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SUSTAINABLE WATER MANAGEMENT TECHNOLOGIES IN AGRICULTURE USING RICE PADDIES AS CASE STUDY, NIGERIA

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DECLARATION

I hereby declare that this thesis “Sustainable Water Management Technologies in Agriculture Using Rice Paddies as Case Study, Nigeria” Submitted for the Award of Doctor of Philosophy in Environmental Engineering has been written by me and it is a report of my research work. It has not been presented in any previous application for state diploma or degree. All quotations are indicated and sources of information specifically acknowledged by means of references.

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DEDICATION

This research work is dedicated to my children Kyle and Kayla Akpami and my Husband Architect Robo Akpami for their love, patience, support and encouragement.

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ACRONYMS

AWD	Alternate Wetting and Drying
ET	Evapotranspiration
FAO	Food and Agriculture Organisation
FMWR	Federal Ministry of Water Resources
GDP	Gross Domestic Product
GHG	Green House Gases
HJRBDA	Hadejia River Basin Development Authority
HNW	Hadejia-Nguru Wetlands
HVIP	Hadejia Valley Irrigation Project
IRRI	International Rice Research Institute
KII	Key Informant Interview
KRIP	Kano Rover Irrigation Project
LDC	Least Developed Countries
NDC	Nationally Determined Contributions
OECD	Organisation for Economic Co-operation and Development
PPP	Public Private Partnership
SDG	Sustainable Development Goals
SRI	System of Rice Intensification
SSC	Saturated Soil Culture
TRIMING	Transforming Irrigation Management in Nigeria
UN	United Nations
UNICEF	United Nations Children Education Fund
WHO	World Health Organisations
WP	Water Productivity

ABSTRACT

Irrigation agriculture accounts for 70% of water use worldwide and irrigation farming over the World is currently facing serious challenges due to growing scarcity and competition for water especially in arid and semi-arid regions In Nigeria, most rice farmers in irrigated areas practice flooded irrigation which requires excessive amounts of water, this has resulted in many irrigation schemes to operate at very low efficiencies. Rice paddies are creating major water consumption concerns due to the flooded nature of the paddies especially in the semi-arid and arid regions within the country, with a focus on Kano state. Many rivers have been dammed in Kano for large scale rice irrigation projects such as the Kano River Irrigation Project (KRIP) thus leading to water shortages downstream of the river due to the continuous flooded nature of the rice paddies. This problem will intensify as agriculture in Nigeria is under pressure to produce more food for a rapidly rising population. Considering the various environmental and social impacts of so much water uptake for flooding rice fields: land degradation, downstream water shortages, habitat change, loss of livelihoods, GHG emissions among others, this thesis was designed to research sustainable water management technologies for the efficient use of the available water resources for rice irrigation farming especially in the northern region of the country. This research examines the major irrigation practices and methods employed for commercial rice farming in the arid and semi-arid zones in Nigeria, water use productivity in terms of water uptake per irrigated rice hectare, water wastages and implications on an environmental and social scale. Most importantly, the research culminates on recommended water management technologies suitable for the study area and best application techniques. Data for the research were collected through structured questionnaire administered to the rice irrigation farmers association, the irrigation project management office, water management institutions in the study area, donor funded rice irrigation projects, direct observation during field visit and secondary sources of data.

The result of the research shows that actual crop water requirements are not the guiding principle for the operation of the Kano River Irrigation Project (KRIP), but rather are based on continuous water supply; traditional technique of continuously flooding their fields to grow rice. About 85% of rice irrigation farming in the study area (KRIP) is the flooded system of rice irrigation while pockets of gravity method and Alternate Wetting and Drying make up the remaining 20%. While the former is the main Government supported scheme in the area, the latter are donor supported projects of Food and Agriculture Organisation (FAO) and OXFAM Climate Adaptation Program (C-CLAP) aimed at sustainable production. The water resources and irrigation management institutions, irrigation projects and farmers in the area are in support of switching to sustainable water management technologies for rice irrigation. This will allow for expansion of more irrigable areas without water over-exploitation, free up water for the other socio-economic and domestic sectors while improving the soil-crop-climate-socioeconomic status of the area. Currently there are scarcely any Government policies which support sustainable water management technologies in rice irrigation. A few policies were noted under the SDG 9 (Industry, innovation and

infrastructure) and SDG 13 (climate action), however these policies only reside within the Federal Ministries of Environment and are not domesticated to the state level nor synergised across relevant institutions in the water resources management sector or agricultural sector.

Using only the proper amount of water to the crop and reducing water losses will improve irrigation efficiency, increase yields and hence water productivity. The implication of flooded rice irrigation is low water productivity in the area, deprivation of water resources to other sectors such as domestic use, fishing and industrial usage which often leads to conflicts between sectors. Water productivity may vary when evaluated at different spatial scales due to influencing factors such as crop choice, climatic patterns, irrigation technology and field-water management, land, and inputs including labor, fertilizer and machinery. At plot and farm scales for example, options may involve combined research on plant physiology, agronomy and agricultural engineering that focuses on making transpiration more efficient or productive, reducing non-productive evaporation and making water application more precise and efficient. At irrigation system and basin scales, options may include reducing non-beneficial depletion, reallocating water among uses and tapping uncommitted outflows resulting in more output per unit of water consumed. Water resources management in rice irrigation is critical for food and water security of the arid and semi-arid regions in Nigeria, which can only be made possible through i) establishment of policies to support sustainable water management technologies in agriculture and 2) implementation of water saving techniques in rice irrigation farming. The alternate wetting and drying has been identified as the most suitable based on this research. The technology promotes efficient water use and generates 15% to 35% water savings compared with the continuously flooded practice of the farmers. In this method, the rice will be flooded to a depth of only 3-5cm instead of the more usual 10cm, moreover, flooding does not have to be continuous, and the soil surface can be left to dry out before re-flooding. A simple 'level gauge' – PaniPipea is required to enable farmers to avoid over-drying the soil and determine when re-flooding. Application of AWD will be successful as the farmers are in associations which will make technology transfer more effective due to availability of technical support from the relevant institutions, and monitoring instrumentation can be maintained at the association level. AWD is not as technical as Saturated Soil Culture (SSC) or System of Rice Intensification (SRI), also associated costs are not as huge as other techniques like sprinkler irrigation and SRI. Government agencies need to collaborate to formulate policies that will support the use of sustainable water management technologies in agriculture fund coordinated assessments of the practical potential to implement different water management techniques at the irrigation district level.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Nigeria, a country located in West Africa along the Gulf of Guinea on the Atlantic Ocean, is a federal constitutional republic comprised of 36 states and its Federal Capital Territory, Abuja. Nigeria is the most populous country in Africa, and the seventh-most populous country in the world, with an estimated population of 206 million (NBS,2021). Its economy is the largest in Africa, the 26th-largest in the world by nominal GDP, and 25th-largest by PPP.

One key sector of the Nigerian economy is agriculture, which employs 34.7% of the workforce and contributes for about 21.9% of GDP[1]. As of 2010, about 30% of Nigerians were employed in agriculture. The sector is made up of four sub-sectors: Crop Production, Livestock, Forestry and Fishing, with the largest driver of the sector being Crop Production as it accounts for 91.6% of the sector. The sector is being transformed by commercialization at the small, medium and large-scale enterprise levels in the form of irrigated agriculture, which has pushed up the demand for water leading to water shortages that have continued to place great pressure on local water resources. Due to increasing demand, scarcity of water is becoming more and more apparent particularly in water short countries. It is estimated that more than 30 countries of the world are already facing severe water shortages, while this number is likely to increase to more than 50 by the year 2025. The United Nations has estimated that by the year 2050, about 4 billion people will be seriously affected by shortage of water (Garg et al., 2007).

Irrigated agriculture offers great potential for economic growth and poverty reduction. In the right circumstances, irrigation can reduce the risks associated with the unpredictable nature of rainfed agriculture in dry regions like the arid and semi-arid regions and increase cropping intensities in humid and tropical zones by ‘extending’ the wet season and introducing effective means of water control. Irrigated agriculture remains the largest user of water globally, a trend encouraged by the fact that farmers in most countries do not pay for the full cost of the water they use. Irrigation agriculture accounts for 70% of water use worldwide and over 40% in many Organisation for Economic Co-operation and Development (OECD)

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[1] https://www.nordeatrade.com/en/explore-new-market/nigeria/economical-context

countries. In many irrigation schemes in semiarid areas, particularly among Least Developed Countries (LDCs) like Nigeria, less than 20 percent of the water delivered is actually transpired by crops (Wallace, 2000). This ‘inefficiency’ coupled with other environmental and social issues, is an overriding concern among those in irrigation and water management fields. For instance, irrigation may lead to waterlogging, salinization, water wastages through runoff and water scarcity for other uses.

On the issue of salinization, about 2 to 3 million ha are going out of production worldwide each year due to salinity problems. On irrigated land, salinization is the major cause of land being lost to production and is one of the most prolific adverse environmental impacts associated with irrigation. Quantitative measurements have generally been limited to the amount of land affected or abandoned. Estimates of the area affected have ranged from 10 to 48% of worldwide total irrigated area. Especially the arid and semi-arid areas have extensive salinity problems. (Fao.org).

On the issue of water usage, traditional irrigation farming is leading to growing water scarcity and competition for water especially in arid and semiarid regions in Nigeria. Irrigation depends largely on small or large dams depending on the scale of farming activities. In recent times these areas experience insufficient water discharged by streams that feed the dams, heavy silting of the dams and insufficient rainfall experienced annually.

Rice feeds billions of people and will continue to play an increasingly relevant role in sustaining food security and livelihoods in various regions of the world. This is especially true in sub-Saharan Africa where rice demand and production is expected to grow most – a 130% increase relative to 2010 (WBCSD, 2021). Rice production is often claimed to be the largest consumer of water in an agricultural context and continuously flooded rice is the largest irrigated crop in the world (Bouman, et al., 2007) with a higher water demand in relation to other cereal crops and the major staple food crop with 54kg consumed per person annually (FAO, 2018).

The Nigerian rice sector has seen some remarkable developments over the last quarter-century. Both rice production and consumption in Nigeria have vastly increased during the aforementioned period. Nigeria is the largest producer of rice in West Africa producing over

46% of the regions total production [2]. In the last 30 years production has increased 6 folds with Nigeria producing 3.28 million tons of paddy rice by 1999 (FAOSTAT 2004).

Flooding irrigation agriculture which is the most practiced for commercial rice farming especially in the semi-arid and arid zones in Nigeria, also presents a number of negative environmental and social impacts. Ranging from creation of so many dams which changes the river course leading to flooding in areas previously experiencing none whilst depriving water to previous water channels. The reduction of water downstream of dammed rivers and change in water patterns is also affecting socio-economic activities in downstream areas including fishing and farming which is the major livelihoods activities of such people. Needless to say the loss of livelihoods is exacerbating conflicts, herders/farmers migration, poverty, malnourishment and insecurity.

Another critical area with flooded irrigated rice fields is the amount of methane gas emitted by rice paddies which is contributing to green house gas emissions and thus climate change. Rice production is estimated to be responsible for 12% of total methane global emissions due to the method of flooded irrigation been employed.

More so, irrigation farming the world over is currently facing serious challenges due to growing scarcity and competition for water by other sectors including domestic, industry, hydropower, especially in arid and semi arid regions, such is the case in Nigeria as well. This problem is compounded by reduction in average annual rainfall, insufficient water discharged by streams that feed irrigation dams and heavy silting of the dams. Best use of irrigation is becoming increasingly important due to climate trends, climate instability, the increasing demand for water, and the decreasing water supply.

