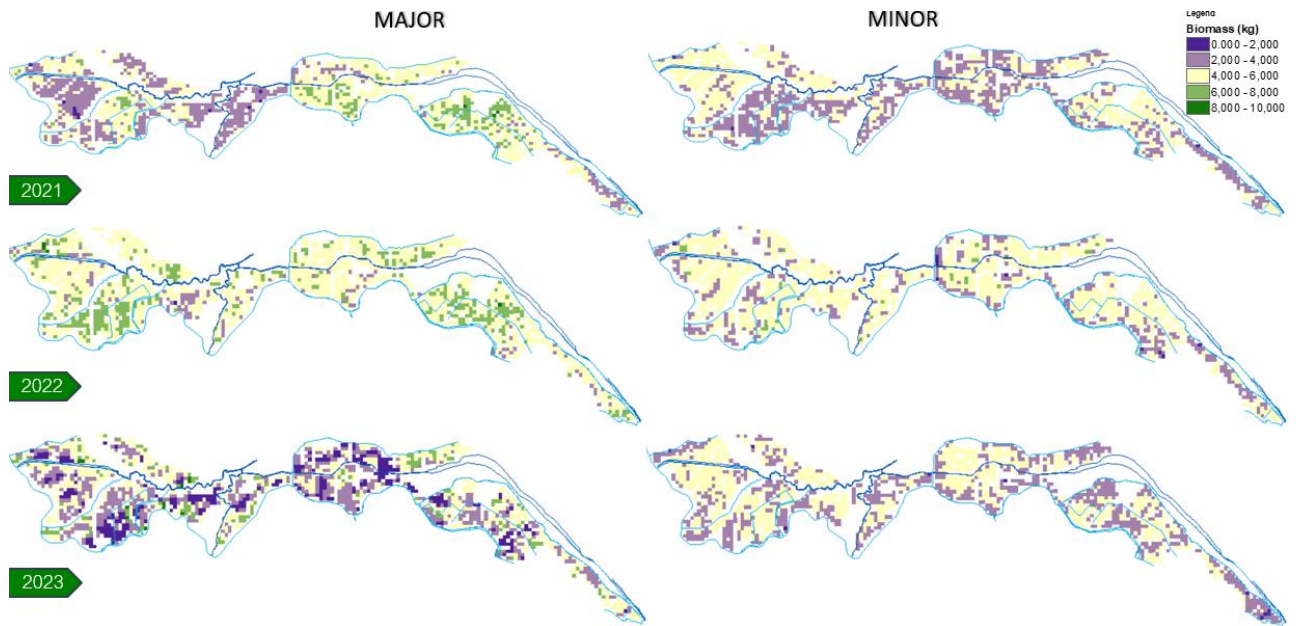


Figure 25: Biomass after rehabilitation

4.2.4.2. Yield

Since yield is a product of biomass, there are similar trends with the estimated yield. The major seasons before the rehabilitation had an estimated yield between 2 – 3 tonnes/ha/season, with some few fields gaining up to 4 tonnes/ha/season, and the minor seasons 1 – 2 tonnes/ha/season. Nonetheless, the minor season of 2019 had an estimated yield up to 2 tonnes/ha for the Section A while Section B had up to 1 tonne/ha.

From *figure 26*, Section A in the major season after the rehabilitation in 2021 had a yield estimate of up to 2 tonnes/ha while the Section B within the same period an estimate of up to 3 tonnes/ha. The 2022 major season for the entire scheme maintained a yield up to 3 tonnes/ha while the minor season had 50% of the field with an estimated yield up to 2 tonnes/ha and the other 50% up to 3 tonnes/ha. Like the biomass, the 2023 major season produces a confusing pattern of yield. Majority of the field produced up to 2 tonnes/ha or even less. Also, unlike the 2022 minor season which showed promising yield of up to 3 tonnes/ha, the 2023 minor season went back to 2 tonnes/ha. This reflects a major disparity as the expectation would be to have a continuous increase yield with the rehabilitation.

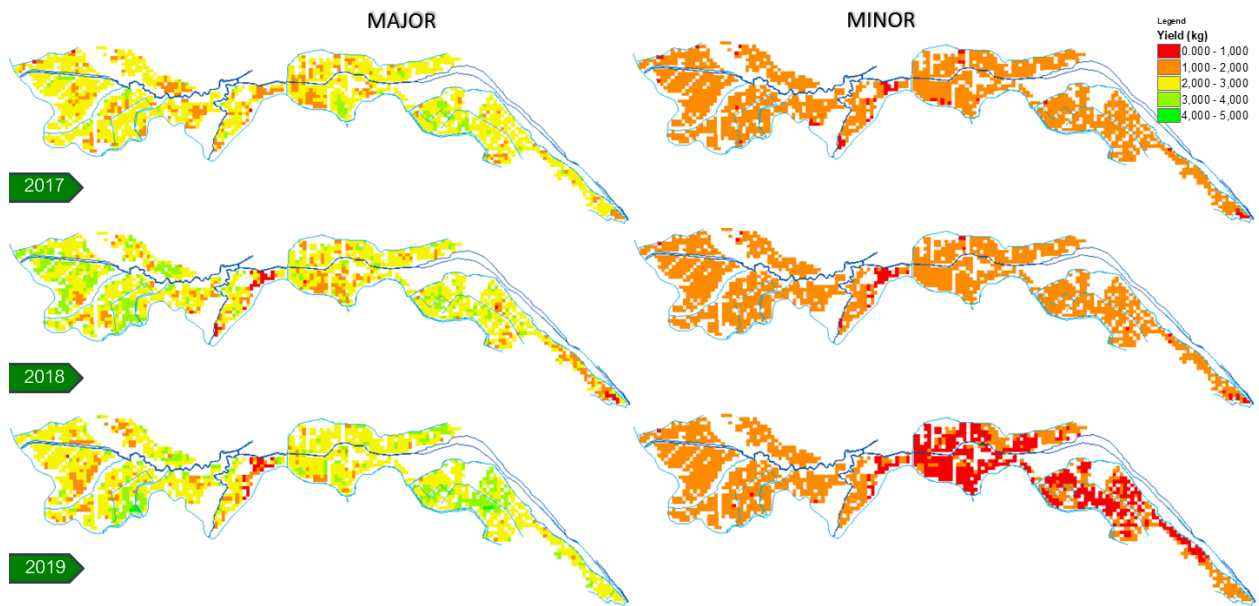


Figure 26: Yield before rehabilitation

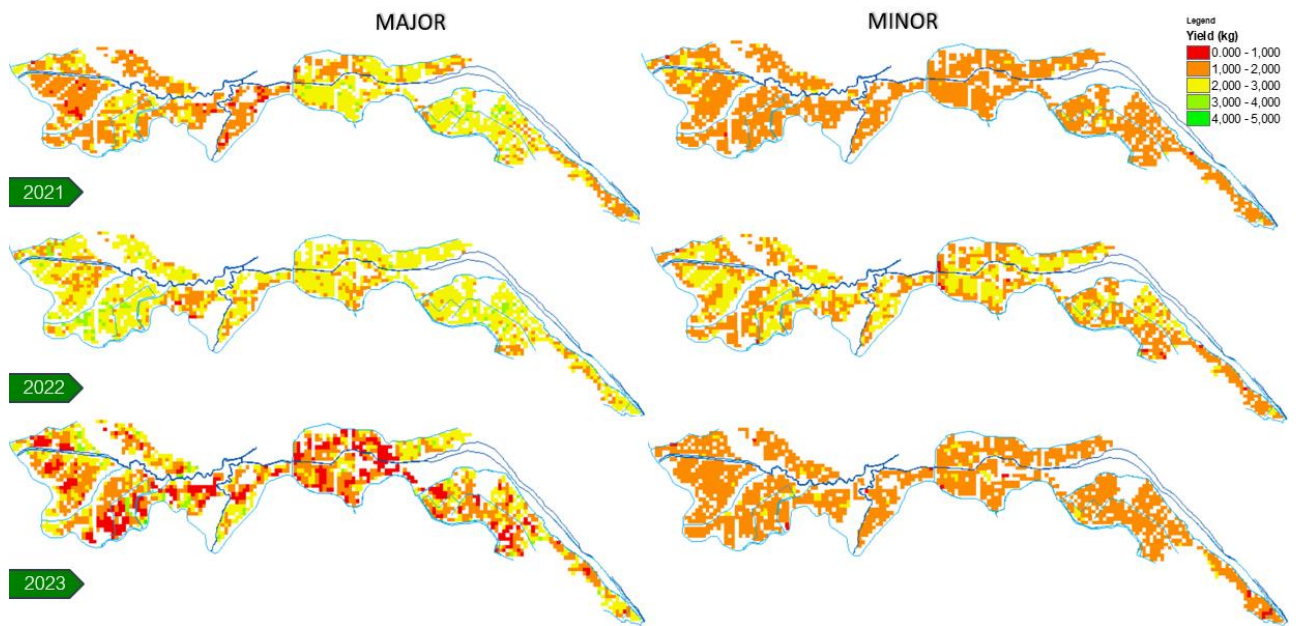


Figure 27: Yield after rehabilitation

4.2.4.3. Biomass/Yield Water Productivity (WPb/WPy)

The Biomass Water Productivity (WPb) resulted between 1.0 – 1.5 kg/m³ for the major seasons before the rehabilitation except the 2019 major which was between 1.5 – 2.0 kg/m³. The minor seasons before the rehabilitation were up to 1.0 kg/m³. For the WPb after the rehabilitation, the major seasons increased from 1.0 – 2.0 kg/m³ and the minor seasons maintaining up to 1.0 kg/m³ except for 2023 minor season which had a boost up to 1.5 kg/m³.

Similarly, as a product of WPb, the yield Water Productivity (WPy) produces similar trends. The major seasons before the rehabilitation had a WPy between 0.4 – 0.8 kg/m³ while the minor with WPy up to 0.4 kg/m³.

For the major season after the rehabilitation, the 2021 season continued with WPy between 0.4 – 0.8 kg/m³, similar to outputs before the rehabilitation. However, the 2022 major season experienced a boost in WPy of up to 1.2 kg/m³ while the major season of 2023 saw some declines even with areas that had a boost from the 2022 major season. The decline in WPy is depicted in *figure 29*. The WPy was up to 0.8 kg/m³ with some areas experiencing up 0.4 kg/m³. Though the minor seasons continued with a trajectory of up 0.4 kg/m³, some area within the scheme saw an increase in WPy up to 0.8 kg/m³. This is more emphasized in the 2023 minor season.

