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Presented by

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UNLOCKING FINANCE FOR ADVANCED IRRIGATION TECHNOLOGIES IN SUB-SAHARAN AFRICA:
A CASE STUDY OF DJARAMAYA SCHEME IN CHAD.

Defended on 03/09/2019 Before the Following Committee:

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DECLARATION

I, hereby, declare that this thesis represents my work released to the best of my knowledge, without plagiarism and has not been submitted before to any institution by myself or any other person for the award of any qualification. I also declare that all information, material, and results from third parties have been fully cited and referenced according to the academic rules and regulations.

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CERTIFICATION

We, hereby certify that this master thesis by **OUMAR AL-FAROUKH Brahim Mahamat**, a Water Policy Master student of Pan African University Institute of Water and Energy Sciences (including climate change) (PAUWES), Tlemcen, Algeria, is candidate's original work and has been prepared under our supervision.

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LIST OF ABREVIATIONS

IsDB: Islamic Development Bank

PAUWES: Pan African University Institute for Water and Energy Sciences (including climate change)

WBG: World Bank Group

AIT: Advanced Irrigation Technologies

NPV: Net Present Value

CBR: Cost-Benefit Ratio (C/B ratio)

IRR: Internal Rate of Return

PP: Payback Period

PPP: Public Private Partnership

MARE: Ministry of Agriculture and Rural Equipment

FAO: Food and Agriculture Organizations

SSA: Sub Saharan Africa

m: meter

C/B ratio or CBR: Costs / Benefit Ratio

ABSTRACT

Nearly 236 million in Sub Saharan Africa (SSA) were undernourished in 2017 due to food shortages. Agriculture in most of the SSA countries is rainfed and where irrigation is practiced inadequate surface method is used. In Chad, the agricultural sector is relatively inefficient despite the availability of fertile soils (39 million hectares) and abundant water resources. Irrigation accounts for less than 1% (out of 6% of cultivated lands) while only 9% of the potential water resources have been utilized. While increasing crop and water productivity, many studies agreed that Advanced Irrigation Technologies (AIT) could be profitable when growing high-value crops. However, little researches if not any, have attempted to study the potential and cost-effectiveness of AIT coupled with a sustainable financial model in the arid regions in Chad. Therefore, the objectives of the present study were to investigate the current socio-economic and environmental setups of Djaramaya irrigation scheme, to assess the adaptability of drip technology under high-value crop development as well as to analyze financial options, and sustainability of the scheme investment. Both qualitative and quantitative methods were used to conduct the research. A survey was carried out in Djaramaya scheme using a structured questionnaire for a sample size of 60 farmers that were purposively selected. Key informants from agricultural-related institutions including Ministries and agencies were also interviewed. Moreover, the research adopted investment appraisal technique using discounted cash flow method to simulate the financial viability of AIT investment in Djaramaya scheme. The results of the study showed that 45% of the studied area is suitable for AIT. The estimated NPV (positive) and C/B ratio (=2.76) at 10% discounted rate suggested that the investment in drip under tomato crop is economically viable. Besides, the study found that farmers would be able to recover the initial investment from the profit generated (IRR=25%) at the end of the third year. Furthermore, the study explored opportunities for sustainable financial model through private sector participation for revitalizing Djaramaya scheme. Guerdane's Public-Private Partnership (PPP) arrangement in Morocco was found to be suitable for the viability of Djaramaya scheme from which best practices can be transferred to Chad.

Keywords: Advanced Irrigation Technologies (AIT), drip, PPP, high-value crop, Djaramaya irrigation scheme, Arid regions.

RESUME

Près de 236 millions de personnes en Afrique Sub-Saharienne (ASS) étaient sous-alimentées en 2017 en raison de pénuries alimentaires. L'agriculture dans la plupart des pays d'ASS est pluviale et partout où l'irrigation est pratiquée, la technique demeure la méthode traditionnelle. Au Tchad, le secteur agricole est relativement inefficace malgré la fertilé des sols (39 millions d'hectares) et l'abondance des ressources en eau. L'irrigation représente moins de 1% (sur 6% des terres cultivées), alors que 9% seulement des ressources en eau ont été utilisées. Au-delà de leur pouvoir à économiser l'eau et leur grand rendement cultural, des nombreuses études ont confirmé que les technologies d'irrigation avancées (TIA) peuvent être très rentables pour les cultures à haute valeur. Cependant, peu de recherches, voire aucune, ont tenté d'étudier le potentiel et la rentabilité de TIA, associées à un modèle financier durable dans les régions arides du Tchad. Ainsi, les objectifs de la présente recherche étaient d'étudier les configurations socio-économiques et environnementales actuelles du système d'irrigation de Djaramaya, d'évaluer l'adaptabilité de la technologie de goutte à goutte dans le cadre du développement de cultures de grande valeur, ainsi que d'analyser les options financières et la durabilité de la technologie proposée. Les deux méthodes qualitatives et quantitatives ont été utilisées pour mener la recherche. Une enquête a été menée dans le cadre de Djaramaya à l'aide d'un questionnaire structuré pour un échantillon de 60 agriculteurs sélectionnés au hasard. Des personnes clés d'institutions liées à l'agriculture, y compris des ministères et des agences, ont également été interrogés. En outre, la recherche a adopté une technique d'évaluation des investissements utilisant la méthode de la valeur actualisée des flux de trésorerie pour simuler la viabilité financière d'investissement en TIA pour le cas de l'aménagement de Djaramaya. Les résultats de l'étude ont montré que 45% de la zone étudiée est propice à la TIA. Les estimations de la VAN (positive) et du ratio C/B (= 2,76) à un taux actualisé de 10% suggèrent que l'investissement dans le goutte-à-goutte sur la culture tomate est économiquement viable. Également, l'étude a révélé que les agriculteurs seraient en mesure de récupérer leur investissement initial (TRI = 25%) seulement à la fin de la troisième année. En outre, l'étude a exploré les possibilités d'un modèle de financement durable grâce à l'implication du secteur privé pour la revitalisation de Djaramaya. Ainsi, le modèle de Partenariat Public-Privé (PPP) de l'aménagement agricole de Guerdane au Maroc, utilisant le gout à gout sur des cultures à haute valeur, s'est révélé approprié pour la viabilité de celui de Djaramaya.