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[2] https://www.tridge.com/insights/nigeria-is-now-the-largest-producer-of-rice-in-africa

1.2 Statement of Research Problem

In Nigeria, rice farmers in irrigated areas normally use excessive amounts of water (DownToEarth, 1992., Materu, et al., 2018), this has resulted in many irrigation schemes to operate at very low efficiencies. Rice paddies are creating major water consumption concerns due to the flooded nature of the paddies especially in the semi arid and arid regions within the country, with a focus on Kano state. Many rivers have been dammed in Kano for large scale rice irrigation projects such as the Kano River Irrigation Project (KRIP) thus leading to water shortages downstream of the river due to the continuous flooded nature of the rice paddies. The performance of agricultural use of irrigation water in sub-Sahara Africa, as compared to Asia, has been characterized by inefficiency and poor management (Nwa, 2003). Currently, large quantities of water are lost each year as a result of poor application of irrigation technologies and techniques (Malabo Montpellier Panel, 2018). This problem will intensify as agriculture in Nigeria is under pressure to produce more food for a rapidly rising population.

Also considering the various environmental and social impacts of so much water uptake for flooding rice fields: land degradation, downstream water shortages, habitat change, loss of livelihoods, GHG emissions among others, there is need to deploy sustainable water management technologies for the efficient use and management of the available water resources for rice irrigation farming especially in the northern region of the country. Using only the proper amount of water to the crop and reducing water losses will improve irrigation efficiency, increase yields and hence water productivity.

1.3 Research questions

i. What are the major irrigation practices and methods employed for commercial rice farming in the arid and semi-arid zones in Nigeria?
ii. How much water uptake is utilised per hectare of irrigated rice fields in the arid and semi-arid areas and what is the percentage of excess water wastage and its implications?
iii. How much water will be conserved for these zones with the deployment of selected sustainable water management technologies suiting to soil-crop-climate-socioeconomic status of the area, and what are the other co-benefits of such technologies? : how to irrigate? when to irrigate? how much to irrigate?

1.4 Aim and objectives of the Research

The aim of the research is to determine irrigation management techniques in rice farming that increase water productivity (WP), allowing a reduction in water input and wastage without negatively affecting grain yield, and support the deployment of sustainable water management technologies for commercial rice irrigation farming in the arid and semi-arid zones in Nigeria. This will be achieved through the following objectives set to:

i. Identify the major irrigation practices and methods employed for commercial rice farming in the arid and semi-arid zones in Nigeria
ii. Examine the amount of water uptake utilised per hectare of irrigated rice fields in arid and semi-arid areas, the percentage of excess water wastage and its implications?
iii. Assess assesses the water-saving potential of alternative management practices at farm levels with the deployment of selected sustainable water management technologies and the other co-benefits of such technologies including best applicable techniques on how to irrigate and when to irrigate.

1.5 Significance of the study

In Nigeria, the agricultural sector is getting a lot of focus and huge investments in commercialization with dependence on irrigation due to the water scarcity issues especially in the arid zones, whilst irrigated agriculture remains the largest user of water globally. While the water resources are unevenly distributed in the country, there is need for the efficient use and management of the available water resources and increasing the productive use especially in the northern region of the country where there is increasing incidence of drought and competing need for water among the different sectors of the economy. The research will provide an understanding on the need to move towards sustainable agricultural production practices even as the country and states are embarking on huge commercial rice production. The study will also create better awareness on the availability, process and use of sustainable water management technologies which will ensure more efficient use of water as a resource, reduce water conflicts and water scarcity while optimizing rice production. The research will also be a platform for enactment of Government policies for a more sustainable agricultural sector.

1.6 Scope and limitation of the study

The scope of the research is on rice irrigation practices in the arid and semi-arid zones in Nigeria using Kano state as a major case study in a bid to understand current practices in rice irrigation farming and proffer sustainable solutions. This research will not be extended to southern part of the country as they experience more annual rainfall and have less issues with water scarcity due to their proximity to coastal areas.

1.7 Thesis Outline

A summary of the structure of this research is as follows:

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Abstract

Chapter 1, provides the background of the study, aim and objectives, and scope of the research

Chapter 2, provides literature review on the subject matter on a global, regional and national scale

Chapter 3, describes the methodology, tools and models used in the research

Chapter 4, results and discussions

Chapter 5, conclusion and recommendations

CHAPTER TWO

LITERATURE REVIEW

2.1 Water as a Resource

Water plays a vital role in the economy of the world as approximately 97% of water on earth is salt water and only 3% fresh water with about 70% of the freshwater used by humans goes to agricultural purposes (Baroni *et al.*, 2007) as all living things require food to grow and reproduce and also fishing in both salt and freshwater bodies is a main source of food for many parts of the world. Water also finds a wide range of uses in industries, homes entertainments etc. The major uses of water include for agriculture, industry, domestic usage and other environmental purposes. These sectors compete interchangeably for water resources.

2.1.1 Industrial Usage of Water

About 22% of worldwide water is used in industry (WBCSD, n.d) Major industrial users include hydroelectric dams, thermoelectric power plants, which use water for cooling, ore and oil refineries, which use water in chemical processes, and manufacturing plants, which use water as a solvent. Water withdrawal can be very high for certain industries, but consumption is generally much lower than that of agriculture.

2.1.2 Agricultural Usage of Water

It is estimated that 70% of worldwide water is used for irrigation, with 15–35% of irrigation withdrawals being unsustainable (WBCSD, n.d). It takes around 2,000 – 3,000 litres of water to produce enough food to satisfy one person's daily dietary need (UN water, 2007). This is a considerable amount, when compared to that required for drinking, which is between two and five litres. To produce food for the now over 7 billion people who inhabit the planet today requires the water that would fill a canal ten metres deep, 100 metres wide and 2100 kilometres long (Molden, 2007). In some areas of the world, irrigation is necessary to grow any crop at all, in other areas it permits more profitable crops to be grown or enhances crop yield. Various irrigation methods involve different trade-offs between crop yield, water consumption and capital cost of equipment and structures.

2.1.3 Domestic Usage

It is estimated that 8% of worldwide water use is for domestic purposes. These include drinking water, bathing, cooking, toilet flushing, cleaning, laundry and gardening. Basic domestic water requirements have been estimated by Peter Gleick at around 50 liters per person per day, excluding water for gardens. Eight hundred and forty four (844) million people still lacked even a basic drinking water service in 2017 (WHO and UNICEF, 2017) of those, 159 million people worldwide drink water directly from surface water sources, such as lakes and streams (Gleeson *et al.,* 2012)

2.1.3 Environmental Uses

Explicit environment water use include water stored in impoundments and released for environmental purposes (held environmental water), but more often is water retained in waterways through regulatory limits of abstraction (National Water Commission, 2010). Environmental water usage includes watering of natural or artificial wetlands, artificial lakes intended to create wildlife habitat, fish ladders, and water releases from reservoirs timed to help fish spawn, or to restore more natural flow regimes.

2.2 Water Resources Management

Due to the enormous uses of water, its management is imperative as water resources are continuously under threat from activities leading to water scarcity, water pollution, water conflict and climate change (Gleeson *et al.,* 2012). The water sector is laden with several challenges including water scarcity (water stress or water crisis) due to unequal distribution (exacerbated by climate change) resulting in some very wet and some very dry geographic location, as listed in 2019 by the World Economic Forum as one of the largest global risks in terms of potential impact over the next decade (Hoekstra and Mekonnen, 2016). Another crisis is water pollution especially in developing countries, from discharge of raw sewage into natural waters. In addition to sewage, nonpoint source pollution such as agricultural runoff is a significant source of pollution in some parts of the world, along with urban storm water runoff and chemical wastes dumped by industries and governments. The effect of climate change is having significant impacts on water resources around the world because of the close connections between the climate and hydrological cycle. However, agriculture, particularly irrigation agriculture accounts for one of the largest competition for fresh water.

2.3 Irrigation agriculture in Nigeria

Irrigation allows farmers to produce all year thereby resulting in higher yield, productivity and ultimately improving farmers' income. In Nigeria, irrigation schemes and projects can be categorized into three; the public irrigation schemes, which are owned and executed by the government, irrigation schemes owned by the farmers and the flood plains commonly referred to as fadama (Adelodun and Choi, 2018). As the need for irrigated crop cultivation grew, study to examine water resources and irrigation potentials were carried out in 1972. This study led to the institutionalizing three model public irrigation schemes namely; Bakolori scheme, Chad Basin scheme and the Kano river irrigation scheme (NINCID, 2015) followed by the addition of eleven more River Basin Development Authorities (RBDAs) which were added across the country after the success of the pilot schemes.

About 70% of the irrigated lands in Nigeria is in the Northern part of the country in the arid and semi-arid zones where they have low average rainfall. In Nigeria, according to NINCID (2009), recent survey suggests that 39% of the land mass is potentially suitable for agriculture and out of this between 4.0 and 4.5 million ha (approximately 4.5 to 5.0%of the land) are judged suitable for irrigated agriculture but only 1.1 million ha can be supported fully by the water available, the remaining 3.4 million ha being Fadama (flooded plains).

2.3.1 Effects of Irrigation Agriculture

2.3.1.1 On water consumption and usage pattern

In the Northern part of the country, seasonal river regime necessitates storage of water for dry season irrigation planting and the dam built for the purpose of storage however it significantly impacts the discharge pattern of water downstream and ultimately on the fishing and agricultural activities around the river downstream of the dam (Adam, 1991). For instance, the construction of the Tiga and Challawa gorge dam in the 1970s gave rise to severe degradation of river Komadugu Yobe Basin by almost 35% leading to decline in its flow, abstraction of water for large scale irrigation (Butterworth *et al.,* 2010).

2.3.1.2 On the environment

Large irrigation projects which may impound or divert river water have the potential to cause major environmental disturbances, resulting from changes in the hydrology of the river basins. The diversion of the water through irrigation may further reduce the water supply for downstream users, including municipalities, industries and agriculture. In Kano state, the high turbidity of the Challawa river, coupled with the elevated position of the intake structures of the Kano City Water Supply (KCWS), have caused silt to build up at the mouths of the intake structures for supplying domestic water to the large city of Kano. This means that more water has to be released from the dams in order to fill up the sumps and lagoons at these intakes. This obscures the traditional seasonal flow patterns of the Hadejia River, making it perennial and hence further aggravating the problem of siltation, weed (typha) infestation and blockages.

2.4 Water uptake and Usage in Irrigation farming: Rice Irrigation

2.4.1 Rice Production and Consumption

Rice is one of the most popular plants that grow in the world. Rice is the primary staple food for more than half of the world's population – over 3.5 billion individuals depend on rice for more than 20% of their daily calories – with Asia, South America and Sub-Saharan Africa the largest consuming regions. For about half of the world's population, rice accounts for about 80 percent of their food consumption. Rice provides up to 50% of the dietary caloric supply for hundreds of millions in Asia and is, therefore, critical for food security (KPMG, 2019).

According to the (USDA, 2020)[3] approximately 500 million tons of milled rice was produced globally during the 2019/2020 marketing year. Production and consumption are concentrated in Asia; China and South-East Asia in particular. China is the largest producer, accounting for 30% of the production, followed by India (24%), Bangladesh (7%), Indonesia (7%), Vietnam (5%) and Thailand (4%) (See Fig.1). In terms of consumption, the ranking is similar: China is the largest consumer (29% of the global consumption), followed by India (21%), Bangladesh (7%), Indonesia (7%), Vietnam (4%) and the Philippines (3%).

In Sub-Saharan Africa, rice is the fastest growing staple food, with annual per capita consumption of 27kg/year (KPMG, 2019). About 700 million tonnes of rice paddy was produced in 2018 (485 million tonnes of milled rice), with 90% (640 million) produced in

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[3] Source: https://www.cotecna.com/en/media/articles/world-rice-trade-in-brief#:~:text=According%20to%20the%20USDA3,South%2DEast%20Asia%20in%20particular.