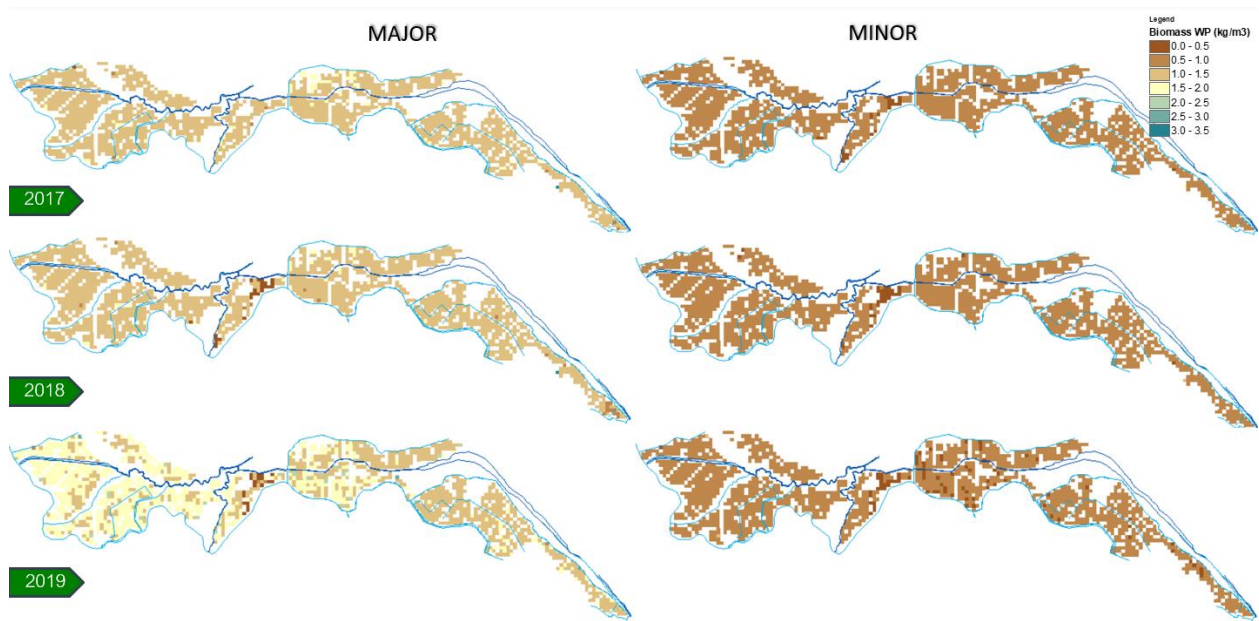


Figure 28: WPy before rehabilitation

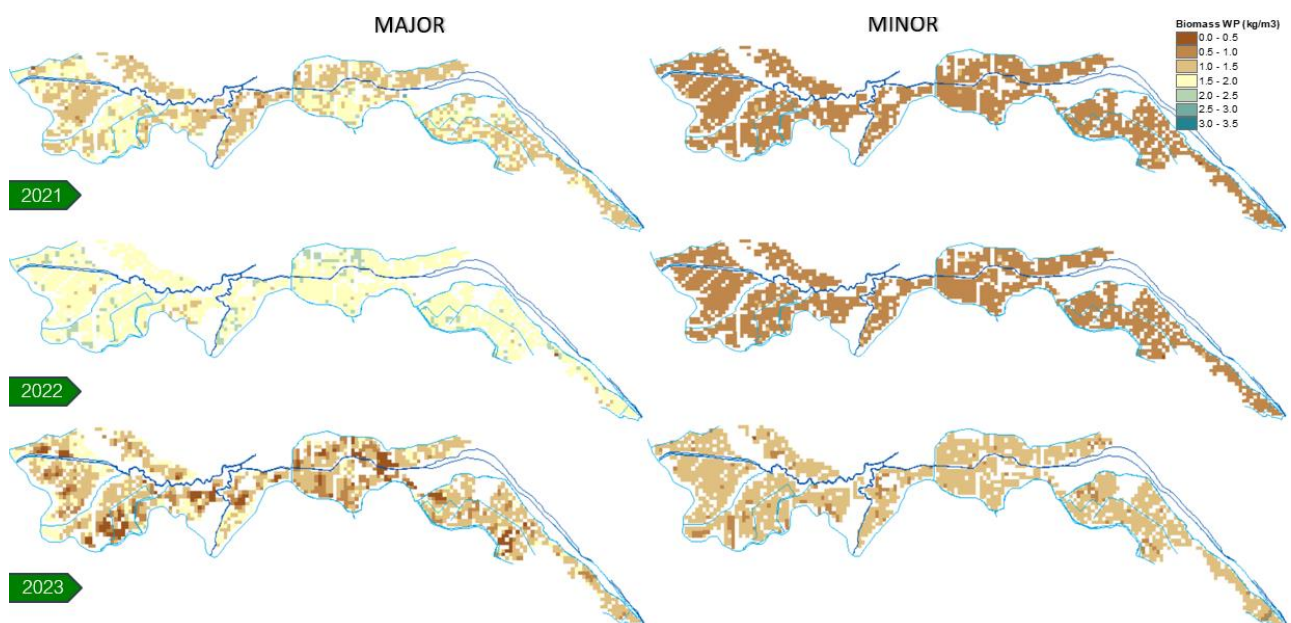


Figure 29: WPb after rehabilitation

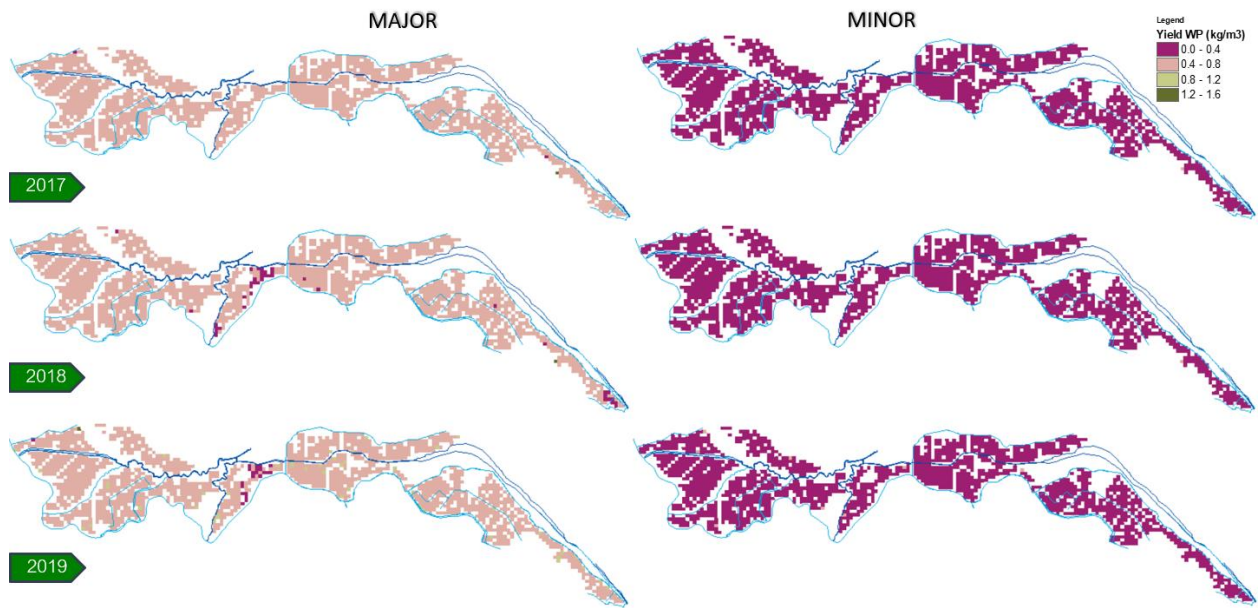


Figure 30: WPy before rehabilitation

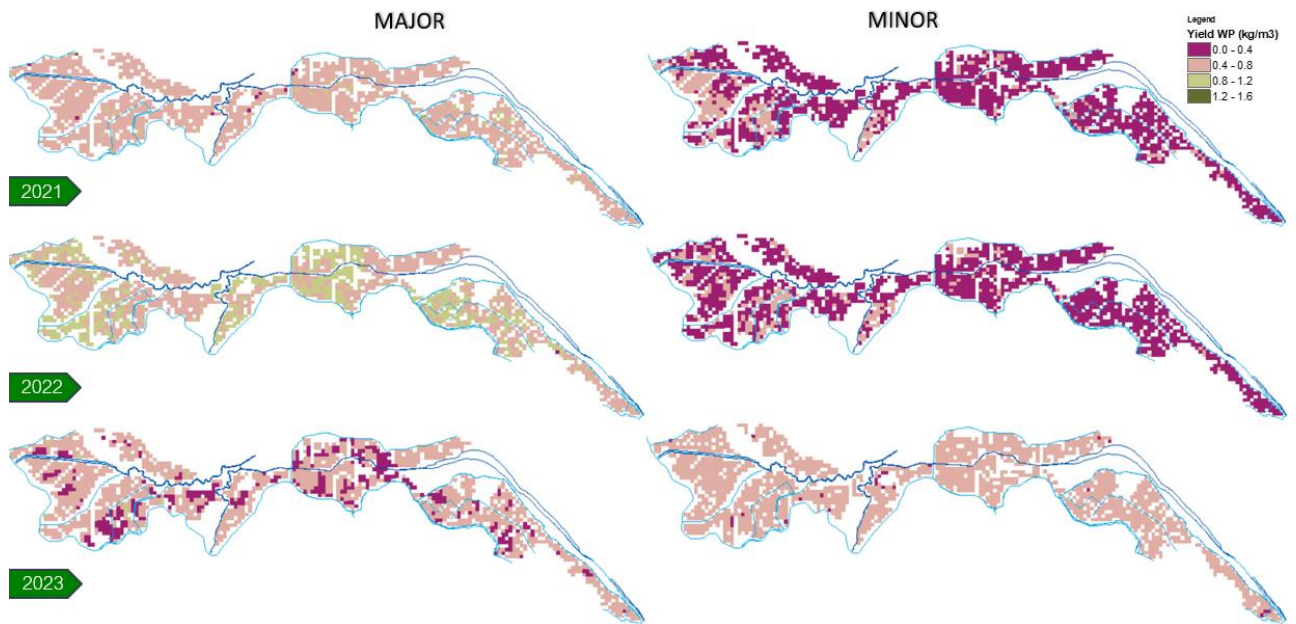


Figure 31: WPy after rehabilitation

4.3. Validation

4.3.1. SOS and EOS

Seasonal changes in canopy have a very large influence on the NPP. This varies over space and time (Bondeau et al., 2008). Based on this, NPP can be used to validate the SOS and EOS of crops. The calculation of NPP

requires weather data, solar radiation, fAPAR, soil moisture, and LUE (WaPOR, 2018). Dekadal datasets from WaPOR were used to validate the FCOVER generated SOS and EOS by CropSAR.

From visual interpretation, the SOS and EOS can be predicted as June to October for the major season while November to April, for the minor season. In comparison to the FCOVER, *section 4.2.2.2*, the result is not far-fetched. There is a slight difference in the Length of Season (LOS) for the minor seasons. While NPP resulted from November to April, the FCOVER resulted from November to March. Notwithstanding, the difference is minimal.

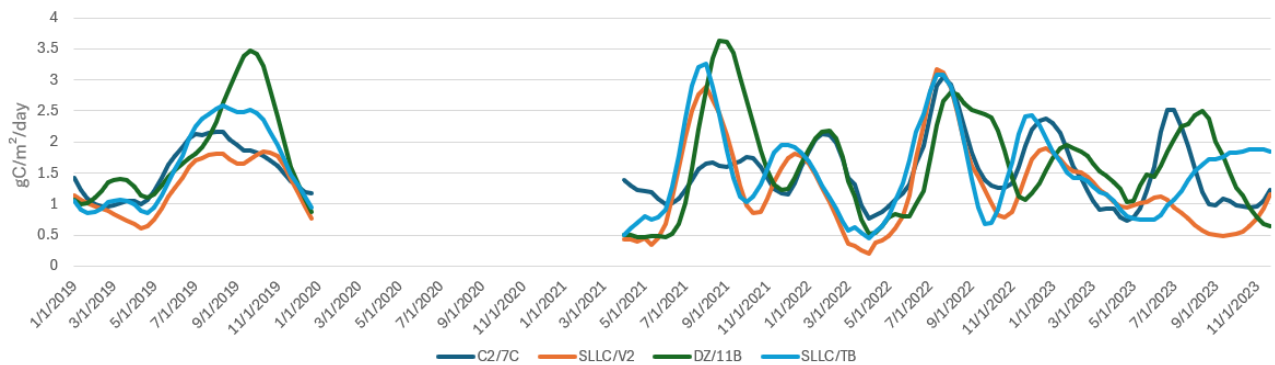
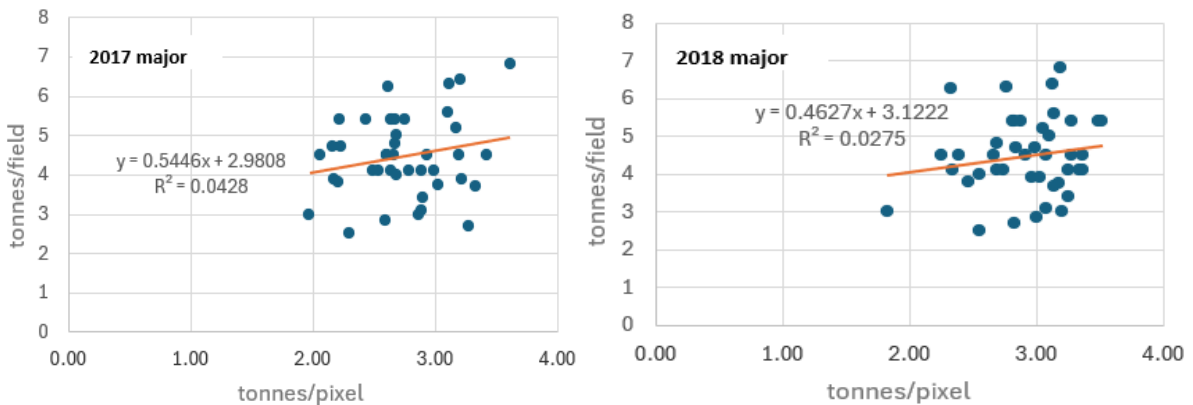


Figure 32: seasonal NPP from 2019 to 2023

4.3.2. Yield

A comparative assessment done between the yield from the field and the maximum yield from WaPOR as illustrated from *figure 33* indicated no correlation between the two. From visual interpretation, the WaPOR yield reflects low outcomes, hence the use of the maximum yield in comparing with the field yield. This comparative analysis was done for the major seasons, both before and after rehabilitation.