Mots clés : Technologies avancées d'irrigation, Gout à Gout, PPP, Culture à haute valeur, Aménagement de Djaramaya, Régions Arides.

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CHAPTER I: INTRODUCTION

I.1 Background

Food insecurity is one of the major challenges the word is facing in this 21st century. Globally, the number of undernourished is estimated to have increased from about 804 million to approximately 821 million between 2016 and 2017 (FAO, IFAD, UNICEF, 2018). The statistics are more alarming for the Sub Saharan Africa where the estimated number of undernourished people has increased from almost 222 million in 2016 to more than 236 million in 2017 (FAO, IFAD, UNICEF, 2018). Agricultural production has intensively been increasing over the last decades due to the continues increase in food demand around the word as a result of rapid increase in world population which is expected to reach 9 Billion by 2050 (FAO, 2014). The global crop production is estimated to double by 2050 in order to meet this pressing food demand and end global hunger (Tilman et al., 2011; Alexandratos and Bru-insma, 2012; Valin et al., 2014). This situation of food insecurity coupled with the population growth will require extensive agricultural production through irrigation which will lead to excessive water use. According to (FAO, 2012), irrigated agriculture represents already 70% of the global freshwater withdrawals and 90% of water consumption which makes it the largest water user; where half a billion around the world experience severe water scarcity almost every year (Mekonnen & Hoekstra, 2016).

Irrigation remains a crucial component of agriculture where the cereal production in the world would decrease by 20% without it (Ja¨germeyr et al., 2015). In the last five decades, irrigated lands have almost double and around 24% of the overall harvested cropland is irrigated and producing more than 40% of the global cereal yield, that is a major contribution to food security (FAO, 2012; Siebert et al., 2015). The last sugested that, to close the food production gaps and achieve the SDGs goals on food security and improved nutrition, more irrigated lands are needed.

Previews studies have concentrated on the aspects of efficiency of irrigation systems; However, little studies have been carried out in translating the research into practice by critically assessing the adaptability of AIT together with an adequate financial model. Most of the existing irrigation technologies (drip irrigation, sprinkler or precision irrigation) have proved technical effectiveness but there are still some gaps and challenges when it comes to the implementation level. One such gaps in Sub Saharan Africa is the lack of understanding and knowledge among farmers on how they can benefit in adopting and upgrading their irrigation systems. Another gap is the inappropriate planning and designing of irrigation technologies coupled with the failure of finding adequate funding mechanisms in order to finance and sustain such investment. Thus, integrating the local realities such as social, cultural, economic and environmental context is critical to holistically manage the scarcity of water resources and cope with the climate change. Therefore, there is a need in considering the readiness, skills, capability, and capacity of local farmers, water users association and the environmental context in order to provide holistically a suitable technology fitting all the stakeholder's needs.

For long period, Government have been the main contributor providing subsidies in supporting farmers activities as well as helping them coping with the climate change (Zhang, Hu, Li, & Pradhan, 2018). Government in SSA lack funds to support key sectors such as agriculture which employed more than 80% (NEPAD, 2013) of the population and significantly contribute to the national GDP. This is mainly due to the limit funding resources of the states that have to be shared among other competing sectors including security and health.

The Private Public Partnership (PPP) remains a common mode of management widely used in the different urban sectors such as transport, public services and facilities (Maatala, Benabdellah, & Lebailly, 2017). This concept of PPP have been recently introduced in the irrigation sector, especially in financing, operating and maintaining large scale irrigation projects (Outputs, Houdret, & Bonnet, 2013; Węgrzyn, 2016). However, very few studies, if any at all, that have tried to explore the potential of PPPs mechanisms in sub urban or rural areas of SSA countries particularly in Chad. It has been proven by some development finance institution including IFC that PPP is among the best alternative of financing large scale irrigation schemes in this 21st century where many governments failed in operating and maintaining their various agricultural projects. Recently, the Moroccan government has initiated a PPP irrigation project in the citrus-growing area of Guerdane, Taroudant province in Southern Morocco which was describe as a unique case worldwide (Houdret & Bonnet, 2016). The project was implemented in 2008 to supply with water an area of 10 000 hectares of highly profitable citrus plantation.