Asian countries. Sub-Saharan Africa produced about 3.5% (19 million tonnes); Northern Africa, about 0.8% (6.2 million tonnes); and Latin and Central America, along with the Caribbean, about 3.7% (27 million tonnes) (KPMG, 2019).

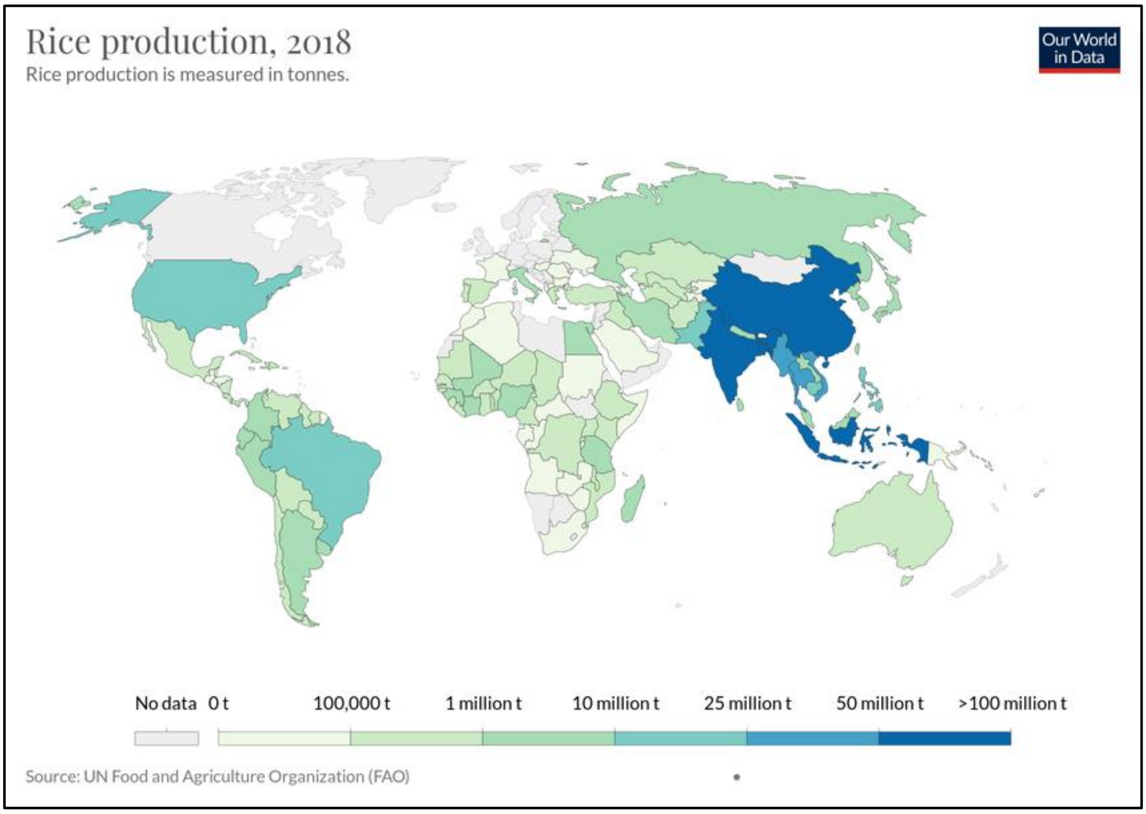


Figure 1: Global Rice production 2018 (Source: Our World in Data, 2018)

2.4.2 Irrigating Rice Fields

2.4.2.1 Global Statistics in Rice Production Water Consumption Pattern

In rice production systems, a large quantity of water is lost through evapotranspiration, surface runoff, seepage, and deep percolation (Materu, et al., 2018). Rice consumes more water than any other irrigated crop and it requires up to 2–3 times more water compared to other crops (Yakubu, et al., 2019). Rice is the major user of freshwater resources in the world (Kumar & Katagami, 2016). Field water use for rice typically ranges from 1000–2000 mm (Bouman & Tuong, 2001), which is 2–3 times of other cereal crops. Rice production accounts for the withdrawal of 24%–30% of the total fresh water and the consumption of 34%–43% of the total irrigation water of the world (Kumar & Katagami, 2016., Bouman, et al., 2007). Majority of the farmers in both irrigated and rainfed rice ecosystems grow rice in puddled transplanted conditions regardless of the topography and availability of irrigation water and this conventional rice production ecosystem requires an average of 2,500 liters of water to produce 1 kilogram of rough rice (Bouman et al. 2007).

According to the Inter-American Institute for Cooperation on Agriculture (IICA, 2015), in Colombia irrigated rice has the highest water requirement per hectare. The crop registers an average evapotranspiration throughout its cycle of 670 to 700 mm (6700-7000 m3/ha). It is irrigated by permanent flooding and, although the plant is adapted to growing under anaerobic conditions, it could be produced without the need to keep the crop flooded throughout the development of the cycle. If, at 7000 m3/ha of the evapotranspiration of rice, a coefficient of 65% to 70% irrigation efficiency is applied (achievable values with appropriate management and control) some 10,000 to 10,800 m3 of water per hectare would be needed on the farm. To this must be added the inefficiency of the water pipelines from the dam to the farm and of the dam itself. Colombia plants 260,000 hectares of rice, of which approximately 65% is irrigated. Given rice's high-water consumption, the government encourages research and experimentation initiatives to improve the water footprint of rice. At the national level, the green footprint of rice represents 3,213 Mm3 and its blue footprint represents 1,130 Mm3. The blue footprint of rice represents 41% of all crops, given that it is grown in the flooding system, using water from dams (IICA,2015).

Bhuiyan (1992) noted that rice requires between 700 and 1500 mm of water per growing season. The reported amount includes 150-250 mm for preparing the land, 50 mm for growing rice seedlings in the nursery and 500-1200 mm to meet evapotranspiration demand and unavoidable seepage and percolation. For a typical 100-day season of modern high yielding rice, the total water input varies from 700 to 5,300 mm, depending on soil, climate and hydrologic conditions, with 1,000-2,000 mm as a typical value for many lowland areas (Tuong and Bouman, 2003). Worldwide, the demand for rice is increasing with growing population (Tongwaranan, 2018; Chauhan, et al., 2017), while water resources are getting scarce. Increasing grain yields and maintaining grain quality while reducing water use, is a great challenge for the rice sector globally. Hence, the rice-growing practices requiring less water input are needed to be adapted.

Rice is typically grown in bundled fields that are continuously flooded, according to Akinbile *et al.*, 2011, irrigated rice was responsible for about 75% of the world's total rice production. Irrigation increases production significantly since it offers an opportunity for intensity in production of two to three times production in a year. On average, it takes 1,432 liters of water to produce 1 kg of rice in an irrigated lowland production system. Total seasonal water input to rice fields varies from as little as 400 mm in heavy clay soils with shallow groundwater tables to more than 2000 mm in coarse-textured (sandy or loamy) soils with deep groundwater tables. Also, around 1300−1500 mm is a typical amount of water needed for irrigated rice in Asia. Irrigated rice receives an estimated 34−43% of the total world's irrigation water, or about 24−30% of the entire world's developed fresh water resources (IRRI, n.d).

Given the fact that rice is the largest consumer of irrigation water, today there is rapidly expanding interest in management practices and technologies that can save water and increase water productivity in rice-based irrigation systems (Barker & Molle, 2004). Globally, there is a lot of research currently ongoing on efficient water use in irrigation and Sub-Saharan Africa, with scarcer water and lighter soils, could benefit most from the results of this research, as it is precisely where most of the expansion in rice demand and production is expected to happen. The water "saved" if rice were to be grown like wheat could be used for other, more valuable crops or uses.

2.4.2.2 Rice Production Water Consumption Patterns in Nigeria

The major type of irrigation practiced especially in the semi-arid and arid zones in Nigeria is continuous flooding of water. After transplanting, water levels are usually around 3 cm initially, and gradually increased to 5−10 cm (with increasing plant height) and remain there all season until the field is drained 7−10 days before harvest.

According to Akinbile (2010), three distinct stages of water application for proper irrigation scheduling were suggested. At the first stage, irrigation should be normal due to low crop water requirements. During the second stage, irrigation should be increased by 100% due to high water demand and at the third stage; irrigation should revert back to normal because sustained increase in water application will not lead to further increase in yield as grain formation must have been completed. The water use efficiencies decreased in accordance with the amount of water received per treatment and in line with water distribution pattern indicating excellent water management. For instance the study carried out by Akinbile and Sangodoyin (2011), stated that increase in applied irrigation water beyond 3100mm, the grain yield remained static hence continuous supply of water will result in waste. The results from the study highlighted the need to save irrigation water while still maintaining grain yields at reasonably high levels.

Since water is a major resource in rice farming in Nigeria, highly efficient water allocation mechanism which is the accurate and efficient distribution strategies of water is needed to increase productivity and crop yield. When irrigation water is properly allocated and used, it reduces water loss, constraints arising from topography and avoids uncontrolled water/soil withdrawals (Mehrabi and Sepaskhah, 2018).

2.5 Study Area and Water Consumption for Rice Production

2.5.1 Study Area – Kano, Northern Nigeria

The target study areas of this thesis are selected areas in Northern Nigeria that are currently facing the greatest risk in terms of drought and water shortage for agricultural purposes with a focus on Kano State with one of the largest rice irrigation schemes. The northern region of Nigeria is made up mostly of arid and semi-arid zones, it is characterized with low rainfall, with the annual rainfall diminishing northwards to an average of less than 500mm in a season of sixty days. This is illustrated in a comparative map in the figure below

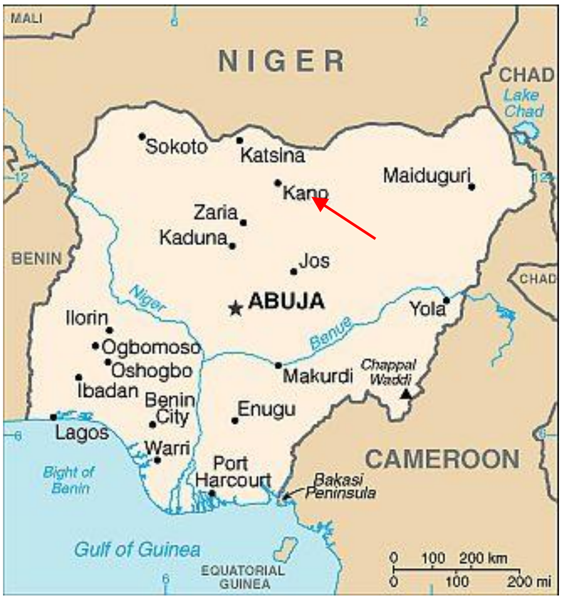


Figure 2: Map of Nigeria showing the northern and southern areas with arrow on the study *area*

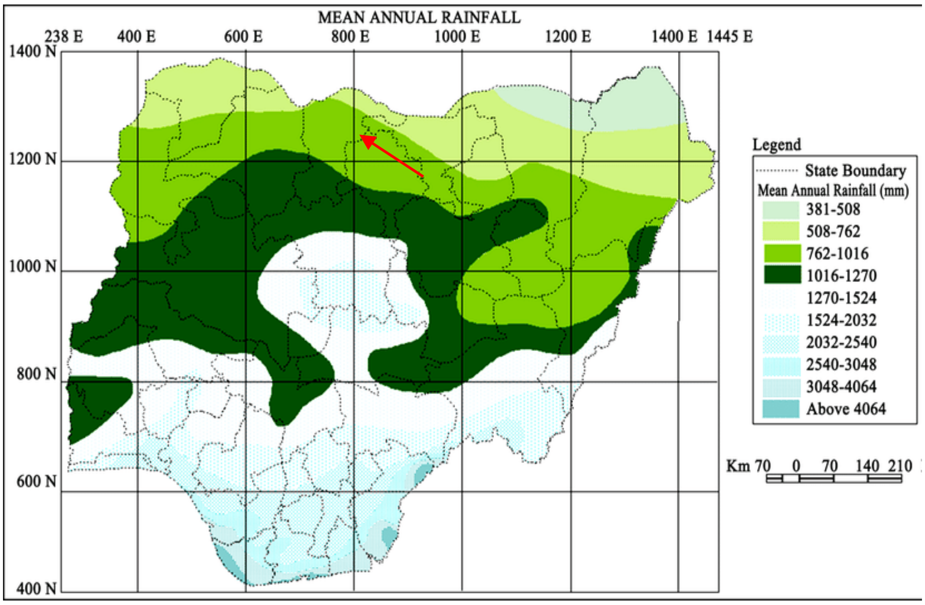


Figure 3: Map of Nigeria showing mean annual rainfall patterns (Source: Ishaku & Majid, 2010)

The low annual rainfall experienced in the study area coupled with the increasing aridity has led to the recent development of several large irrigation schemes for rice such as the Kano River Irrigation scheme and the Hadejia valley irrigation scheme both in the same river basin.