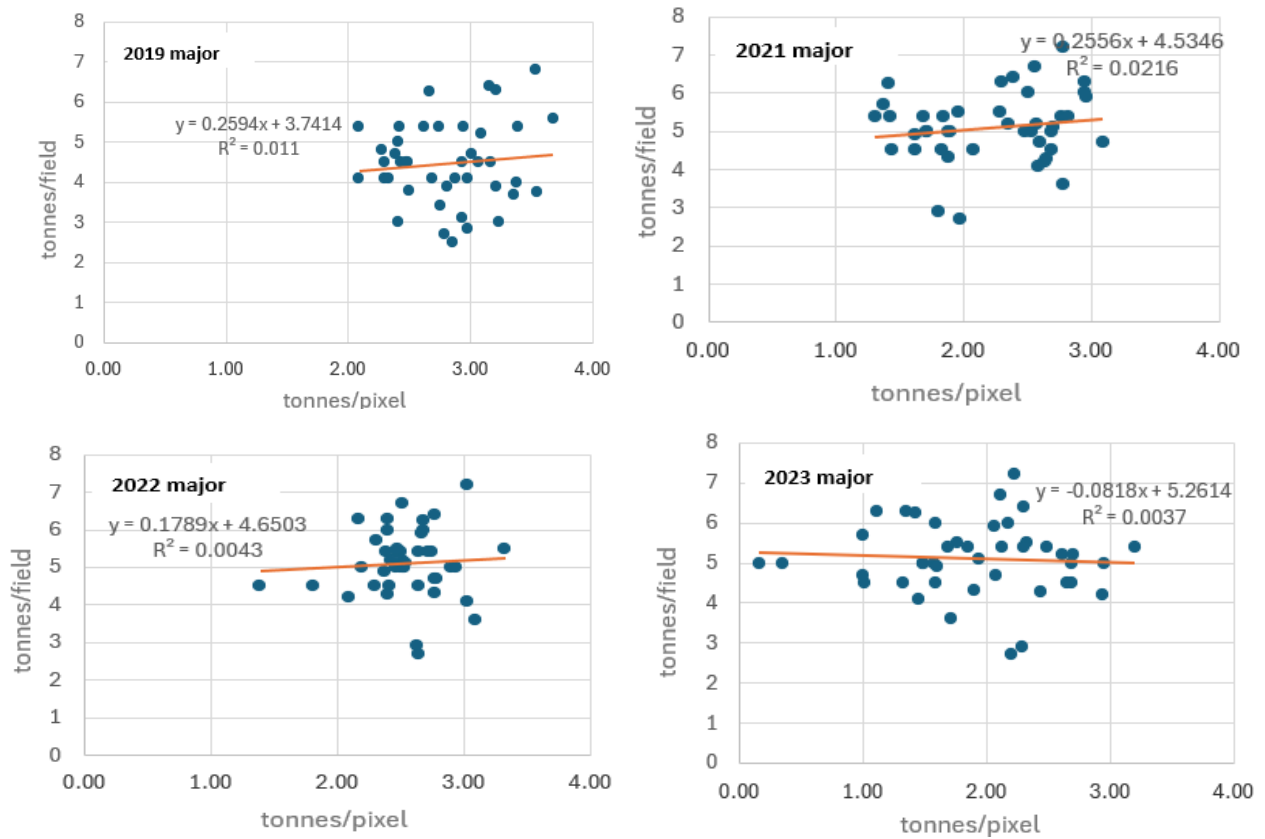


Figure 33: comparative assessment of yield between WaPOR and farmer survey

4.3.3. Actual Evapotranspiration

Figure 34 displays a graph, a and b comparing the mean WaPOR AETI to CROPWAT ETC. The ETC from CROPWAT indicates the actual evapotranspiration (Dhruw & Pandey, 2023; Stancalie et al., 2010). CROPWAT provides a threshold of 546.4 mm and 466.5 mm as crop water requirements for the major and minor seasons respectfully. The CROPWAT ETC estimates were calculated using the interpolated Kc values and the RET (refer to table 2 and appendices 8.6 respectively) with the SOS and EOS used for the spatial analysis.

Deductions indicated that WaPOR had lower mean AETI for the major seasons, both before and after the rehabilitation, when compared to the threshold from CROPWAT. Interestingly, the major seasons also were below the effective precipitation by CROPWAT, except for the 2018 major season. Refer to table 3 for effective precipitation for each season or the CROPWAT rainfall data in appendix 8.7. The mean AETI for the major season after the rehabilitation were much lower compared to the major seasons before the rehabilitation. Breakdown of the minor season indicates that the 2023 minor season shows a deviation from the CROPWAT threshold by 100mm. The other AETI's could be said to be with acceptable limits.

Table 3: CROPWAT Effective Rainfall – Major and Minor Season

Month	Eff. Rainfall (major)	Month	Eff. Rainfall (mnor)
June	134.2	November	86.7
July	61.4	December	36.3
August	37.4	January	21.2
September	84	February	40.9
October	105.3	March	84.7
	422.3		269.8

Except for the major seasons, WaPOR shows good estimates of AETI's for KIS in the minor season before and after rehabilitation. Further investigations on the other hand may be required to ascertain why the major seasons, especially after rehabilitation results in low crop water requirements compared to the FAO standard.

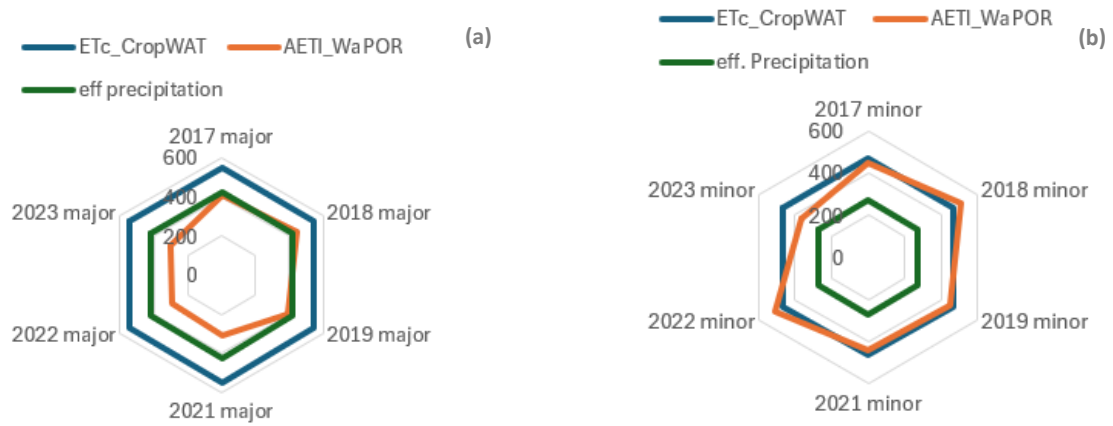


Figure 34: Validation of Actual ET: (a) major season, (b) minor season

5.0. DISCUSSION

5.1. SOS and EOS Analysis

Based on the survey, the majority of farmers identified April to August/September as the major growing season, with October – January/February cited as the minor growing season. Another significant portion of respondents indicated that the major season spans from May to August, while the minor season extends from October/November to March. This pattern reflects the practices of farmers who uses seed varieties with growing periods of 3.5 or 4 months. It was unanimously agreed that maintenance work are carried out in March. The Start of Season (SOS) and End of Season (EOS) also factored the land preparation period.

The FCOVER analysis presented a different prediction, identifying June to October as the major season and November to March as the minor season, as outlined in *section 4.2.2.2*. This assessment excludes the land preparation period, which was incorporated into the cropping calendar based on the field survey. These seasons fall within a 120-day timeframe.

From the preliminary studies, it is important to note that the consultant’s report on the SOS and EOS prior to the rehabilitation presented a different perspective. The major season was reported to extend from February/March to August/September, and the minor season from September to February/March, as detailed in *section 3.1*. However, the consultant proposed three different groups with distinct calendars, as illustrated in *figure 35*, (Peysson, 2017). Whether this proposal has been implemented is yet to be known.

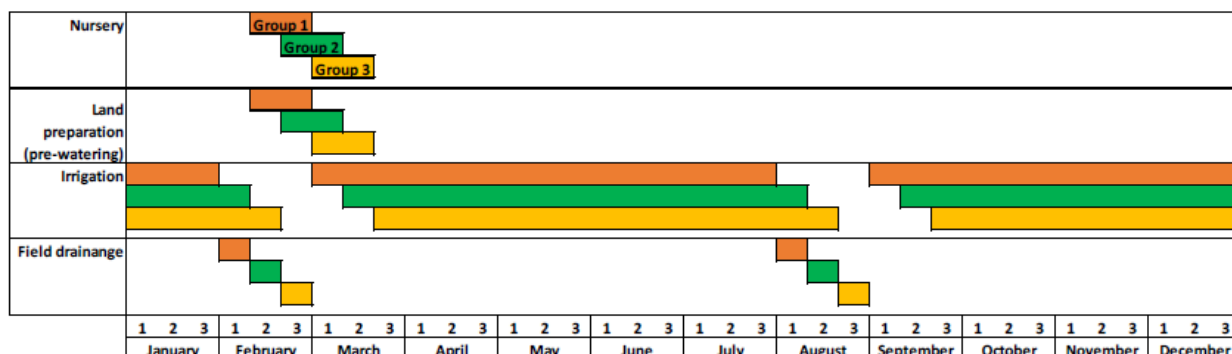


Figure 35: Consultants recommended cropping calendar for KIS

The methodology employed by the Consultant to determine the SOS and EOS in the preliminary studies, as mentioned in the research proposal, remains unclear. It is possible that the Consultant's survey encompassed a substantial portion of the farming population, *section 4.1*, which may have provided a comprehensive perspective on the seasonal patterns. If this was indeed the case, the reported SOS and EOS data could be considered more valid. However, there is also a possibility that this was not the case.

The survey was limited to a sample size of 14 scheme managers and 44 farmers. Given the larger farmer population, this sample may not accurately represent the overall situation. Despite this limitation, the consistency observed between the responses from the scheme managers and the farmers suggests that the established Start of Season (SOS) and End of Season (EOS) could be valid.

Although farmers generally reported a two-season year, significant gaps between seasons may exist (refer to Appendix 8.5). There is a potential shift, with some farmers possibly cultivating more than two seasons

annually, resulting in five seasons over a two-year period. This is particularly evident in the time-series outcome of the FCOVER, as discussed in *Section 4.2.2.2*. Some scheme managers have noted that this is currently experimental and not fully implemented.

This indicates that the scheme has the potential to accommodate 5 cropping seasons within 2 years, provided that conditions such as water availability and water-use efficiency are met. However, it is important to note that the scheme officially operates under a double-season framework, consisting of the major and minor seasons.

The SOS and EOS based on the FCOVER used in the data analysis could have inherent limitations. Responses cited from the field survey suggested different SOS and EOS for individual farmers/fields. However, the results may not be far-fetched.

There are different factors that contribute to the different cropping calendar of farmers. Contributing factors were dependent largely on access to market and the rice seed variety. While some farmers utilize certified seeds provided by the scheme, others opt for uncertified seeds due to the higher costs associated with certified ones. Also, water challenges before the rehabilitation contributed to farmers' decision on when to start and end the season.