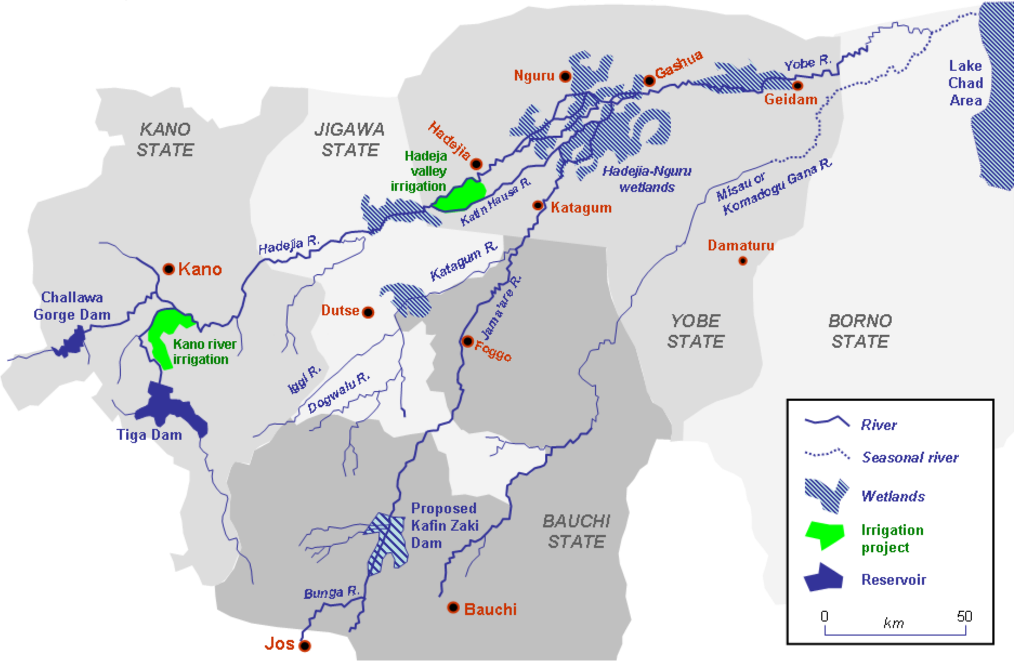


Figure 4: Map showing the large irrigation schemes in the project area and the hydrology pattern of the basin (Source: Haskonin, 2015)

The rice irrigation schemes as shown in the figure above are the Kano River Irrigation Project (KRIP) and the Hadejia Valley Irrigation Project (HVIP). The largest of these schemes is the KRIP, with a target of total irrigated area of 67,000 hectares while HVIP has a potential for 25,000 hectares.

2.5.2 Rice Production Exacerbating Water Scarcity in the Study Area

Water supplies for this large irrigation schemes are provided by Dams on the upstream section of the river. However, these dams are also the major source of water for domestic and industrial usage in the area. Unfortunately, there is more focus from policy makers and institutions responsible for water management in channeling the water from the dam to the large rice irrigation schemes while depriving the other sectors of water.

Natural phenomena combined with long time institutional failure in management of water resources of the basin have led to environmental degradation, loss of livelihoods, resources use competition and conflicts, apathy and poverty among the various resource users in the basin. Continuous diversion of water for such upstream irrigation projects reduces the flow of water through the watershed and drainage basin, directly affecting the supply of water available downstream.

2.5.2.1 Impact on domestic water Usage in the Study Area

According to Kankara and Farouk (2018), The daily average water use per resident of Kano municipal L.G.A. is greater than national average which is 35 gallon in (1998-2001), with a population of about 9,383,682 million people is facing serious shortage problem of portable water supply, yet, there are so many dams in the area including the Tiga Dam (2,000,000 cubic metres) which is meant to provide portable water to the citizens but due to improper utilization of the water, has been focused to mainly rice irrigation, the Kano River Irrigation Project in particular.

2.5.2.2 Effects on Downstream Hydrology and Socioeconomics

The Hadejia-Nguru Wetlands (HNW) is a floodplain of importance which is also affected by over-abstraction of water upstream in Kano for the rice irrigation scheme, because the Knao river upstream spill into the flood plains. The HNW is on the list of Ramsar wetlands of international importance due to its fundamental ecological functions, socioeconomic value and presence of protected areas. Furthermore, the Hadejia-Nguru Wetlands used to support a population of about 10 million people including farmers, herders, fishermen who primarily depend on the ecosystem for their livelihood (Muslim, 2008), but now supports less than one-tenth of that number due to continuous abstraction of water upstream for rice irrigation in both the KRIS and HVIP as discussed in figure 4 above.

Thus, this research aims to provide sustainable means of utilizing the minimum amount of water necessary for rice irrigation while conserving water for other uses and other ecosystem functions.

2.6 Institutional Responsibility for Water Resources Management in Agriculture Nigeria

The development of water resources in Nigeria has happened overtime since the pre-colonial era till the present era of Integrated Water Resources Management (IWRM) whose mission is to reconcile the different uses of water which are in competition through stakeholder participation and decentralization of governance to the lowest possible hydrologic unit (Smith and Clausen, 2018; Ngene *et al.,* 2019).

These efforts towards the provision of water gave rise to the first intervention in water resources development through the first National Development plan of 1962-1968 which saw the establishment of River Niger and Lake Chad Basin Commission. These establishments were closely followed by the creation of Sokoto-Rima and Chad Basin Authorities in 1973 and 1974 (Nwankwoala, 2014). The River Basin Development Decree of 1979 saw the eleven (11) River Basin Development Authorities and this invalidated the earlier decree of 1976 and its amendment in 1977 (Ngene *et al.,* 2019). From 1976 and 1990 the River Basin Development Authorities grew to 12 with the view of covering the whole country (Ngene and Obianigwe, 2018) and they were charged with the responsibility of harnessing, developing and controlling available land, surface and underground water resources of the country with the view of improving agricultural output and providing raw water as necessary input for multipurpose uses (Nigeria National Policy, 2004; Ngene *et al.*, 2019).

At present, the Federal Ministry of Water Resources (FMWR) is the national body with the full responsibility of managing the water resources of Nigeria. As with many developing countries, the ministry through its parastatals and agencies utilises a sectoral, top-down approach where each agency is concerned with a particular water use (Ngene *et al.,* 2019). However, with respect to water requirements for large irrigation projects, there is a strong collaboration between the Federal Ministry of Water Resources and the Federal Ministry of Agriculture and Rural Development, while the States and River Basin Development Authorities have jurisdictional monitoring responsibilities.

This research also aims to support policy formulation within the relevant institutions for effective implementation of water management technologies in rice irrigation and the river basin at large.

CHAPTER THREE

METHODOLOGY

3.1 Approach

The approach and design of the study was to determine irrigation management techniques in rice farming that increase water productivity (WP), allowing a reduction in water input and wastage without negatively affecting grain yield that will be suitable for the study area and the region at large.

Water Productivity (WP) is defined as the ratio of net benefits from crop and mixed agricultural systems to the amount of water required to produce those benefits; this implies a ratio of total weight of harvested crop or monetary value of proceeds to the amount of water used for its production (Molden & Oweis, 2007). Water productivity is indicated in different forms such as:

1) as amount of grain per transpired amount of water,

2) as amount of grain per amount of evapotranspiration water

or 3) as amount of grain per amount of input water used (Bouman et al. 2007).

Water use can be defined as:
1) total amount of water from irrigation and rainfall or 2) as evapotranspiration (ET) (Belder, et al., 2005) Water use efficiency is usually used synonymously to water productivity. To to estimate water productivity of rice, the scale of water losses was considered as follows: percolation, seepage and overbund flow water which is lost to the farmer and the recuperation of water further downstream is still linked with costs for some form of energy for pumping. Taking the viewpoint of either field level or larger irrigation system level, water productivity calculations will differ with smaller water productivity at field level and higher water productivity at larger scale level (Kriesemer, 2013)

Water productivity consists of two components: production (either as crop yield or biomass) and water consumed. Water consumption occurs through evapotranspiration which is the sum of plant transpiration through the stomata in the leaves, and evaporation that occurs from the soil surface and intercepted water by the leaves (Opstal, et al.2020).

3.2 Methodology

3.2.1 Methodologies Employed

i. Field visit and understanding of the study area

The Kano River Basin Area was selected as the study area based on the fact that it is one of the largest and longest operating irrigation schemes in the country. Initially, intensive desktop research was carried out before the reconnaissance trip was conducted. Field observations to determine and investigate the method of water applications, and practices related to water management techniques adopted by the farmers was carried out in the River Basin. The study area is located in the Kano State of Nigeria in Kano State between latitudes 11˚30'N and 12˚03'N and longitudes 8˚30'N and 9˚40'E. Kano River Irrigation Project, Phase I (KRIP I) is part of the Kano River Project which began in 1965 as a pilot project. It covers potentially irrigable land of 22,000 ha, which forms the study area. To this end, the area developed for irrigation is 16,500 ha while the area cropped ranges between 13,900 ha for dry season and 16,450 ha in wet seasons. Information collated include the following:

- Geographic location
- Physical characteristics
- The rainfall pattern
- River formation
- Vegetation
- Area of land under irrigation

ii. Interactions with water management and irrigation management institutions to include:
    - Information on the river basin and irrigation water sources
    - Information related to water distribution practice, and organizational structures
    - Inflows and outflows of command areas
    - Total area under irrigation
    - Irrigation infrastructure
    - Irrigation water input
    - Water and irrigation management

- Water productivity
- Water efficiency in rice irrigation
- Quantification of water losses
- Competing sectors for water resources

iii. Questionnaire administration to institutions, farmer associations and water users to include:
  - Rice farming seasons/ cropping patterns
  - Types of irrigation system applied in the scheme
  - Paddy production determined by unit harvested and interviews with farmers
  - Details on the percentage yield of rice (quality and quantity definition)
  - Land degradation coefficient either as a result of salinization
  - Fertility reduction
  - any other notable parameter
  - Knowledge and application of sustainable irrigation practices for rice farming

iv. Culmination with secondary sources of data.

Data was also obtained from previous project documents, published peer-reviewed papers and interviews with stakeholders to include the following:

- Water wastages and inefficiencies associated with flooding rice irrigation system
- Water efficiency in various sustainable water management rice irrigation practices

3.2.2 Questionnaire administration

To obtain data and information on irrigation efficiency vis a vis rice production in the area, a comprehensive questionnaire covering different aspects of water productivity and efficiency was designed and administered to selected institutions including the Hadejia River Basin Development Authority (HJRBDA), Kano state Ministry of Water Resources, Kano Rover Irrigation Project (KRIP), Transforming Irrigation Management in Nigeria (TRIMING) Project, Rice farmers associations, water users association. The institutions directly involved in the management of the irrigation schemes were interviewed through key Informant

Interview (KII) to acquire information on design and implementation of the project. The survey covered a total of 42 workers from the study site using semi structured questionnaire. It was envisaged that the collected data from the questionnaire survey will be used in the preliminary assessment of irrigation efficiency and water productivity of irrigated rice. Further, including semi-structured interviews, a case study of the irrigation project, personal correspondence, field visits, observation and secondary data was used in this research. Basic data such as existing water allocation practices and water demand, uses and consumption patterns were collected. The information derived from the questionnaire were analyzed using simple descriptive statistics. Interview results were presented through narration.

3.2.3 Limitations to the Research Findings

Although efforts were made to obtain quantitative data on water efficiency, water balance, water productivity and other indicators, responses were limited as the institutions and farmers could not provide most of the quantitative data due to lack of emphasis on quality data monitoring practices. As a result, most responses and information obtained was more theoretical and qualitative. A major objective of this project was to carry out a comparative assessment of continuous flooded and other sustainable methods of irrigation practiced in the area and other water saving irrigation methods. However, results show that only minimal areas practice Alternate Wetting and Drying, and also drip gravity method in the area. Thus, a huge reliance of this research on secondary data. It is recommended that future studies analyse the direct impacts of water saving techniques on rice yields.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physical Parameters of the Study Area

The Kano River formation is made up of Hadejia, Katagum and Jama'are rivers that converge to form the River Yobe and drain Kano and Jigawa States into the Lake Chad. Climatically, the average annual rainfall is 860 mm. Rainfall is more in five months (May-September) with August, recording the highest amount and mean annual temperature ranges from 26˚C - 33˚C. There are three distinctive features; Warm rainy season (June to September), cool dry season (October to February) and a hot dry season (March to May). The soils belong to Enteric Gumbisol with loam texture of the surface, moderately deep, and well drained with some scatter of iron pans.

Vegetation is a typical Sudan savanna consisting of a variety of trees, shrubs, and grassland communities. Geomorphologically, the Kano region is situated in the Western African plains, with a flat to slightly undulating surface, bordering the Jos plateau in the northeast. The strongly weathered Western African basement complex and respective sediments in the lower landscape positions dominate the geology.

Geomorphologically, the Kano region is situated in the Western African plains, with a flat to slightly undulating surface, bordering the Jos plateau in the northeast. The strongly weathered Western African basement complex and respective sediments in the lower landscape positions dominate the geology. The main soil type of the Kadawa scheme is the reddish-brown to brown regosols, with mainly sandy to clay loam texture. The soils tend to be slightly alkaline, and soil organic matter content and cation exchange capacity are low (pH: 8.0; soil organic matter content: 0.26%; CEC: 1.34 me per 100 g soil; see more details in table 1), The latter indicates a dominance of kaolinitic clay minerals.

4.1.1 Kano River Irrigation Project

The Kano River Project was initiated with the construction of the Tiga dam between 1970 and 1974 to irrigate a total area of about 62000 ha in two phases. The first phase with a potential of 22,000 ha irrigated area was completed in 1974 and continues to be largely operational. The Kano River Irrigation Project (KRIP) is one of the largest and most successful irrigation schemes in Nigeria. It is located in Bunkure, Kura and Garum Malam local government areas of Kano state with an office at Kura. Its source of water is the Tiga Reservoir, which provides a perfect setting for gravity irrigation. Its total irrigable area is 22 000 ha.

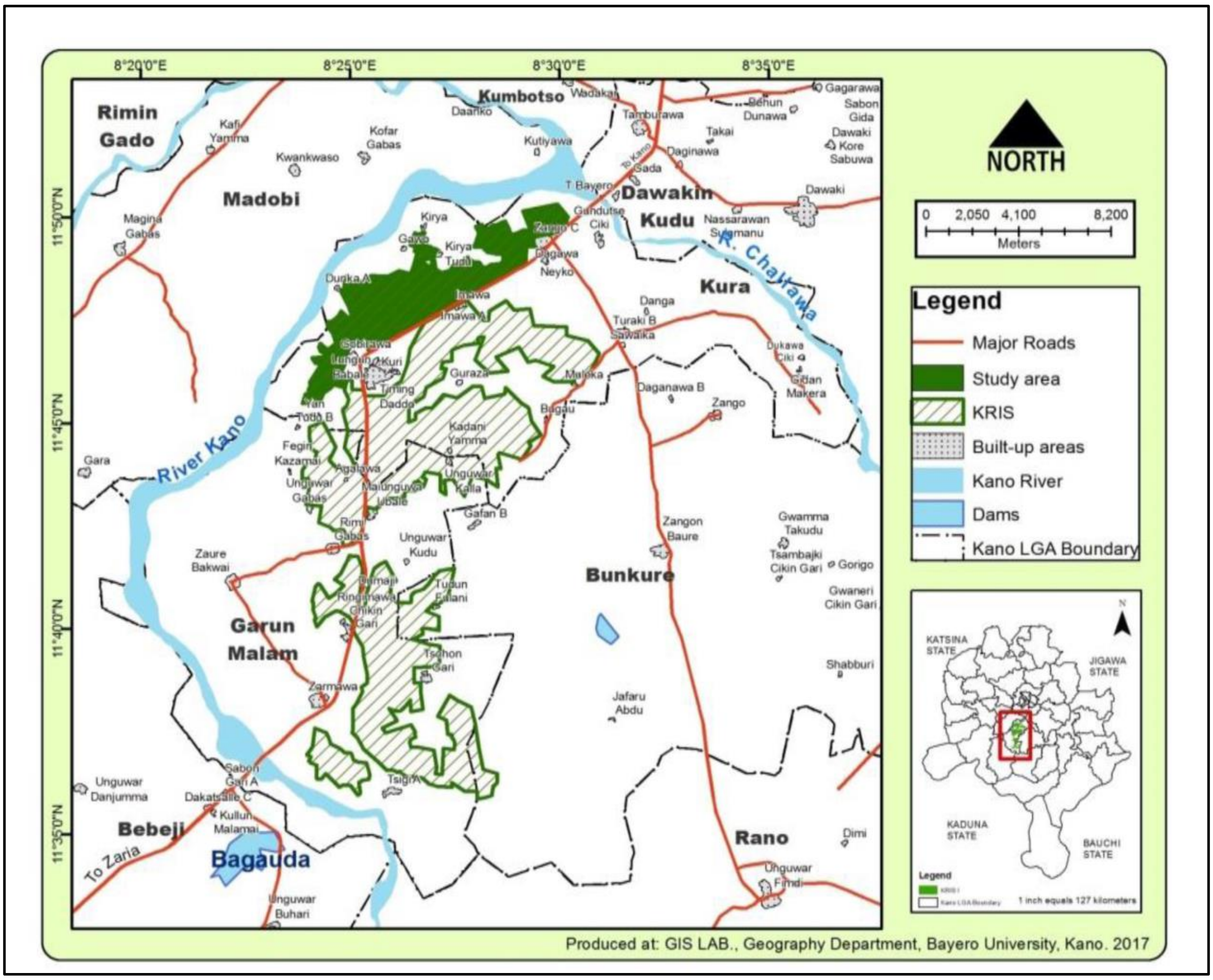
The project was started by the Kano state government in 1976 but was transferred to the federal government in 1982. Phase I of the project commenced operation in 1976 and was expected, according to the original design, to be completed by the end of 1982. However, by 1978 about 4000 ha were completed and only 2000 ha of these were actually irrigated. So far, a total of only 15000 ha have been developed for irrigation. Although the scheme was initiated by the Kano state government, the management of the water resources in the scheme was taken over by the Hadejia Jamare River Basin Development Authority (HJRBDA) following the creation of several states within the former Kano state.

4.1.2 Operation and Maintenance of Kano River Irrigation Project

Water supply to KRIP is from the Tiga Reservoir, which has a storage capacity of 1968 millionm3 and a length of 6 km. Water is supplied through the main canal by gravity to the area of the scheme, where the distribution network, comprising branch, distributary and field canals, takes over. KRIP I is a unique design, in that, the entire water distribution network operates on gravity owing to the elevation of 440 meters above sea level, with a minimum of the supply dam at 506.50 meters. The irrigation water is conveyed from Tiga dam to the Project site through an 18 km long Main Canal (MC), which splits into east and west branches. These are then further broken into lateral canals (LC), field channels (FC) and finally to the farm for irrigating crops. The existing scheme includes storage and diversion dam; night reservoirs; main canals with upstream water control; lateral and sub-lateral canals; and drainage systems. Water from Tiga dam is discharged into the main irrigation canal having main outlet capacity of 56 m^3 s-1, and through Ruwan Kanya Reservoir (surface area of 1500 ha and 339106 m^3), it enters the project area at Rano off-take, and then is subdivided between west and east branch canal.

The irrigated area is divided into 49 sectors of which 38 are irrigated and 11 sectors are yet to be completed. KRIP infrastructures are generally in fairly good condition, such as the main canals, farm outlet structures, and hydro-mechanical equipment. The main drainage systems are eroded in some places, but are operational. Vegetation like Typha grass grows in branch canals, lateral canals, and distribution canals. In several sections, canals are exposed to erosion and silt deposition was also observed in many lined canals. Water is supplied during dry months from November to March coinciding with peak demand of irrigation.

According to Ahmad & Haie (2018), actual crop water requirements are not the guiding principle for the operation of KRIP, but rather are based on continuous water supply through the main canal to the irrigated areas. Despite significant increases in water demand, it is essentially a supply-based system. Hence, it cannot accommodate changing water demands during the crop season. The period farmers apply water depends on dryness of crops and soils and in some areas based on recommended day’s interval. For instance, Yakasai at Kosawa area is allocated water on every Thursday and Saturday. The total command area of the scheme and the total area that received irrigation water per season is about 9000 hectares/per season.