5.2. Spatio-Temporal Rainfall Trends and their Implications on KIS

Satellite-derived rainfall is considered complementary to spatio-temporal rainfall data analysis, especially in areas where there are limited rain gauges (Gebremedhin et al., 2021). This study utilized CHIRPS time-series data developed in GEE to understand the trends of climatic events at the KIS. The period for the analysis spanned from 1990 to 2024. As illustrated in *section 4.2.1*, it is evident that there are spatio-temporal changes in the rainfall regime in the KIS. Notably, the scheme has experienced erratic rainfalls in recent years.

A breakdown of the seasonal distribution before and after the rehabilitation indicates visible changing trends in both the major and minor seasons. *Figure 36* shows a comparison of the CHIRPS seasonal rainfall distributions to the effective rainfall as indicated by CROPWAT, *table 3 or appendix 8.7*, aside the 2021 and 2023 major seasons, the other major seasons were below the effective rainfall threshold for the season.

Similarly, the minor seasons equally indicated above normal averages except the 2019, 2021, and 2022 seasons which were below the effective rainfall threshold. It is to be noted that the effective rainfall value used were without contributions to nursery/land preparation and were based on the SOS and EOS of the analysis. This trend in rainfall over the seasonal periods indicates how changes in climatic patterns has affected the scheme in recent times.

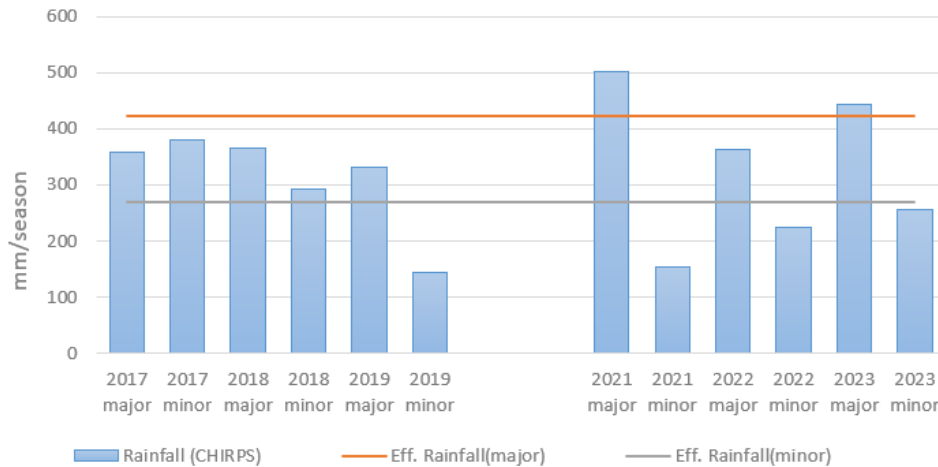


Figure 36: Seasonal Averages compared to Effective Rainfall

According to the Ghana Business News, the year 2023 received above-normal rainfall within the Volta basin affecting some farms within the region (Ghana Business News, 2023a). This reportage is synonymous to the feedback by farmers at KIS, who reported flooding of their fields during the same period.

The visible variability of rainfall patterns equally echoes farmers’ accounts on the effects of the changing weather patterns on the scheme and their crop production. There are claims that the rains show up during harvesting, maintenance periods, and the start of the minor season which is contradictory to events to previous years. This unpredictable weather has left Scheme Managers uncertain about how to advise farmers in their seasonal preparations.

Ashaley et al. (2020) iterated in their research that the fluctuating patterns of precipitation and temperature are likely to have long-term adverse effect on KIS. The panacea is to have/develop an early warning system to trigger anticipatory actions to expedite planning and effective utilization of water resources. This approach would promote sustainability and help increase yield.

Most farmers in KIS rely on the rain with irrigation water as supplementary during the major season. According to FAO, the seasonal water needs of paddy rice is between 450mm and 700mm (FAO, n.d.-a). However, the analysis of WaPOR data indicates a declining trend in the AETI during the major seasons. For instance, in the 2022 major season, the mean AETI was recorded at 290mm, the lowest observed in KIS at post-rehabilitation. This trend underscores the impact of changing rainfall patterns on the major growing seasons.

Secondly, when comparison is made between *figure 34 and 36*, the 2021 and 2023 major seasons received rainfall which were above the effective rainfall for the major season by CROPWAT. However, this doesn’t translate in the mean AETI of these seasons. The mean AETI were rather below the effective rainfall by 100mm. While the scheme attests to improvement in yield as displayed in *table 1* due to water availability after the rehabilitation, the mean AETI within the period does not depict such conclusion. This shows the lack of correlation between the mean AETI for these seasons with the rainfall, effective rainfall and yield by the scheme.

In contrast the minor season post-rehabilitation has shown improved mean AETI levels with dependence on irrigation. Given the erratic nature of the rains lately, it would be prudent for farmers to reconsider their

dependency on the rains for the major season. This will require a concerted effort to educate farmers on the current situation, supported by evidence in changing their mindset.

5.3. Irrigation Performance Assessment and its Implications

To assess the spatio-temporal trends of the KIS rice scheme, 4 irrigation performance indicators were employed using WaPOR datasets. These indicators include uniformity/equity, adequacy, efficiency, and relative water deficit. These indicators were used to assess the major and minor seasons both before and after the partial rehabilitation. These assessments were done from 2017 to 2019 before rehabilitation and from 2021 to 2023 after rehabilitation.

One of the major challenges of the scheme was access to sufficient water for irrigation, hence the rehabilitation. With the WaPOR assessment, a comparative analysis was undertaken to ascertain the difference or the impact the rehabilitation has had on the scheme in terms of adequacy. This was done by calculating the average of adequacy before the rehabilitation, that is, from 2017 to 2019 for both seasons. A similar calculation was done for after rehabilitation. The difference between after rehabilitation and before rehabilitation was computed and mapped. *Figure 37* shows the outcome of the analysis.

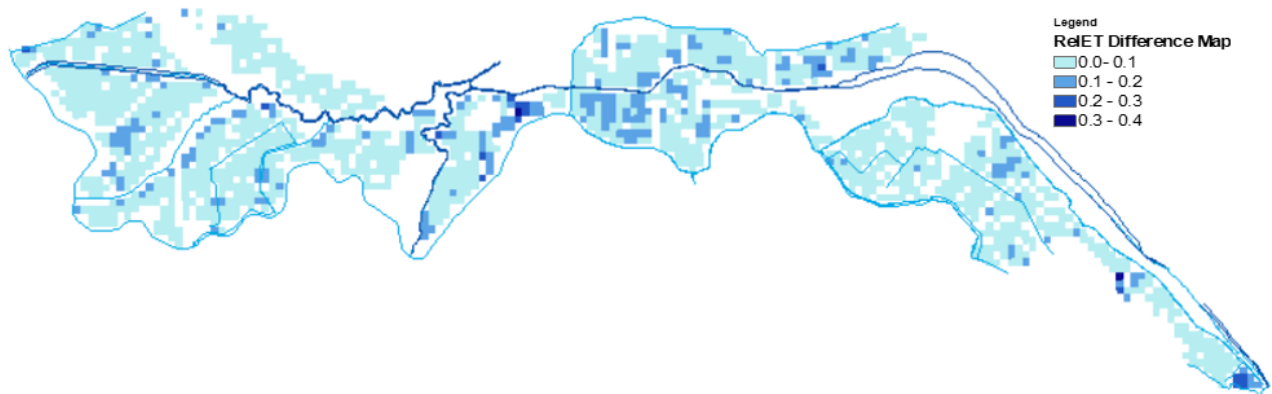


Figure 37: Difference Map between before and after rehabilitation – Relative ET

From the outcome, it can be clearly concluded that the impact of the rehabilitation in terms of the average distribution of water have been up to 10%, though there are some areas like the central part of the scheme and the tail end reflecting a 20% increment on the average. When the above outcome is scrutinized with only the AETI levels after rehabilitation as discussed in *section 5.2*, then it would be difficult to make sense of this. However, due to the lower potential ET experienced after the rehabilitation compared to the potential ET before the rehabilitation, there is an increase in adequacy.

The overall uniformity/equity of the fields are relatively fair, with mean CV ranging from 10% to 23%, although the 2023 minor season seem to reflect a good uniformity of 6% CV. Though a good indicator of uniformity for the 2023 minor season, compared to the other seasons one would conclude this outcome as unreasonable compared to the trends throughout the seasons. This can be referred to in *figure 38*. The scheme could perform better if keen attention is given to land development. The history of the scheme, from the farmer perspective, suggests that land development wasn't a component considered in the planning and design of the scheme. This is very common amongst irrigation schemes in Ghana, where the focus is predominantly on land suitability, headworks, drainage, and conveyance systems, while land development

is often neglected. These observations are based on the personal experience of the author, who has worked in the field of irrigation as a Geodetic Engineer in Ghana.

In the context of KIS, farmers received training from the JICA MASAP project during the rehabilitation period to sub-divide their fields with bunds. This was to ensure even distribution of water resources on their fields. However, not all farmers are able to do this due to its labour-intensive nature and associated cost. Improper levelling of the field leads to non-uniformity. Part of the field then become under-irrigated leading to stunted growth and low yield. The over-irrigated part causes lodging in plants due to excess water. The inability to achieve uniform water distribution may be a contributing factor to the lower yields observed among some farmers. When farmers achieve high yield, payment of ISC would not be a challenge. Scheme management would have enough funds for their maintenance and other projects, but the reverse might be a challenge.

It is incumbent for the scheme management and to a large extent irrigation practitioners to place premium, as they do with the other aspects of irrigation, to prioritise investment in land development. This is crucial to managing and saving water especially in this climate change regime where water resources are becoming scarce. This would contribute to the overall yield performance of farmers. Further investigations are required to match-up field survey/measurements with satellite derived products.

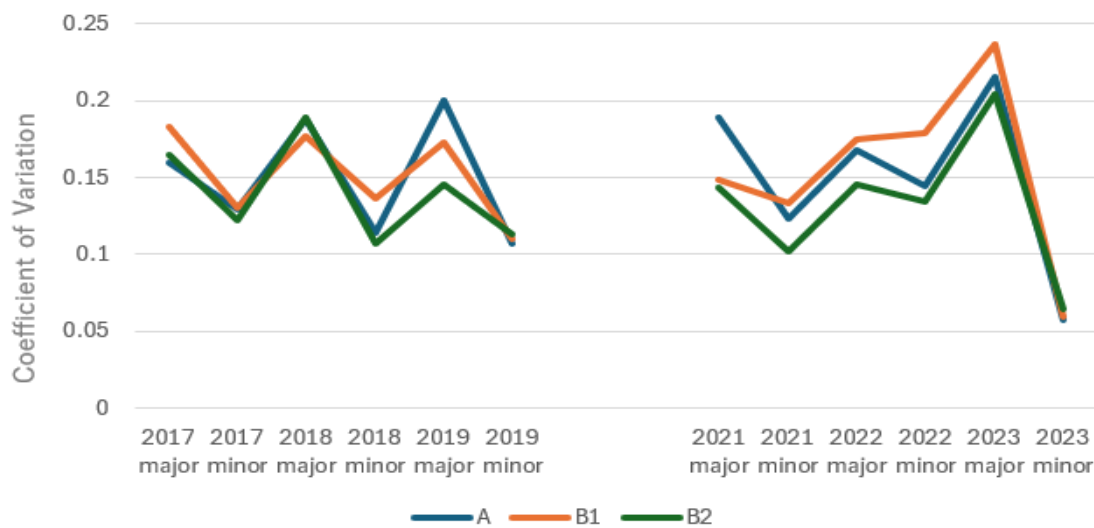


Figure 38: mean CV for Section A, B1 and B2

Despite the low recorded AETI, the beneficial water consumption proved to be better except for the 2023 major season which recorded a mean efficiency of 57% (see figure 39). Better irrigation management practices such as plant and crop management are likely to contribute to better transpiration of the rice, thereby reducing non-beneficial uses/consumption leading to a better crop water use efficiency. The JICA MASAP project could have had a positive impact on the scheme. This is very evident in the minor seasons after the rehabilitation.