Produced at: GIS LAB., Geography Department, Bayero University, Kano. 2017

Figure 2: Kano River Irrigation project 1 Showing the study area. (source: Geography Department, Bayero University, Kano. 2017)

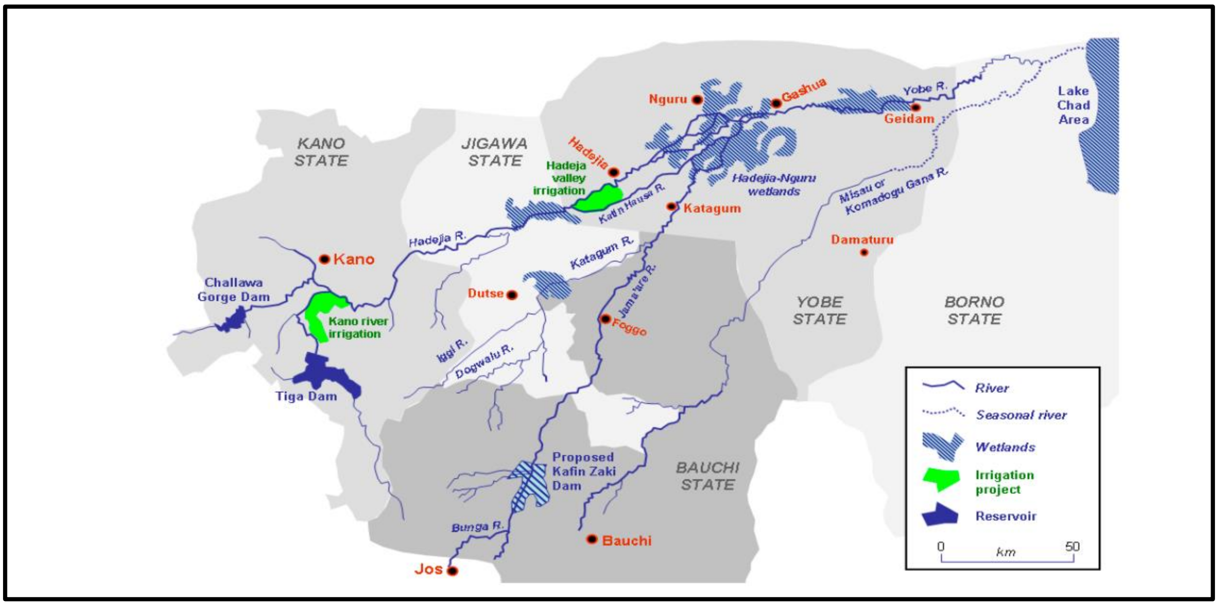


Figure 3: Showing the rice irrigation project in the river basin (source: Ahmad & Haie. 2018)

Response to the questionnaires show that two crops per year are grown at the scheme. The major wet season crop is rice, but maize is also cultivated in areas with inadequate irrigation (higher landscape positions, outside the perimeter). Dry season crops include crops such as maize, cowpea, wheat, pepper, tomato, onions and vegetables. Most farmers interviewed have a long history of rice cropping and irrigated agriculture. Rice is produced mainly for cash, and production is sold individually to traders. In terms of gender, women are active in rice cultivation among small-scale farmers, taking part in activities such as uprooting of seedlings, transplanting, weeding, harvest and winnowing. In the wet season however, irrigation is undertaken only to complement water from rainfall. Small-scale farmers use small bunded plots (about 5 x 5 m) to retain rainwater and minimize surface runoff. The same technique is used outside the perimeter for rainfed cropping.

4.2 Summary of Current Rice Irrigation situation in the study area

Currently, most rice farmers in the study area still rely on traditional technique of continuously flooding their fields to grow rice. Lower lying areas of the scheme are completely flooded during the wet season, and rice cropping is the only option in these areas. Optimal rice planting date is May to June. With late planting, low temperatures in November result in elongation of the crop cycle and can cause spikelet sterility. Crop establishment techniques include broadcasting (of dry seed), drilling (seed placement with a stick, often practiced in a row) and transplanting. Harvesting occurs from October to December. Straw remaining in the field after harvest is either burnt or consumed by cattle entering the scheme between cropping seasons.

The snag with this technique of rice irrigation is the decreasing trend in the water resources availability especially during dry season in most areas of Northern Nigeria. Additionally, the water demands for domestic and industrial water supply in the area is on the increase. Consequently, the water availability for agriculture purposes is decreasing and conflicts among the water users and among farmers cannot be avoided. Public irrigation schemes in Nigeria are characterized by inefficient water use, varying and low productivity. In addition, the schemes are further known for poor performance which hinders their expansion. The farmers association and the KRIP irrigation management noted that large amount of water is “spent” on irrigation and they also opined they think were willing to adopt new water saving techniques in their operation if given the opportunity.

4.2.1 Temporal Discharge of Water to the Project Sites

From the initial design specified for the water level and water discharge rate, the water level of the Tiga dam should not be less than 491.82 m/day, according to the findings of this study it was discovered that 520.08 m/day was obtained. Moreover, for the system to perform satisfactorily water discharge to the project site was proposed to be 3.2 l/s. The upstream water head proposed was 0.20 m above FTO (Table 1).

Table 1: Designed/implemented Water Discharged in KRIP 1 (Source, Field work and Malami et al, 2021)

Parameter	Design	Implementation
Water level (m)	491.82	520
Water quantity discharge KRIP (1/s)	3.2	3.5
Upstream Water Head	0.20	0.21

4.2.2 Water Distribution Systems in KRIP 1

The sectors are divided into blocks each and served by distributary canals; larger sectors are divided in blocks that branch off from a lateral canal or sub-lateral canal. The canals observed are; the Main Canal (MC), Lateral Canal (LC), Distributary Canal (DC) and Field Canal

(FC). The result showed a total canals design in KRIP 1 to be 487, and 460 canals were implemented which represented 94% achievement. The result also indicated a total design length of the canals to be 794,186 m and the findings show 397,670 m were implemented, which represented 50% achievement (Table 2). The findings indicated that the canals were adequately in place as far as KRIP 1 is concerned, which suggested a well-connected drainage network.

Table 2: Design and Implementation of Canals in KRIP 1 Source Fieldwork

Item	Total designed	Total implemented	Percentage implemented
Number of canals	487	460	94
Length of canals (m)	794.186	397.670	50

The findings indicated that from the blue print main canal proposed was to have a total distance of about 25,000 m. The result showed that a distance of 24,525m was implemented; that is 98.1% of the design, and also the feasibility report showed the main canal width designed of 5 m and the result of the study unravelled that it attained 100%. The study indicated the design depth of 2.5 m and 2.2 m implemented, which accounts for 88%, and for the canal construction it is stone pitching/earth line throughout.

4.3 Water Saving Technologies in the area

While result from the questionnaire analysis showed that irrigation method in the basin is mainly surface irrigation, investigation also revealed that gravity irrigation is practiced in some areas under KRIP 1 in a few pilot projects of less than 3 hectares maximum. Alternate Wetting and Drying (AWD) is also practiced in some small areas especially by donor supported projects like Food and Agriculture Organisation (FAO) and OXFAM Climate Adaptation Program (C-CLAP). Both projects are small scale as compared to the Kano River Rice Irrigation Scheme which is a rice flooded system.

Most of the respondents noted that they have heard of system of rice intensification (SRI) water saving technique. Only few (12%) of the respondents have heard about the AWD system of rice farming. The respondents noted overwhelmingly that poor water management was the major problem in the scheme and they also affirmed that there was a high degree of water wastage in the area.

4.3.1 Water application method in KRIP 1

Gravity Method

The study established that the gravity method recommended from the design is currently being practice by some cluster of farmers in the project. This was made possible because land clearing and levelling was done according to specification just because farmers must do that for them to receive water released from the FC. The slope according to the blue print was to control erosion and to ensure reasonable travel time, considering infiltration. The time recommended for water application is morning, and the days meant for irrigation water interval per sector is seven-day frequency. The two major indicators of watering farmlands for as outcome of the research are dryness of soils and crops are related in the sense that dryness in soil conditions is often reflected in the condition of crops. According to the findings, farmers used soil (29.7%) as the major indicator for irrigation, and about 28.7% used crop dryness. Moreover, only 10.4% used the design indicator, which is seven days interval, while 20.2% used about eight days and above, but it depends on the time of planting, early watering is seven days while at the middle of irrigation and towards the end it exceeded eight days. In terms of annual rice yield, the average yield stated was 2000kg per hectare per season.

4.3.2 Alternate Wetting and Drying (AWD)

As earlier mentioned Alternate Wetting and Drying (AWD) is also practiced in some small areas especially by donor supported projects like Food and Agriculture Organisation (FAO) and OXFAM Climate Adaptation Program (C-CLAP). Irrigation water is applied to flood the field a certain number of days after the disappearance of ponded water. Hence, the field is alternately flooded and nonflooded. entails an irrigation scheduling in which the field is allowed to dry for a number of days before re-irrigation, without stressing the rice plants. The number of days of nonflooded soil in AWD before irrigation is applied can vary from 1 day to more than 10 days (Sibayan, et al., 2018). Among the water-saving technologies, Alternate wetting and drying (AWD) has been widely advocated for its potential to reduce water consumption, methane emission, while maintaining rice yield compared with the traditional approach of conventional flooding.

4.3.3 Data according to Literature

Many alternate ways to the traditional system have been developed with a considerable water saving potential such as dry-seeded rice, aerobic rice, and transplanted rice with AWD (Datta, et al., 2017). Water savings of 35–57 % have been reported for cultivating rice in non-flooded and non-puddled soils compared with traditional transplanted rice. Some popular Water-wise rice production technologies across the world include Alternate Wetting and Drying (AWD), System of Rice Intensification (SRI), Saturated Soil Culture (SSC), Aerobic rice production and Drip Irrigation.

4.3.3.1 The System of Rice Intensification (SRI)[4]

SRI is an ensemble of rice systems management practices based on 4 principles: wide spacing, young seedling, use of organic fertilizer and AWD (See Satyanarayana et al., 2007 for review on SRI and its historical development). Experiments conducted on SRI demonstrated its benefits on water saving, yield increase and soil fertility improvement (Dobermann, 2004; McDonald et al., 2006; Sheehy et al., 2004). However, SRI has not been widely adopted by small-scale farmers due to several reasons including high labour requirement, and organic fertilizer, often limiting, particularly in the Sahelian environment where rainfall is too low and livestock production requires organic matter.

4.3.3.2 Saturated Soil Culture (SSC) [5]

In saturated soil culture (SSC), the soil is kept as close to saturation as possible. In this situation the hydraulic head of the ponded layer of water is reduced and hence the water losses by seepage and percolation decreases. Saturated soil culture in practice means that only a small amount of irrigation water is applied to the field to get a ponded water depth of 1 cm a day after the ponded water has disappeared.

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[4] In some literature, AWD is considered a part of SRI, so it is not covered in depth in this proposal

[5] For further details on the SSC method See (Borrell , et al., 1997) (Kima , et al., 2014), (Singh, et al., 2020), (Dias, 2018)

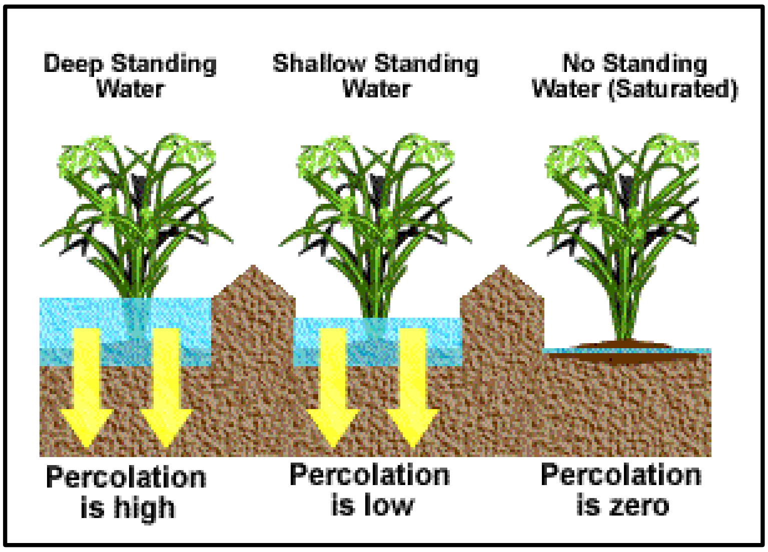


Figure 7: Saturated soil culture (http://www.knowledgebank.irri.org/ewatermgt/courses/course1/modules/module03/m03l05.html)

Tabbal et al. (2002) reported water savings under SSC in transplanted and direct wet-seeded rice in puddled soil, and in direct dry-seeded rice in nonpuddled soil. (Borrell , et al., 1997) Bouman & Tuong, (2001) analysed a data set of 31 published SSC field experiments and found the decrease in water input by an average of 23% compared to continuous submerged condition, with a non-significant 6% of average yield reduction.

This mostly means that a shallow irrigation is given to obtain about 1-cm floodwater depth a day or so after the disappearance of standing water. With SSC, the water inputs decreased by 30- 60% and the yield dropped by 4-9%, with one exceptional value of 30% in the very permeable soil of Guimba-2 in 1991. Because the water inputs decreased more than the yields, the water productivity (calculated as the ratio of yield over total water input) increased by 30-115%. Bouman and Tuong (2001) compiled a database on SSC and AWD from their own IRRI experiments and experiments reported in the literature. Implementing SSC requires good water control at the field level and frequent shallow irrigations that are labor-intensive.

4.3.3.3 Drip Irrigation

Subsurface drip irrigation is a new agricultural water-saving irrigation technology: it has been widely used in arid areas in recent years. Compared with traditional irrigation, drip irrigation under mulch can promote crop water and nutrient absorption, improve crop yield and quality, and better control irrigation water, the level of adoption of drip irrigation is abysmally low in Nigeria; apart from the total lack of local production of the system, farmers depend too heavily on rain fed systems for their cultivation. They also note that the use of surface irrigation and sprinkler systems has however been in practice in the country since 1925; from 1970 – 1990, the country witnessed massive development of surface irrigated schemes without any consideration for the more efficient drip irrigation system.

In recent time, a number of research efforts has however been directed at promoting drip irrigation systems for dry season farming in Nigeria.

However, there are several challenges faced by smallholder farmers in managing this system. Hence, field trials are recommended for drip irrigation technologies. This is to be carried out simultaneously with surface irrigation method which is currently the method applied in the area. For on-farm application it is recommended that small-scale trials of drip irrigation be carried out in selected areas within the Kano River Basin in a comparative context with the surface irrigation method. This is not just to allow farmers to gain more insights in the management of drip systems but also allow the researchers to able to compare the drip system with existing techniques in terms of their water saving capacity. It is recommended that a study be conducted to determine the actual costs and benefits of using the drip and surface irrigation. Drip could be piloted for small farm area per farmer to allow them gain experience and slowly adopt the technology if found useful and productive.

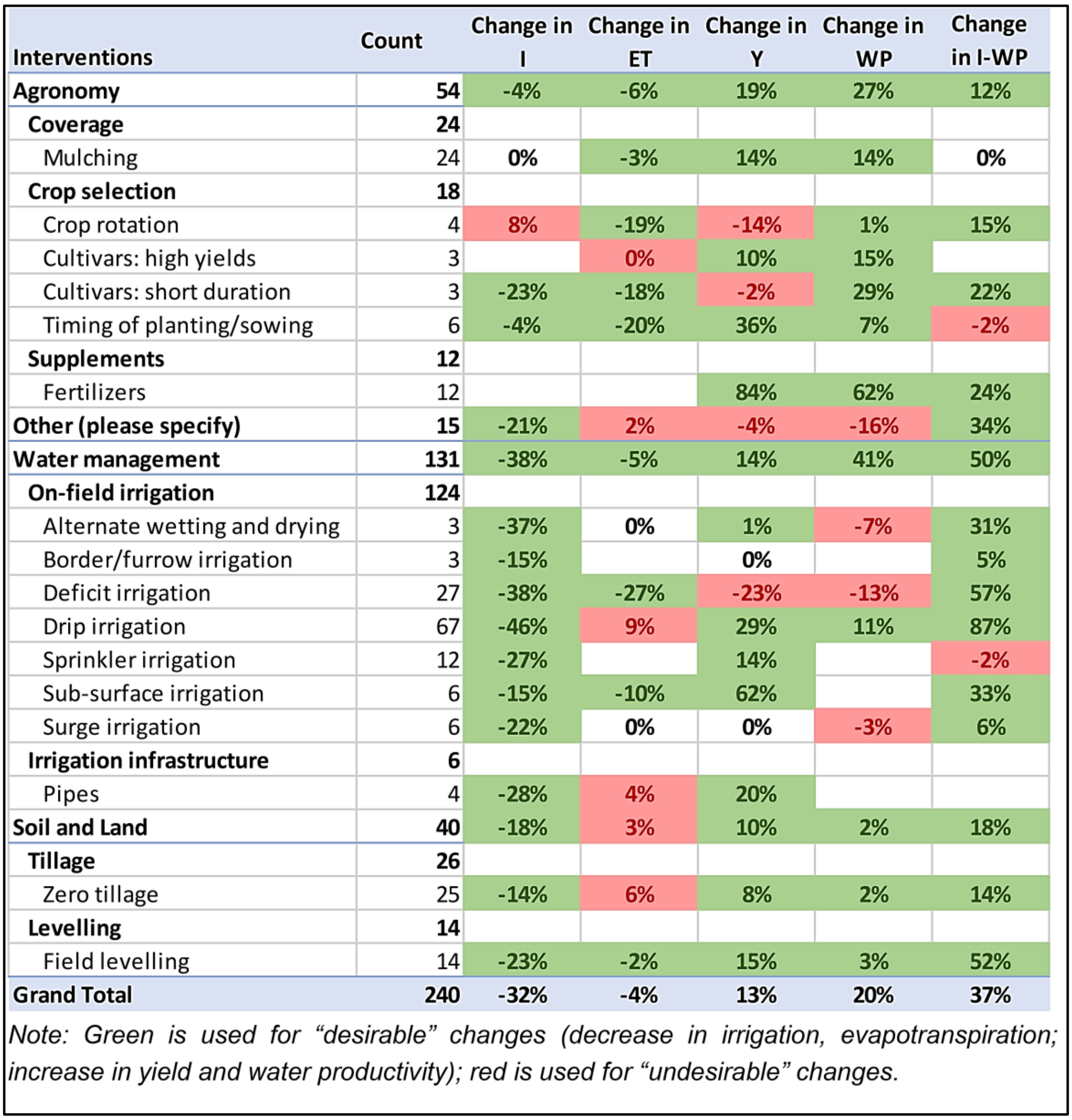
4.3.3.4 Water Saving Techniques: Global Experiences

Opstal, et al.(2020) on behalf of the FAO (Food and Agriculture Organization) carried out a comprehensive comparative assessment on water saving techniques and quantified the impact each intervention had on water management and saving. They conducted a literature review of a plethora of peer reviewed article and books on water saving techniques and created an inventory showing the impact each measure had on water saving potential. Figure 8 shows the result of the assessment. Publications were included that could indicate a change in water volumes or crop production due to an implemented intervention. These changes were quantified as percentages of change compared to the original condition (baseline). Changes were noted for the following aspects

- Irrigation or water applied
- Evapotranspiration or water consumption
- Return flow as runoff or drainage (if mentioned)
- Crop yield
- Water productivity: yield per unit of evapotranspiration (water consumed)

- Irrigation water productivity: yield per unit of irrigation (water applied)

For each intervention under the specified theme and category, the average changes in each aspect is presented. In addition, the number of studies used for computing the average is indicated in the 'count' column. Interventions with two or fewer publications are excluded from the table. A total of 240 studies are used of which 131 for water management, 40 for soil and land management, 54 for agronomy, and 15 other interventions that were not included in the intervention framework (irrigation scheduling, raised beds, etc.).



Interventions	Count	Change in I	Change in ET	Change in Y	Change in WP	Change in I-WP
Agronomy	**54**	-4%	-6%	19%	27%	12%
Coverage	**24**					
Mulching	24	0%	-3%	14%	14%	0%
Crop selection	**18**					
Crop rotation	4	8%	-19%	-14%	1%	15%
Cultivars: high yields	3		0%	10%	15%	
Cultivars: short duration	3	-23%	-18%	-2%	29%	22%
Timing of planting/sowing	6	-4%	-20%	36%	7%	-2%
Supplements	**12**					
Fertilizers	12			84%	62%	24%
Other (please specify)	**15**	-21%	2%	-4%	-16%	34%
Water management	**131**	-38%	-5%	14%	41%	50%
On-field irrigation	**124**					
Alternate wetting and drying	3	-37%	0%	1%	-7%	31%
Border/furrow irrigation	3	-15%		0%		5%
Deficit irrigation	27	-38%	-27%	-23%	-13%	57%
Drip irrigation	67	-46%	9%	29%	11%	87%
Sprinkler irrigation	12	-27%		14%		-2%
Sub-surface irrigation	6	-15%	-10%	62%		33%
Surge irrigation	6	-22%	0%	0%	-3%	6%
Irrigation infrastructure	**6**					
Pipes	4	-28%	4%	20%		
Soil and Land	**40**	-18%	3%	10%	2%	18%
Tillage	**26**					
Zero tillage	25	-14%	6%	8%	2%	14%
Levelling	**14**					
Field levelling	14	-23%	-2%	15%	3%	52%
Grand Total	**240**	-32%	-4%	13%	20%	37%

Note: Green is used for "desirable" changes (decrease in irrigation, evapotranspiration; increase in yield and water productivity); red is used for "undesirable" changes.

Fig 8: Inventory summary with average reported changes (%) in irrigation (I), evapotranspiration (ET), crop yield (Y), water productivity (WP), and irrigation water productivity (I-WP) for various field interventions.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Summary

The challenge to produce more rice with less water, economically and in ways that will be adopted by farmers in a context of reformed agricultural and water policies and integrated water resources management appears formidable yet is vital for the food and water security of the arid and semi-arid regions in Nigeria. About 85% of rice irrigation farming in the study area (KRIP) is the flooded system of rice irrigation while pockets of gravity method and Alternate Wetting and Drying make up the remaining 20%. While the former is the main Government supported scheme in the area, the latter are donor supported projects aimed at sustainable production.

It is also clear from the studies that there is huge water uptake in the flooded rice system and excess water wastages as compared to the gravity and AWD methods which correlates with secondary sources of data. The implication of this is low water productivity in the area, deprivation of water resources to other sectors such as domestic use, fishing and industrial usage which often leads to conflicts between sectors. Unavailability of water resources to other areas due to over-concentration to the rice irrigation project is a major factor pushing human migratory patterns especially among the youths, as the areas deprived of water cannot sustain livelihood activities. On the other hand, there is increased salinity in flooded fields resulting in land degradation, reduction in soil fertility and thus decline in quality and quantity rice yields. Based on climate change research, rice paddies have been identified as major methane emitters contributing to increase to atmospheric greenhouse gases and thus climate change, especially from flooded rice fields.

The water resources management institutions, the irrigation management institutions, irrigation projects and farmers are in support of switching to sustainable water management technologies for rice irrigation. This will allow for expansion of more irrigable areas without water over-exploitation, free up water for the other socio-economic and domestic sectors while improving the soil-crop-climate-socioeconomic status of the area.

Currently there are scarcely any Government policies which support sustainable water management technologies in rice irrigation. A few policies were noted under the Sustainable

Development Goals SDG 9 (Industry, innovation and infrastructure) and SDG 13 (climate action), however these policies only reside within the Federal Ministries of Environment and are not domesticated to the state level nor synergised across relevant institutions in the water resources management sector or agricultural sector.

5.2 Conclusion

In rice production systems, a large quantity of water is lost through evapotranspiration, surface runoff, seepage, and deep percolation (Materu, et al., 2018)**.** Rice consumes more water than any other irrigated crop and it requires up to 2–3 times more water compared to other crops (Yakubu, et al., 2019)**.** There are several strategies to save water and increase productivity and efficiency of water in rice production in Nigeria; these include minimizing water losses by only applying the proper amount of water to the plant; reduce losses during field preparation and to reduce percolation and evaporation water.

Water productivity may vary when evaluated at different spatial scales due to influencing factors such as crop choice, climatic patterns, irrigation technology and field-water management, land, and inputs including labor, fertilizer and machinery (Rosegrant *et al*., 2002; Kijne *et al*., 2002). At plot and farm scales for example, options may involve combined research on plant physiology, agronomy and agricultural engineering that focuses on making transpiration more efficient or productive, reducing non-productive evaporation and making water application more precise and efficient. At irrigation system and basin scales, options may include reducing non-beneficial depletion, reallocating water among uses and tapping uncommitted outflows resulting in more output per unit of water consumed (Molden *et al*., 2003).