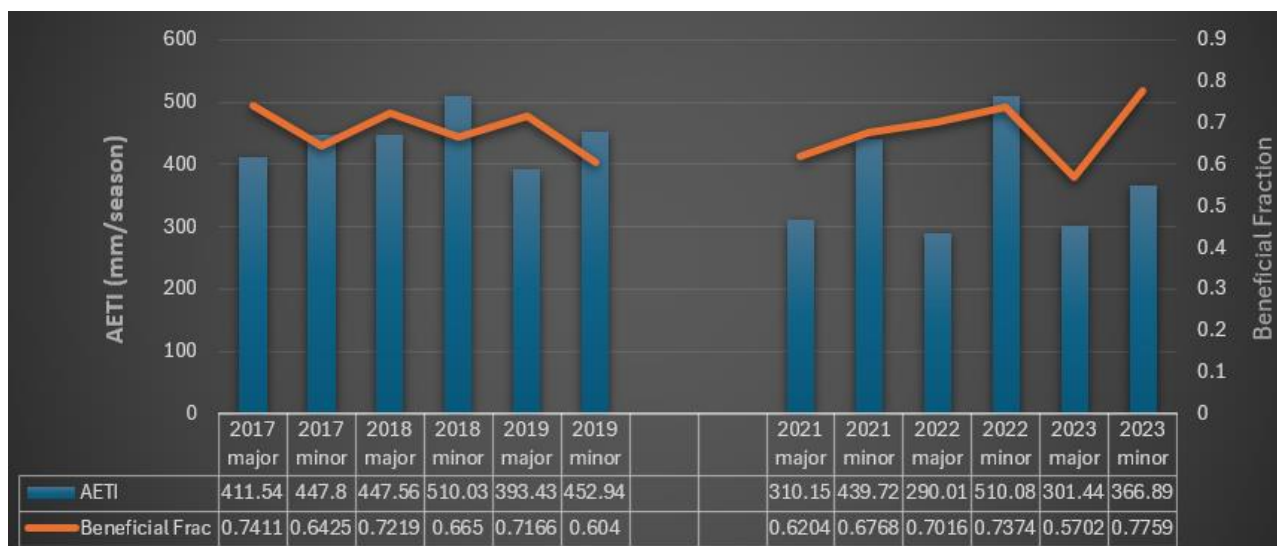


Figure 39: Comparative assessment between mean AETI and mean beneficial fraction

From visual interpretation, *figure 39*, it is noteworthy that certain areas in the 2023 major season exhibited efficiencies as low as 20% or less, despite the overall mean efficiency for the season being 57%. The transpiration rate for most pixels with efficiency at or below 20% were usually between 4mm and 100mm. The reasons for the lower efficiency during this period are unknown. Most satellite imageries of Ghana are usually overwhelmed with cloud coverage. It can be assumed that due to climatic conditions, the product generated had issues with heavy cloud coverage which affected the gap filling process, hence affecting the accuracy of the transpiration data.

5.4. Land and Water Productivity

Biomass has a linear relationship with yield. The harvest index (HI), AOT, and moisture content ratio were parameters used to arrive at the estimated yield, all of which were obtained from WaPOR. It is uncertain whether these corresponds to in-situ measurements as these are fixed. Perhaps, the need for field assessment to determine the corresponding parameters for KIS.

According to FAO, modern cultivars from the tropics can yield 8-10 tonnes/ha in the dry season while the wet season can yield between 6 to 8 tonnes/ha, under continuously flooded conditions (Steduto et al., 2012). Under the pre-rehabilitation period, 50% of farmers from the survey indicated their yield between 3.5 to 4.5 tonnes/ha/season. Post-rehabilitation, farmers are yielding between 5 to 6 tonnes/ha/season. The latter is indicative of 60% of the respondents. The satellite assessment, however, showed different outcomes. The general outputs from the WaPOR assessment indicated one half of those reported by farmers. This comparative assessment for major seasons, both before and after rehabilitation, revealed little to no correlation between the yields from farmers and those estimated by WaPOR, *section 4.3.2*.

According to Chukalla et al. (2022), a larger number of cloud-covered images used for analysis and numerical interpolation significantly compromise the quality of data and increase uncertainty in the indicators. Chukalla et al. (2022) also noted that the generation of NPP and AETI from WaPOR is based on the Land Surface Temperature (LST) from MODIS with a resolution of 1km which could thus affect the spatial variation of the biomass and AETI data. Furthermore, the time of the day in which the image was taken and the angle

in which they were captured could also affect the integrity of the data. These factors likely contribute to the discrepancies observed between the KIS analysis and the field survey outcomes.

The farmers' interest is to utilise their field with every drop of water to achieve maximum yield, thereby promoting food security and reducing poverty. Further investments in field measurements are required to strengthen open-source global satellite-data for agricultural water productivity to limit existing constraints to the barest minimal.

According to FAO, the water productivity for rice ranges from 0.6 to 1.6 kg/m³. With respect to total water input, including irrigation and rainfall, the water productivity is around 0.4 kg/m³ (Steduto et al., 2012). Even though some WPy correspond to the water productivity provided by FAO, it remains uncertain whether these WPy values accurately reflects the water productivity of KIS. This is based on the earlier analysis comparing the WaPOR yield and the farmers' yield.

6.0. Conclusion

In an era of climate change, agricultural Water Use Efficiency (WUE) is crucial to promote food security and reduce poverty. Farm water management and farmers' yield are closely linked to the quantity of water supplied and their uniformity on the field (Clemmens, 2006; Pereira et al., 2012). The role of WUE is to promote beneficial consumption of water supplied to the field, hence reducing non-beneficial use to the barest minimal.

However, the collection of water management information is rarely collected (Bastiaanssen & Bos, 1999). Until a problem pops up, Scheme Managers and farmers are unable to ascertain how efficiently water resources are being utilized. Based on this analogy, the objective of this research has been to evaluate the Land and Water Productivity of the rehabilitated KIS scheme by comparing pre to post rehabilitation and ascertain areas that require improvement. The sub-sections will discuss conclusions on the sub-objectives, limitations and recommendations for the future.

6.1. Stakeholder Perception Pre and Post Rehabilitation

Indications during the pre-rehabilitation period shows that availability of water was never a challenge but rather access. This was due to the dilapidated canals, seepages and evaporation in the laterals, competition of water with aquatic weeds, choked drains, etc. With the partial rehabilitation canals were partially lined except the main canal, the open channel lateral system converted to close conduit pipe, drains reshaped and desilted, etc., promoting increased access to water even to the tail ends of the canal. Farmers' yield has seen increment to 5 or 6 tonnes/ha in the last few years.

Although the scheme has had improvement in recent times, there remain some challenges even with the rehabilitated system. One challenge is the defects in construction, especially with the chambers. They are either higher or lower than the farmer's field. They are also shared with other blocks which sometimes causes conflict. Moreso, the issue of uniformity remains a challenge even though there are improvement in supply. Due to labor and associated cost, not all farmers are able to promote uniformity on their fields. For efficient irrigation, it is important to develop land properly. This might be seen as a seasonal activity of farmers, however, for sustainable irrigation it is important to engineer the land to ensure a smooth and uniform irrigation process.

Farmers and Scheme Management are hopeful that phase II of the rehabilitation will soon take its course to ensure a complete rehabilitation of the scheme. There are high expectations of addressing defects in construction, lining all canals, and automating the system to control flow.

Even though it is in its experimental stage, full implementation of the Alternate Wetting and Drying could contribute to the scheme's performance and promote overall water use efficiency. Based on recent climatic trends and Ashaley et al., (2020) research at KIS, it would be of great benefit for the scheme in terms of water management, that is, the intermittent flooding and draining of fields. Continuous education and experimentation are required to tune farmers' mind towards this possibility.

6.2. Satellite-based Irrigation Performance and Land/Water Productivity

The research provides a comprehensive assessment using satellite Remote Sensing towards Agricultural Water Management. This is the first of such assessment in Ghana using WaPOR datasets, contributing to the scientific world. WaPOR has contributed to the scientific domain by making it possible and easier to conduct Irrigation Performance Assessments (IPAs) especially for areas with difficulty in investing in in-situ data due

to the cost implications (Chukalla et al., 2022). As an open-access platform at a global scale, it would provide irrigation practitioners the opportunity to evaluate their scheme performances for informed decision-making. Other contributions include the use of CropSAR for the determination of the SOS and EOS serving as inputs towards these assessments.

The Start of Season (SOS) and End of Season (EOS) remains a vital part of the irrigation performance assessment. Based on findings from the FCOVER, there is the possibility of exploring a five-cropping season in two years at the KIS under better water and agronomic conditions, although the research was limited to two seasons. However, this aspect needs to be explored further for better decision-making process.

Despite the successes chalked with WaPOR datasets in other parts of the world, the outcome from this research could not be concluded when compared to the field survey and standard practices. In the research of IPA's on a sugarcane estate based in Xinavane, Mozambique, it was noted that there are inaccuracies in the estimation of the evaporation and transpiration of WaPOR datasets. Although the biomass was acceptable within statistics, Chukalla et al. (2022) attributed these inaccuracies to several factors as outlined in the previous discussion section (see *section 5.4*). A similar challenge was faced with the Actual Evapotranspiration and Interception (AETI) and Biomass estimates for KIS. These estimations were either generally low or do not correspond to reportage from the field surveys.

Yield estimates based on biomass depicted half of what was reported from the survey. They showed no correlation with field survey. The Beneficial fraction was good, but Uniformity was generally fair; however, it is unclear whether these reflects what is on ground. This research presents an opportunity for WaPOR to expand its investment portfolio into the tropical regions which are usually cloud-prone for extensive field measurements in validating their datasets. Achieving this could strengthen their presence in the scientific community when opting for remote sensing data for irrigation performance assessments.

6.3. Bright Spots and Productivity Gaps

Identifying bright spots and productivity gaps is generally dependent on the Water Productivity outcomes. Since the yield estimates were not reflective of the field survey. There was uncertainty in the outcomes for the Water Productivity and therefore could not identify bright spots or productivity gaps.

6.4. Limitations

The survey was limited to 14 Scheme Managers and 44 farmers. This represents a minute fraction of the farmer population and therefore may not accurately represent the overall situation. This shows the relevance of involving major stakeholders in diagnosing effective and efficient agricultural water management practices. However, with the consistency between the responses from the Scheme Managers and the farmers, it can be established that the SOS and EOS is valid.

A number of factors such as access to market for produce, rice seed variety, access to credit, land preparation, and many other could have significant impact on the SOS and EOS, hence farmers' different planting and harvesting periods. Having cited this, it is a call to attention that based on the SOS and EOS derived from the FCOVER used in the analysis, the outcome may differ to some extent particularly if they do not meet a certain criterion.

The SOS and EOS were predicted for two seasons, i.e. major and minor season. The analysis through this report was based on this assertion. However, it is likely that some farmers might be cultivating five seasons in two years. This may equally affect the outcomes of this study.

It is evident that cloud-cover remains a significant challenge within KIS and Ghana at large. Therefore, some data resulted in zero output per pixel. This is clearly seen in the efficiency, biomass/yield and water productivity outputs, *sections 4.2.3 and 4.2.4*. These zero-pixels were particularly found in the transpiration and NPP datasets used for the analysis.

Furthermore, the overall output appears to deviate from standard criteria like that of the FAO and field survey and therefore may not present a clear picture of the situation. For instance, according to FAO, the crop water needs for rice ranges from 450mm to 700mm. However, the outcome indicated a range of 150mm to 690mm, with the major season after the rehabilitation recording the very low AETI values. Similarly, yield outputs from WaPOR did not correlate with field observations. Furthermore, the harvest index (HI), AOT, and moisture content ratio were fixed parameters used for the estimation of yield. These may not reflect in-situ field measurements.

The spatial resolution might contribute to the low outcomes of the IPA's and the Water Productivity estimates. The assessment utilised WaPOR L2 datasets of 100m resolution for about 1ha individual field plot of KIS. According to Blatchford et al. (2020), WaPOR L2 is not ideal for comparative assessment of inter-field plots as compared to WaPOR L3. However, due to complex parameterization with limited access to data especially for tropical areas, the WaPOR L2 was adopted. Also, WaPOR L3 is only limited to certain areas which does not cover any part of Ghana.

Another limitation with the WaPOR L2 is how the NPP are being produced. The L2 uses generic cropland LUE value of 2.49 in its estimates. Unlike the L3, crops are not identified with L2 (FAO, 2020a). Since the estimation of biomass and yield are more reliant on the data, their outcomes may not reflect true ground conditions. This is very evident in the Water Productivity outcomes of this research.

6.5. Recommendation

Generally, it can be said that the partial rehabilitation has served a great purpose in farmers getting access to water and increasing their yield. Although there are challenges with the outcomes of the satellite-based analysis, there will be the need to enhance the accuracy and reliability of the remote sensing data.

Firstly, investments should be made for further research focusing on correlating in-situ field measurements with satellite data. In particular, areas within the tropics can be invested in. These areas are usually deeply cloud-covered for most optical satellite images. Scientist and future missions would also have to invest in innovative sensors calibrated to measure variability of Land Surface Temperature (LST) especially for tropical areas for better interpretation.

Alternately, Synthetic Aperture Radar (SAR) images could be developed for water accounting and auditing. SAR has a number of advantages over optical sensors. These include the ability to penetrate clouds, vegetation, dry soils and even snow, sensitive to surface roughness and moisture content, and generally an all-weather imagery. This might, however, come at a higher cost which only a selected few could afford. Smallholder farmers and irrigation schemes may not be able to invest in this venture.

With Copernicus expanding its mission to developing Land Surface Temperature (LST) Mission and the Rose-L, key information on measuring LST and evapotranspiration would enhance agricultural water productivity and food security (ESA, n.d.).

Most Satellite Irrigation Performance Assessments are usually on-field applications. Investigations into the performance of the conveyance systems are less researched into. It would be of added advantage if platforms like WaPOR could delve into research into conveyance systems performance. This might create a holistic approach to Water Use Efficiency (WUE) in irrigation. Additionally, economic water productivity is also another aspect of irrigation water accounting that could be delve into.

For the Kpong Irrigation Scheme, full rehabilitation is crucial to expanding the canal lining. This would solve problems with competition with aquatic weeds, crocodile and rodent invasion, seepages, and restoring the overall health of the system. Addressing construction defects must not be an oversight in the new phase. Further, the installation of the automation system will go a long way to bring sanity onto the scheme.

Given the erratic rainfall events, Scheme Managers are not able to executive their duties in providing information concerning the weather patterns. It would be prudent for the development of an early warning system that could ensure efficient uitlisation of water resources. Perhaps, this can be factored into the automation system in the phase II of the rehabilitation. This could better inform farmers and limit their dependence on the rains especially in the major season.

Land development is key to effective management of water resources. Continuous education of farmers could be a solution; however, a more engineered irrigation field would go a long way in managing and sustaining water resources. This is relevant for improving uniformity and efficiency of the scheme. A scheme with improper land development leads to under or over irrigation.

Lastly, the Alternate Wetting and Drying method is an adaptive method which is usually overlooked but could be a great avenue for water conservation and management. This could be achieved with continuous field experiences comparing yield from such trials to the yield from the traditional practices.

7.0. References

- Alcamo, J., Flörke, M., & Märker, M. (2007). Future long-term changes in global water resources driven by socio-economic and climatic changes. *Hydrological Sciences Journal*, 52(2), 247–275. <https://doi.org/10.1623/hysj.52.2.247>
- Amisigo, B. A., McCluskey, A., & Swanson, R. (2015). Modeling impact of climate change on water resources and agriculture demand in the Volta Basin and other basin systems in Ghana. *Sustainability (Switzerland)*, 7(6), 6957–6975. <https://doi.org/10.3390/su7066957>
- Ashaley, J., Anornu, G. K., Awotwi, A., Gyamfi, C., & Anim-Gyampo, M. (2020). Performance evaluation of Africa CORDEX regional climate models: case of Kpong irrigation scheme, Ghana. *Spatial Information Research*, 28(6), 735–753. <https://doi.org/10.1007/s41324-020-00331-z>
- Bastiaanssen, W. G. M., Molden, D. J., & Makin, I. W. (2000). *Remote sensing for irrigated agriculture: examples from research and possible applications*.
- Bekoe, E. O., & Logah, F. Y. (2013). The impact of droughts and climate change on electricity generation in Ghana. *ENVIRONMENTAL SCIENCES*.
- Bhadoriya, U. P. S., Mishra, A., Singh, R., & Chatterjee, C. (2020). Implications of climate change on water storage and filling time of a multipurpose reservoir in India. *Journal of Hydrology*, 590. <https://doi.org/10.1016/j.jhydrol.2020.125542>
- Blatchford, M., M. Mannaerts, C., Zeng, Y., Nouri, H., & Karimi, P. (2020). Influence of Spatial Resolution on Remote Sensing-Based Irrigation Performance Assessment Using WaPOR Data. *Remote Sensing*, 12(18), 2949. <https://doi.org/10.3390/rs12182949>
- Bondeau, A., Kicklighter, D. W., & Kaduk, J. (2008). *Comparing global models of terrestrial net primary productivity (NPP): importance of vegetation structure on seasonal NPP estimates*. <https://doi.org/https://doi.org/10.1046/j.1365-2486.1999.00005.x>
- BRLI. (n.d.-a). *KIS SURVEY v2*.
- BRLI. (n.d.-b). *WATER BALANCE OF THE KIS-EXTRACT FROM BRLI PRELIMINARY DESIGN REPORT (page 25, 38)*.
- Cai, X. L., & Sharma, B. R. (2010). Integrating remote sensing, census and weather data for an assessment of rice yield, water consumption and water productivity in the Indo-Gangetic River basin. *Agricultural Water Management*, 97(2), 309–316. <https://doi.org/10.1016/j.agwat.2009.09.021>
- Chukalla, A. D., Mul, M. L., Van Der Zaag, P., Van Halsema, G., Mubaya, E., Muchanga, E., Den Besten, N., & Karimi, P. (2022). A framework for irrigation performance assessment using WaPOR data: The case of a sugarcane estate in Mozambique. *Hydrology and Earth System Sciences*, 26(10), 2759–2778. <https://doi.org/10.5194/hess-26-2759-2022>
- Clemmens, A. J. (2006). Improving irrigated agriculture performance through an understanding of the water delivery process. *Irrigation and Drainage*, 55(3), 223–234. <https://doi.org/10.1002/ird.236>
- Deng, X. P., Shan, L., Zhang, H., & Turner, N. C. (2006). Improving agricultural water use efficiency in arid and semiarid areas of China. *Agricultural Water Management*, 80(1–3), 23–40. <https://doi.org/10.1016/J.AGWAT.2005.07.021>

- Dhruw, M., & Pandey, V. K. (2023). Estimation of Actual Evapotranspiration (ETa) of Major Crops of a Tributary of Mahanadi Canal Command Using CROPWAT 8.0 Model by Penman: Montith Method. *Current Journal of Applied Science and Technology*, 42(20), 26–32. <https://doi.org/10.9734/cjast/2023/v42i204149>
- Diack, I., Diene, S. M., Louise, L., Aziz, D. A., Benjamin, H., Olivier, R., Philippe, L., Alain, A., Idrissa, S., & Moussa, D. (2024). Combining UAV and Sentinel-2 Imagery for Estimating Millet FCover in a Heterogeneous Agricultural Landscape of Senegal. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 17, 7305–7322. <https://doi.org/10.1109/JSTARS.2024.3373508>
- ESA. (n.d.). *Copernicus Sentinel Expansion missions*. Wwww.esa.int. https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Copernicus_Sentinel_Expansion_missions
- Er-Raki, S., Chehbouni, A., & Duchemin, B. (2010). Combining satellite remote sensing data with the FAO-56 dual approach for water use mapping in irrigated wheat fields of a semi-arid region. *Remote Sensing*, 2(1), 375–387. <https://doi.org/10.3390/rs2010375>
- FAO. (n.d.-a). *CHAPTER 2: CROP WATER NEEDS*. Retrieved June 28, 2024, from <https://www.fao.org/4/s2022e/s2022e02.htm>
- FAO. (n.d.-b). *Reference Evapotranspiration*. Retrieved December 11, 2023, from <https://www.fao.org/3/X0490E/x0490e05.htm>
- FAO. (2020a). WaPOR database methodology. In *WaPOR database methodology*. FAO. <https://doi.org/10.4060/ca9894en>
- FAO. (2020b). WaPOR V2 quality assessment – Technical Report on the Data Quality of the WaPOR FAO Database version 2. In *WaPOR V2 quality assessment – Technical Report on the Data Quality of the WaPOR FAO Database version 2*. FAO. <https://doi.org/10.4060/cb2208en>
- FAO. (2024a). *CLIMWAT*. <https://www.fao.org/land-water/databases-and-software/climwat-for-cropwat/en/>
- FAO. (2024b). *CROPWAT*. <https://www.fao.org/land-water/databases-and-software/cropwat/en/>
- Ganeva, D., Tallec, T., Brut, A., Prikaziuk, E., Tomelleri, E., Koren, G., Verrelst, J., Berger, K., Graf, L. V., Belda, S., Cai, Z., & Silva, C. F. (2023). In-situ start and end of growing season dates of major European crop types from France and Bulgaria at a field level. *Data in Brief*, 51. <https://doi.org/10.1016/j.dib.2023.109623>
- Gebremedhin, M. A., Lubczynski, M. W., Maathuis, B. H. P., & Teka, D. (2021). Novel approach to integrate daily satellite rainfall with in-situ rainfall, Upper Tekeze Basin, Ethiopia. *Atmospheric Research*, 248. <https://doi.org/10.1016/j.atmosres.2020.105135>
- Ghana Business News. (2023a, October 20). *Akosombo Dam spillage: Troubled waters and traumatized victims*. <https://www.ghanabusinessnews.com/2023/10/20/akosombo-dam-spillage-troubled-waters-and-traumatized-victims/#:~:text=About%206%2C000%20people%20have%20so%20far%20had%20their,2023%2C%20following%20rising%20water%20levels%20in%20both%20reservoirs>

- Ghana Business News. (2023b, October 21). *Akosombo, Kpong Dams spillage impact farmers livelihoods, companies*. <https://www.ghanabusinessnews.com/2023/10/21/akosombo-kpong-dams-spillage-impact-farmers-livelihoods-companies/>
- Gobin, A., Sallah, A. H. M., Curnel, Y., Delvoe, C., Weiss, M., Wellens, J., Piccard, I., Planchon, V., Tychon, B., Goffart, J. P., & Defourny, P. (2023). Crop Phenology Modelling Using Proximal and Satellite Sensor Data. *Remote Sensing*, 15(8). <https://doi.org/10.3390/rs15082090>
- Hu, Y., Moiwo, J. P., Yang, Y., Han, S., & Yang, Y. (2010). Agricultural water-saving and sustainable groundwater management in Shijiazhuang Irrigation District, North China Plain. *Journal of Hydrology*, 393(3–4), 219–232. <https://doi.org/10.1016/J.JHYDROL.2010.08.017>
- IHE Delft. (2020). *Standardized protocol for land and water productivity*.
- Jobbágy, J., Dančanin, P., Krištof, K., Maga, J., & Slaný, V. (2021). Evaluation of the quality of irrigation machinery by monitoring changes in the coefficients of uniformity and non-uniformity of irrigation. *Agronomy*, 11(8). <https://doi.org/10.3390/agronomy11081499>
- Kang, S., Su, X., Tong, L., Zhang, J., Zhang, L., & Davies, W. J. (2008). A warning from an ancient oasis: Intensive human activities are leading to potential ecological and social catastrophe. In *International Journal of Sustainable Development and World Ecology* (Vol. 15, Issue 5, pp. 440–447). <https://doi.org/10.3843/SusDev.15.5:5>
- Kang, Y., Khan, S., & Ma, X. (2009). Climate change impacts on crop yield, crop water productivity and food security - A review. In *Progress in Natural Science* (Vol. 19, Issue 12, pp. 1665–1674). Science Press. <https://doi.org/10.1016/j.pnsc.2009.08.001>
- Karimi, P., Bongani, B., Blatchford, M., & de Fraiture, C. (2019). Global satellite-based ET products for the local level irrigation management: An application of irrigation performance assessment in the Sugarbelt of Swaziland. *Remote Sensing*, 11(6). <https://doi.org/10.3390/rs11060705>
- Kumi M, A. A. (2015). Predicting Hydrological Response to Climate Change in the White Volta Catchment, West Africa. *Journal of Earth Science & Climatic Change*, 06(01). <https://doi.org/10.4172/2157-7617.1000249>
- Liu, M., Xu, X., Jiang, Y., Huang, Q., Huo, Z., Liu, L., & Huang, G. (2020). Responses of crop growth and water productivity to climate change and agricultural water-saving in arid region. *Science of the Total Environment*, 703. <https://doi.org/10.1016/j.scitotenv.2019.134621>
- López-Mata, E., Tarjuelo, J. M., de Juan, J. A., Ballesteros, R., & Domínguez, A. (2010). Effect of irrigation uniformity on the profitability of crops. *Agricultural Water Management*, 98(1), 190–198. <https://doi.org/10.1016/j.agwat.2010.08.006>
- Magadza, C. H. D. (2000). climate impact on human settlement. *Environmental Monitoring and Assessment*, 61, 193–205.
- Ministry of Food and Agriculture. (2023). *Ghana Commercial Agriculture Project (GCAP)*. <https://www.mofa.gov.gh/site/projects/ghana-commercial-agriculture-project-gcap>
- Ndehedehe, C. E., Awange, J. L., Kuhn, M., Agutu, N. O., & Fukuda, Y. (2017). Analysis of hydrological variability over the Volta river basin using in-situ data and satellite observations. *Journal of Hydrology: Regional Studies*, 12, 88–110. <https://doi.org/10.1016/j.ejrh.2017.04.005>