Generally, the strategies for increasing water productivity at the field level include improved practices at field level relate to changes in crop, soil and water management, selecting appropriate crops and cultivars; planting methods (e.g. on raised beds); minimum tillage; timely irrigation to synchronize water application with the most sensitive growing periods; nutrient management etc. Increasing water productivity at the field level can be accomplished by: (i) increasing the yield per unit cumulative ET; (ii) reducing the unproductive water outflows and depletions (SP, E); or (iii) making more effective use of rainfall. The last strategy is important from the economic and environmental points of view, where the water that needs to be provided through irrigation can be offset by that supplied or replaced entirely by rainfall (Tuong and Bouman, 2003).

Water resources management in rice irrigation is critical for food and water security of the arid and semi-arid regions in Nigeria, which can only be made possible through i) establishment of policies to support sustainable water management technologies in agriculture and 2) implementation of water saving techniques in rice irrigation farming.

5.3 Recommendation

While several water saving techniques exists such as alternate wetting and drying, saturated soil culture, aerobic rice farming, low pressure pipe irrigation, drip irrigation, sprinkling irrigation, however, for the region under study, the alternate wetting and drying has been identified as the most suitable based on this research.

In general, improving water management in rice production will have the following benefits:

- improving water management in rice production can financially benefit farmers by lowering water costs, lowering electricity (pumping) costs, raising crop yields, and/or reducing labor costs. However, in many other cases, additional incentives will be necessary in order to make improved water management practices cost effective for farmers.
- in some contexts, improving water management can increase rice yields and reduce pressure to convert additional land to agriculture
- interrupting flooding in rice paddies reduces the emissions of methane—a potent greenhouse gas—by reducing the populations of methane-producing bacteria and stimulating the breakdown of methane by other bacteria.
- reduces demand for irrigation water, which can increase freshwater supply for other users or provide downstream ecosystem services

5.3.1 Alternate Wetting and Drying (AWD)

Rice irrigation in the study area is dominated by lowland farming, Alternate Wetting and Drying (AWD) is suitable for lowland (paddy) rice farmers to reduce their water use in irrigated fields. AWD are among the most widely promoted water-saving irrigation technique introduced by the International Rice Research Institute (IRRI) to cope with the increasing threat of water scarcity in rice cultivation.

The technology promotes efficient water use and generates 15% to 35% water savings compared with the continuously flooded practice of the farmers (Lampayan et al 2005). This savings can pave the way to possibly increasing the area that can be irrigated in a cropping season within an irrigation system. It can also provide the basis for the preparation of an effective schedule of irrigation water delivery, ensuring equitable water distribution among farms regardless of location within the service area of an irrigation system. Numerous field experiments also suggest that if properly employed, these practices will at least maintain rice yields, and sometimes increase them.

5.3.2 Technique for AWD

In this method, the rice will be flooded to a depth of only 3-5cm instead of the more usual 10cm, moreover, flooding does not have to be continuous, and the soil surface can be left to dry out before re-flooding. The cycle of alternate low-level flooding and drying can also be repeated throughout the growth of the crop, although flowering is a critical period when the soil must be flooded, this cycle can continue from 20 days after sowing until 2 weeks before flowering. As much as 30 per cent less water is needed for AWD and no other significant changes to crop management are required, except to ensure that fields are accurately levelled to avoid ‘ponding’ (pools of water) in low spots and excessive drying where the ground is high. Levelling also has the added benefit that seed germination and growth are more even and weed growth is more consistently controlled, so yields are enhanced (IRRC, 2013).

Based on multi-location and multi-season experiments, IRRI scientists recommend irrigating when soil water tension in the rootzone reached a threshold value of 10kPa[6]: when field water level receded to 15cm below the soil surface, soil water tension in the rootzone is always less than 10kPa, reflecting that water in the soil is still available for plant use.

A simple ‘level gauge’ – PaniPipea is required to enable farmers to avoid over-drying the soil and determine when re-flooding. A 40cm length of 15cm diameter plastic pipe or bamboo, with drilled holes, is sunk into the rice field until 20cm protrudes above soil level. This enables farmers to monitor the level of water inside the pipe: when the water level inside drops to 15cm below ground level, the field is ready to be re-flooded. (as illustrated in figure 9 below)

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[6] (measure used to express moisture availability in the soil for plant use)

Figure 9: Demonstrating the AWD technique (source: (Bouman and Tuong 2001).

5.3.3 Overcoming Challenges with AWD

In AWD, a major portion of the water resource is managed by an irrigation/farmers' association instead of by individual farmers. Considering majority of individual farmers in the study area are illiterate, it becomes better to work in associations which will make technology transfer more effective due to availability of technical support from the relevant institutions, and monitoring instrumentation can be maintained at the association level

Challenges in understanding and accurately measuring water depth, increased labor requirements and costs due to frequent irrigation. This challenge will be lessened as technique will be implemented at the association level, where there is more technical support Furthermore, AWD is not as technical as Saturated Soil Culture (SSC) or System of Rice Intensification (SRI). SSC requires good water control at the field level and frequent shallow irrigations that are labor-intensive. As compared to the flooded rice irrigation and SRI, less labour is required, also associated costs are not as huge as other techniques like sprinkler irrigation and SRI.

While AWD can be applied alone, based on secondary research, techniques like drip irrigation is more efficient when combined with surface irrigation.

5.3.4 Policies and Incentives

Government agencies should fund coordinated assessments of the practical potential to implement different water management techniques at the irrigation district level.

The state ministries of water resources and state ministries of agriculture will need to collaborate to formulate policies that will support the use of sustainable water management technologies in agriculture. This can be linked to incentives such as:

- support with provision of agricultural inputs like rice seedlings and organic manure,
- reform water and energy subsidies and tax rebates
- provide trainings
- collaborate with off-takers to promote farmer sales
- promote investment in research on irrigation practices and technologies

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APPENDIX

QUESTIONNAIRE

General information		
Name of organization		
Name of representative		
Name of the scheme		
Administrative region (states within which the irrigation scheme lays		
Name of the river Basin(s)		
Describe the end users of the scheme		
Please provide a description of how the scheme operates		
If available please provide technical details of the operations		
What is the Irrigation water sources		
How much irrigation water is inputed		
Please provide details of water efficiency and productivity of the scheme (See table below) NB: Please feel free to include other parameters on water productivity used by the scheme		
Please provide details on the percentage yield of rice (quality and quantity definition) in terms of what was planted and what was harvested in the past 10 years (It can be longer)		

Irrigation Methods • Surface irrigation • Sprinkler irrigation • Drip irrigation • AWD • SRI • All of the above • Other (list)		
Do you know about the following rice cultivation technologies? • Alternate Wetting and Drying (AWD) • Direct seeded metho • System of Rice Intensification (SRI) • Other		
Have you applied any of this method?		
Please describe the associated difficulties in maintaining your system, in terms of the following • wastages, • land degradation coefficient either as a result of salinization • fertility reduction • any other notable parameter		
Are there other competing sectors in terms of water usage? Mention these sectors Provide some numeric value for distribution of water between and amongst competing users		
Are there other areas practicing sustainable rice irrigation? Please mention		

Total annual volume of irrigation water managed by authorities. (MCM)	This is the irrigation water that is imported into the project boundaries by the authority, plus any internal groundwater pumped by the authorities. The value is not used to compute any efficiencies, as some of the internal pumping may be recirculation of original source water. However, this is the volume of water that the project authorities administer, so it is used for the computations related to costs.	
Please indicate total annual volume of irrigation water delivered to users by project authorities.	Total volume of water delivered to water users by the authorities over the year that was directly supplied by project authority (including WUA) diversions or pumps. Water users in this context describe the recipients of irrigation service, these may include single irrigators or groups or irrigators organized into water user groups. This does not include farmer pumps or farmer drainage diversions.	This can be directly measured, or is more commonly estimated based on an assumed conveyance efficiency.
Total command area of the system (ha)	The physical hectares of fields in the project that that are provided with irrigation infrastructure and/or wells.	
Irrigated area, including multiple cropping (ha)	The hectares of cropped land that received irrigation. If a 1 hectare field has two irrigated crops per year, the reported irrigated area would be 2.0 hectares.	
Annual irrigation supply per unit command area (m^3/ha)	Total annual vol. of irrig. supply into the command area Total command area of the system	Total annual volume of irrigation supply into the command area: See earlier definition. Total command area of the system: See earlier definition

Annual irrigation supply per unit irrigated area (m^3/ha)	<u>Total annual volume of irrigation supply</u> Total annual irrigated crop area	*<u>Total annual volume of irrigation supply</u>*: See earlier definition *<u>Total annual irrigated crop area:</u>* See earlier definition. Includes multiple cropping.
Conveyance efficiency of project-delivered water, % (Weighted value using stated values))	<u>Volume of irrigation water delivered by authorities</u> (Total annual volume of project authority irrigation supply)	*<u>Volume of external irrigation water delivere by authorities</u>*: Total volume of irrigation water supply that is <u>delivered</u> to water users by the project authorities over the year. Water users in this context describe the recipients of irrigation service, these may include single irrigators or groups or irrigators organized into water user groups. *<u>Total annual volume of project authority irrigation supply</u>*: Defined earlier
Annual Relative <u>Irrigation</u> Supply (RIS)	<u>Total annual volume of irrigation supply into the 3-D boundaries</u> Total annual volume of ET – effective precipitation	*<u>Total annual volume of irrigation supply into the 3-D boundaries:</u>* Defined earlier *<u>Total annual volume of ET – effective precipitation</u>*: Defined earlier.

Water delivery capacity	Canal capacity to deliver water at system head Peak irrigation water ET requirement	*Canal capacity to deliver water at system head:* Actual gross discharge capacity of main canal(s) at all diversion point(s). (CMS) Peak irrigation water ET requirement*:* Defined earlier (CMS)
Security of entitlement supply, %	The frequency with which the irrigation organization is capable of supplying the established system water entitlements	*System water entitlement:* The bulk volume (MCM) or bulk discharge of water (CMS) to which the scheme is entitled per annum.
Average Field Irrigation Efficiency, %	(ET - Effective precipitation + LR water) x 100 (Total Public and Private Water Delivered to Fields)	All values are expressed in 12 month volumes.
Command area Irrigation Efficiency, %	(ET + Leaching needs - Effective ppt.) x 100 (Surface irrigation imports + Net groundwater)	All values are expressed in 12 month volumes.
Total annual value of agricultural production (US$)	Total annual value of agricultural production received by producers.	
Output per unit command area (US$/ha)	Total annual value of agricultural production Total command area of the system	*Total annual value of agricultural production:* Total annual value of agricultural production received by producers. *Total command area of the system:* The command area

		is the nominal or design area provided with irrigation infrastructure that can be irrigated.
Output per unit irrigated area, including multiple cropping (US$/ha)	Total annual value of agricultural production Total annual irrigated crop area	*Total annual value of agricultural production:* Defined earlier *Total command area of the system:* Defined earlier
Output per unit irrigation supply (US$/m^3)	Total annual value of agricultural production Total annual volume of irrigation supply into the 3-D boundaries of the command area	*Total annual value of agricultural production:* Defined earlier *Total annual irrigated crop area:* Defined earlier
Output per unit water supply (US$/m^3)	Total annual value of agricultural production Total annual volume of water supply	*Total annual value of agricultural production:*. Defined earlier *Total annual volume of water supply:* Defined earlier
Output per unit of field ET (US$/m^3)	Total annual value of agricultural production Total annual volume of field ET	*Total annual value of agricultural production:* Defined above

		Total annual volume of field ET: Defined earlier
Land Degradation		