- Owusu, K., Waylen, P., & Qiu, Y. (2008). Changing rainfall inputs in the Volta basin: Implications for water sharing in Ghana. *GeoJournal*, 71(4), 201–210. <https://doi.org/10.1007/s10708-008-9156-6>
- Parr, D., Wang, G., & Fu, C. (2016). Understanding evapotranspiration trends and their driving mechanisms over the NLDAS domain based on numerical experiments using CLM4.5. *Journal of Geophysical Research*, 121(13), 7729–7745. <https://doi.org/10.1002/2015JD024398>
- Pereira, L. S., Cordery, I., & Iacovides, I. (2012). Improved indicators of water use performance and productivity for sustainable water conservation and saving. *Agricultural Water Management*, 108, 39–51. <https://doi.org/10.1016/j.agwat.2011.08.022>
- Peysson. (2017). *Ministry of Food and Agriculture CONSULTANCY SERVICE TO UPDATE THE DESIGN AND CONSTRUCTION SUPERVISION OF THE REHABILITATION OF KPONG IRRIGATION SCHEME (KIS)-PHASE A Detailed Design Report (Final) Volume I-Main Report*. www.brli.fr/brli
- PlanetScope. (n.d.). *Basemap Viewer*. Retrieved July 30, 2024, from https://www.planet.com/basemaps/#/mosaic/global_quarterly_2024q2_mosaic/zoom/2.15
- Reinders, F. B. (2022). Irrigation water use efficiency: A water balance approach. *River*, 1(2), 142–148. <https://doi.org/10.1002/rvr2.18>
- Reyes-González, A., Kjaersgaard, J., Trooien, T., Hay, C., & Ahiablame, L. (2018). Estimation of Crop Evapotranspiration Using Satellite Remote Sensing-Based Vegetation Index. *Advances in Meteorology*, 2018. <https://doi.org/10.1155/2018/4525021>
- Safi, A. R., Karimi, P., Mul, M., Chukalla, A., & de Fraiture, C. (2022). Translating open-source remote sensing data to crop water productivity improvement actions. *Agricultural Water Management*, 261. <https://doi.org/10.1016/j.agwat.2021.107373>
- Schnellhuber, H. Joachim., Cramer, W. P., & International Symposium on Stabilisation of Greenhouse Gas Concentrations, A. D. C. C. (2005 : E. (2006). *Avoiding dangerous climate change*.
- Stancalie, G., Marica, A., & Toullos, L. (2010). Using earth observation data and CROPWAT model to estimate the actual crop evapotranspiration. *Physics and Chemistry of the Earth, Parts A/B/C*, 35(1–2), 25–30. <https://doi.org/10.1016/j.pce.2010.03.013>
- Steduto, P., Hsiao, T. C., Fereres, E., & Raes, D. (2012). *Crop yield response to water*.
- TAHMO. (n.d.). *About TAHMO*. Retrieved October 17, 2023, from <https://tahmo.org/?station=TA00248&variable=ws&period=H>
- TERRASCOPE EOPLAZA. (2024). *CropSAR 2D*. <https://portal.terrascope.be/catalogue/app-details/86>
- Tinsley, R. (2009). *ACDI/VOCA Farmer-to-Farmer Program Increasing Rice Productivity for the Kpong Irrigation Project, Akusa-Asutsuare, Ghana*.
- Van Der Tol, C., & Parodi, G. N. (2012). *Guidelines for Remote Sensing of Evapotranspiration*. www.intechopen.com
- VITO. (2021). *Vito*. Vito.be. <https://blog.vito.be/remotesensing/cropsar-for-land-infrastructure-management>
- Vozhehova, R. A., Lavrynenko, Y. O., Kokovikhin, S. V., Lykhovyd, P. V., Biliaieva, I. M., Drobitko, A. V., & Nesterchuk, V. V. (2018). Assessment of the CROPWAT 8.0 software reliability for evapotranspiration

and crop water requirements calculations. *Journal of Water and Land Development*, 39(1), 147–152.
<https://doi.org/10.2478/jwld-2018-0070>

WaPOR, F. (2018). *WaPOR Database methodology: Level 2 data*. www.fao.org/publications

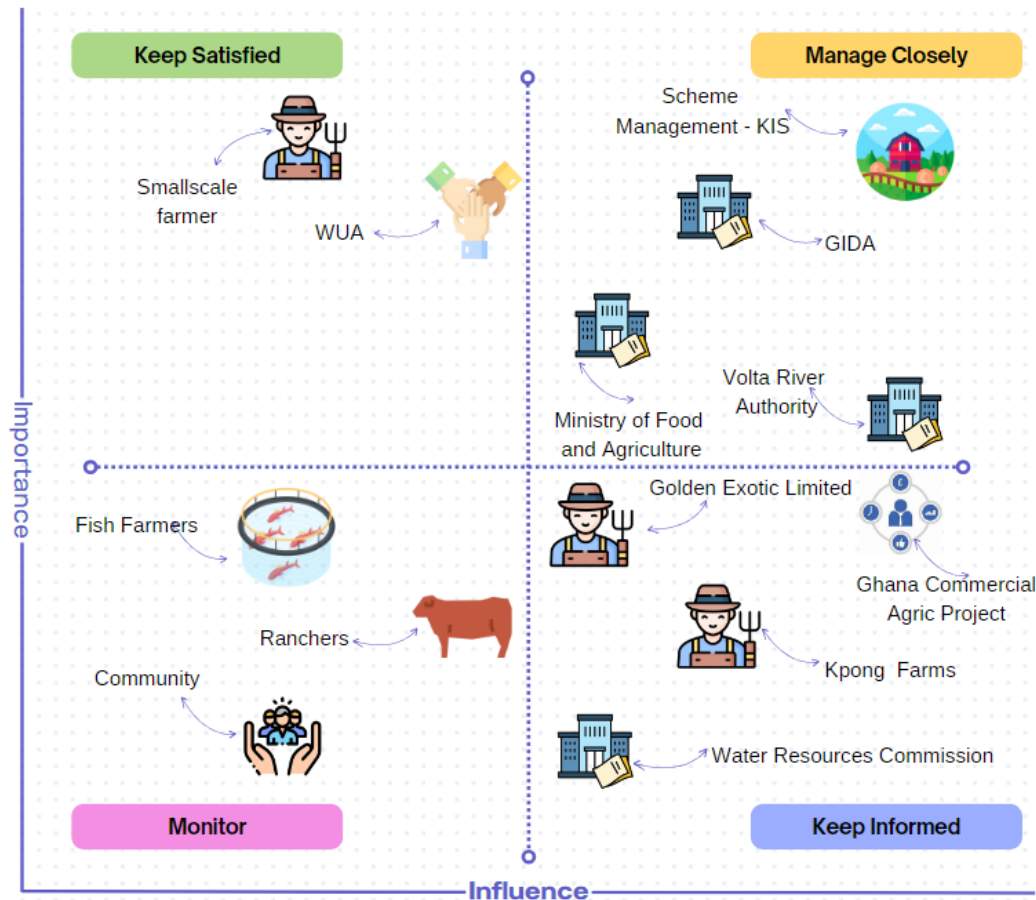
Weerasinghe, I., Bastiaanssen, W., Mul, M., Jia, L., & Van Griensven, A. (2020). Can we trust remote sensing evapotranspiration products over Africa. *Hydrology and Earth System Sciences*, 24(3), 1565–1586.
<https://doi.org/10.5194/hess-24-1565-2020>

World Bank Group. (2016). *High and Dry*.

Zwart, S. J., & Leclert, L. M. C. (2010). A remote sensing-based irrigation performance assessment: A case study of the Office du Niger in Mali. *Irrigation Science*, 28(5), 371–385.
<https://doi.org/10.1007/s00271-009-0199-3>

8.0. Appendix

8.1. Stakeholder Map



8.2. Survey Questionnaires

SURVEY QUESTIONNAIRES FOR FARMERS

SATELLITE-BASED IRRIGATION PERFORMANCE ASSESSMENT – A CASE STUDY OF THE KPONG IRRIGATION SCHEME (KIS)

Consent and Disclaimer:

This research is done by ITC, University of Twente as part of a partial fulfilment of research towards a graduate thesis report. The overall objective of this research is to assess the irrigation performance of the Kpong Irrigation Scheme on Water Productivity and Water-Use Efficiency comparing its performance before and after the rehabilitation programme.

The information provided is strictly for academic purposes and will be treated with absolute confidentiality. You are therefore encouraged to be as candid as possible in responding to these questionnaires. Participation in this research is voluntary and you have every right to decline your participation as such.

SECTION A: ENUMERATOR

Name of Interviewer:

Interviewer's contact:

Email:

Date of Interview:

GPS location of farm:

SECTION B: WATER USE AND CHALLENGES BEFORE REHABILITATION

1. How long have you been farming on the scheme?
2. When are the growing or planting seasons?
3. How frequently do you receive water on your farm?
4. Are there specific challenges you have encountered over the years with the flow of water from the canal or laterals?
5. Did it affect the water supply to this area?
6. How do you monitor the water level supplied on the farm?
7. Does every part of your farm receive supply?
8. Do you have enough supply?
9. If no, what do you consider the main challenge of not getting adequate water?
10. How effective was the drainage network?
11. Who ensures that conveyance and drainage systems are well maintained?
12. Do you know the water requirements of your farm area?
13. How do you measure your yield?
14. How was your yield performance in the past years?
15. What are the main challenges in achieving a better yield? Are they related to question 4?
16. What kind of support did you have in ensuring a good yield?
17. Based on the challenges mentioned, do you agree to the rehabilitation?
18. If no, what do you think would have been the best way to address this challenge?

SECTION C: WATER USE EFFICIENCY AND CHALLENGES AFTER REHABILITATION

19. Are there specific challenges you have encountered with the current canal or laterals?
20. How do you monitor the water level supplied on the farm? Does every part of your farm receive supply? Do you have enough supply?
21. If no, what do you consider the main challenge of not getting adequate water?
22. Do you know the water requirements of your farm area?
23. How effective is the drainage network?
24. Who ensures that conveyance and drainage systems are well maintained?
25. How do you measure your yield?
26. How is your yield performance this time around?
27. Do you think you can achieve a better yield?
28. What kind of support do you have in ensuring a good yield?
29. Was the rehabilitation beneficial to you?
30. If no, what do you think would have been the best way to address this challenge?
31. Any other remarks?

Thank you for your cooperation.

SURVEY QUESTIONNAIRES FOR SCHEME MANAGEMENT

Consent and Disclaimer:

This research is done by ITC, University of Twente as part of a partial fulfilment of research towards a graduate thesis report. The overall objective of this research is to assess the irrigation performance of the

Kpong Irrigation Scheme on Water Productivity and Water-Use Efficiency comparing its performance before and after the rehabilitation programme.

The information provided is strictly for academic purposes and will be treated with absolute confidentiality. You are therefore encouraged to be as candid as possible in responding to these questionnaires. Participation in this research is voluntary and you have every right to decline your participation as such.

SECTION D: WATER USE EFFICIENCY AND CHALLENGES BEFORE REHABILITATION

1. What method do you adopt in measuring yield?
2. What was the average yield per hectare, that is before and after drying?
3. How was your schedule irrigation during the growing stages of crops? Are they consistent with the pre-design schedule including the crop water requirement at each growing stage?
4. How was the maintenance culture on the conveyance and drainage system? How regular were they? Who oversees such activity? Were they performed before, during, or after the irrigation season?
5. What were the major causes of seepage, siltation or waterlogging on these farms?
6. Was the water received enough and uniform throughout their fields?
7. Why were farmers at the tail end (DZ) not receiving water?
8. How did you control flow on individual farms?
9. Were there structures that required attention?

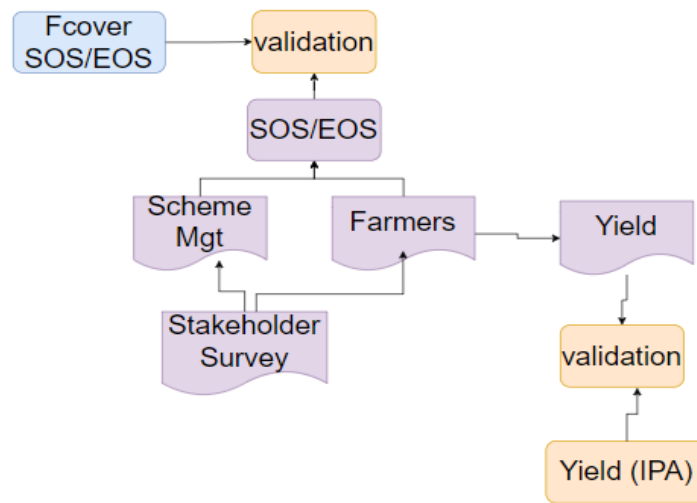
SECTION E: WATER USE EFFICIENCY AND CHALLENGES AFTER REHABILITATION

10. Do you think yields have improved after the rehabilitation?
11. What is the average yield per hectare?
12. What method do you adopt in measuring yield?
13. What were the major causes of seepage, siltation or waterlogging on these farms
14. Why were farmers at the tail end (DZ) not receiving water
15. Is the water received now enough and uniform throughout their fields?
16. How do you control flow on individual farms considering the current supply of water through hydrants of the closed conduit pipes?
17. Is the scheme free from seepage, siltation or waterlogging?
18. Are there structures that may require further attention?
19. What monitoring mechanisms are in place to ensure efficient use of water on the field
20. How do you schedule irrigation during the growing stages of crops? Are they consistent with the pre-design schedule including the crop water requirement at each growing stage?
21. What methods have you adopted in monitoring the climatic conditions as against irrigation scheduling?
22. What is the maintenance culture of conveyance and drainage system? How regular are they? Who oversees such activity? Are they performed before, during, or after the irrigation season?
23. What training efforts have been provided to ensure that farmers are efficiently using water?
24. How can government or management assist farmers to efficiently use water?
25. Any other remarks?

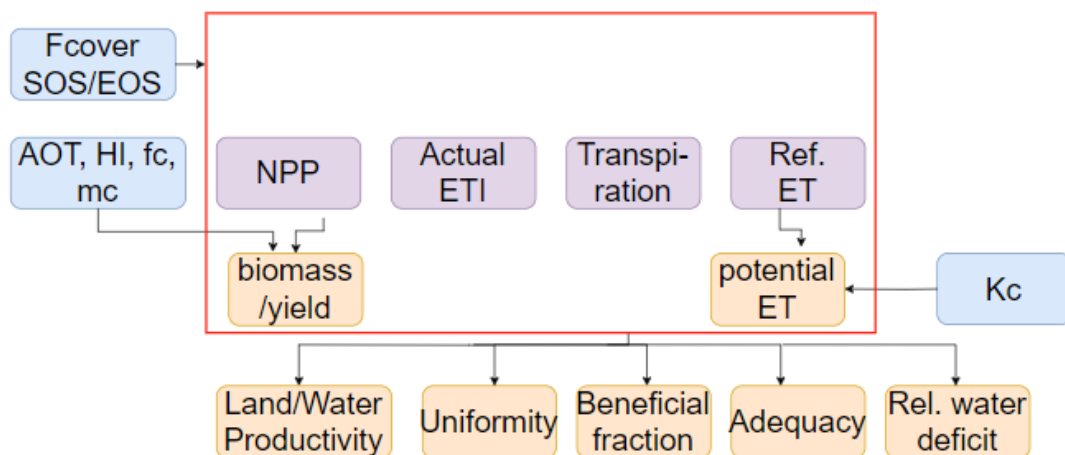
Thank you for your cooperation.

8.3. Breakdown of Workflow

8.3.1. Field Survey



8.3.2. Irrigation Performance Assessment



8.3.3. Ethical Considerations, Risk and Contingencies

The study relates to a societal concern that involves stakeholders and datasets to establish scientific facts for further improvements. Since this study involves people and datasets, it will be expedient to consider all ethical issues that could arise during the study. Hence adherence to the Research Ethics of ITC and or the university will be made paramount in this study. Checks were be made with the committee in charge in order not to breach ethical protocols while undertaking this study.

Finding out more about the scheme could reveal a great deal about its current state, which might not be convenient for certain parties or stakeholders. This may impact their position both as farmers and as scheme

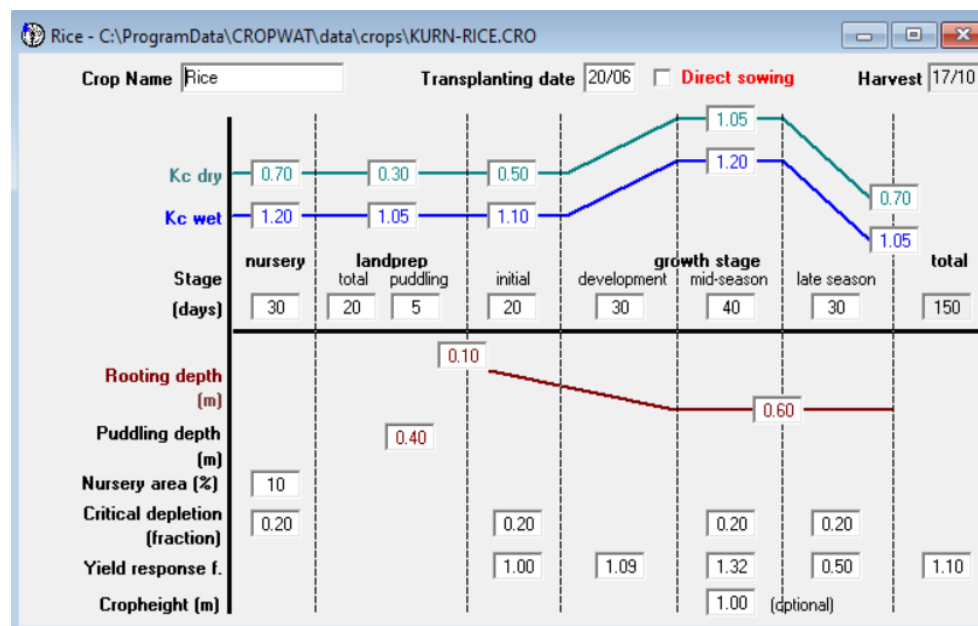
staff as they are impacted by their participation in the scheme. Due to such situations, volunteers were protected in order to maintain their security. Approval was sought from primary sources ensuring that consent was being obtained, anonymity and confidentiality were preserved. Information required from stakeholders were made voluntary for all participants.

8.4. Survey Outcome

ID	SOS_Major	EOS_Major	SOS_Minor	EOS_Minor	Yield_Before	Yield_After
1	April/May	August	September/October	January	4.1	5
2	April	August/September	October	January	5.4	4.3
3	May	October	November	March	4.5	5.5
4	April/May	July/August	October	February	5.4	2.7
5	May	September	September	Janaury/February	4.1	5
6	April	August/September	October	January	4.5	5.4
7	April/May	September	September	January	5.4	5.4
8	May	September	January	April	5	5.5
9	April	September	October	January	5.4	5.9
10	May	September	November	March	4.1	5
11	May	August	November	February	4.5	5
12	April	August	September	December	5.4	5.4
13	June	August	November	February/March	5.2	6.4
14	April	October	December	March	2.7	4.5
15	March/Aprill	September	October	January	3	4.5
16	April/May	August	September/October	January	4.5	5.4
17	May	September	October	January	3.4	4.9
18	May	September	October	January	4.8	5.7
19	May	September	October	December	4.1	4.5
20	May/June	October	November/December	March/April	6.25	6.25
21	March	June/July			4.7	6.7
22	April	August	September/October	January	4.7	4.7
23	April	August	September	January	3.7	6
24	March	July	September	December	3.8	4.5
25	April	July	September	December	4	6
26	March/April	September	October	January	3	5.2
27	March/April	September	October	January	1.6	1.6
28	March/April	September	October	January	3.75	5
29	April	July/August	September	December/January	4.1	5
30	May	August	October	February	6.4	5.4
31	May	July	October	January/February	4.5	5.2
32	April	July	November	March	6.3	4.2
33	May	September	November	March	3.9	4.7

34	April	August/September	December	March	3.1	5.4
35	May/June	October	November	February	2.85	4.29
36	June	October	October	February	6.8	3.6
37	March/April	August/September	October	March	4.5	6.3
38	April	July	October	December	5.6	7.2
39	April	July/August	November	March	5.4	4.1
40	May	September	November	March	3.9	5.1
41	April	July	September	February	2.5	5
42	April/May	September	November	March	4.5	6.3
43	April	August	October	January	4.1	4.5
44	June	September	December	March	Abandoned	2.9

8.5. Crop Coefficient for KIS rice scheme



8.6. CROPWAT Climatic Parameters

Monthly ETo Penman-Monteith - C:\myDrive\itc\spatial_engineering\MSc_Thesis\Data\climat...

Country: Location 15 Station: AKUSE

Altitude: 19 m Latitude: 6.10 °N Longitude: 0.11 °E

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m ² /day	ETo mm/day
January	21.2	34.3	71	112	6.5	17.8	4.18
February	22.6	35.1	68	138	6.9	19.3	4.82
March	23.5	34.6	71	156	6.5	19.5	4.91
April	23.3	34.2	74	104	6.3	19.1	4.50
May	22.8	33.0	76	130	6.3	18.6	4.37
June	22.1	31.0	80	86	4.9	16.1	3.55
July	21.5	29.8	80	130	4.4	15.4	3.47
August	21.2	30.1	77	147	4.7	16.3	3.75
September	21.7	31.5	76	121	5.0	17.1	3.91
October	21.7	32.0	78	86	6.5	18.8	4.02
November	21.7	32.7	78	78	7.5	19.3	4.07
December	21.3	33.3	75	69	7.0	18.1	3.85
Average	22.1	32.6	75	113	6.0	17.9	4.12

8.7. CROPWAT Rainfall Data

Monthly rain - C:\myDrive\itc\spatial_engineering\MSc_Thesis\Data\climate\AKUSE...

Station: AKUSE Eff. rain method: USDA S.C. Method

	Rain mm	Eff rain mm
January	22.0	21.2
February	44.0	40.9
March	101.0	84.7
April	129.0	102.4
May	161.0	119.5
June	195.0	134.2
July	69.0	61.4
August	40.0	37.4
September	100.0	84.0
October	134.0	105.3
November	104.0	86.7
December	39.0	36.6
Total	1138.0	914.2