With similar studies, this research sought to contribute to existing literature by identifying potential options for AIT in Chad and SSA based on best irrigation practices and lessons learned from various case studies including Morocco. The study investigated the current socio economic and environmental setups of Djaramaya irrigation scheme, assessed the environmental and technical adaptability of drip irrigation technology under high value crop development as well as to analyzed financial options, and sustainability of the proposed drip irrigation technology. Furthermore, the research evaluated the potential for a PPP mechanism in irrigation projects in Chad (case of Djaramaya).

I.2. Problem statement

The economies of most countries in Sub-Saharan Africa (SSA) relies on the agriculture sector which is mainly rainfed, nevertheless the productivity of the sector remains very low despite the abundant water resources (Fonteh, 2017). Like the other SSA countries, in Chad, the agricultural sector employed more than 80% of the labor force (RGPH2, 2012). The agricultural sector dominated the country's economy until 2003, accounting for 40% of GDP in 2002 (World Bank Report). Since 2003, oil exploitation has changed the economic base of the country and the share of agriculture in GDP was only 23% in 2005 (World Bank Report). The agriculture in Chad is mainly rainfed and irrigation account only for less than 10% (out of the total harvested 1 300 000 hectares annually, irrigated lands represent only 100 000 hectares of the total) (SDEA, 2003). Even though, irrigated agriculture is a priority for the country's national develpmenent plan and in spite its vaious advantages, many irrgation schemes in Chad still use systems with less than 50% efficiency, leading to inefficient crop and water production.

During 2002-2012 decade, the Government of Chad has developed several framework documents to guide policies and strategies for agricultural, rural and food security development. All these frameworks confirmed that, beyond the opportunities offered by the oil exploitation, food sovereignty, the emergence of a diversified and competitive economy, and sustainable growth rely on the agricultural and pastoral sector. Some of these frameworks include the Declaration of Maputo (2003), the Intervention Plan for Rural Development (PIDR, 2002), the Master Plan of Water and Sanitation (SDEA, 2003-2020), the National Strategy for Poverty Reduction I (SNRPI, 2003-2006 and SNRPII, 2008-2011), the Master Plan of Agriculture (SDA, 2006-2015), the National Development Plan (PND, 2013-2015), the Five-Year Plan for Agricultural Development (2013 -2018) and the Comprehensive African Agriculture Development Program (CAADP). From these frameworks, many irrigation programs and projects were initiated in the differents regions of the country in order to unsure food security for all. However, most of the initiated projects focuse on developing surface irrigation schemes with total or partial water control. Due to the poor planning and implementation, inadequate financial model as well as high operation and maintenance costs and farmers inclusivness, several completed projects failed to reach their initial goals, and the ones in the process of completion were stopped because of some challenges. Djaramaya project, a large sclae irrigation scheme of 10 000 hectares located at 40 km downstream the city of Ndjamena, is one of these uncompleted projects initiated by the Governement to ensure food security in the locality and also supply with food the rapid gowing population of capital city Ndjamena.

In the other side, small scale irrigation schemes in the sub urban areas and around the city of Ndjamena, have been for years the main source of fresh food supply of the city. In the areas such as Linia, high value crop (onion, tomato, eggplant, green & red peper, cabbage…) were grown during the dry seasons contributing to support the life of many households. However, farmers in these irrigation schemes face many challenges due to the high operation cost, the water shortages, the limited fund sources as well as the poor irrigation system used which is mainly surface equiped with unimproved earth canals. A farmer in this area can easily pump water for at least an hour through the earth canals in supplying the farm, that is a huge amount of water wasted through unproductive infiltration as well as evaporation beside the high operation cost.

Therefore, this study focused at assessing the challenges faced by farmers and exploring opportunities for revitalizing Djaramaya scheme whereby proposing a suitable advanced irrigation technologies for adaptability in the case study.

I.3. Objectives of the study

1.3.1. Main Objective

The main objective of this study is to develop conceptual advanced irrigation technologies for adaptability in arid areas in Chad

1.3.2. Specific objectives research questions and working hypothesis

The specific objectives research questions and working hypothesis are summarized in the below table 1.1:

Table 1. 1: Specific objectives research questions and working hypothesis

Specific Objectives	Hypotheses	Research Questions
To investigate the current socio economic and environmental setups of Djaramaya irrigation scheme.	Farmers perceptions and assessment of the current socio demographic, economic, technical, economic, financial and institutional are key factors in providing suitable irrigation technologies for any site location.	What is the socio economic and environmental setups of the study area?
To assess the environmental and technical adaptability of drip irrigation technology under high value crop development in Djaramaya irrigation scheme.	Appropriate advanced irrigation technologies generate effectiveness in all the irrigation stages and hence increase the crop and water productivity.	What are the environmental and technical adaptability factors for drip irrigation technology under high value crop development in Djaramaya irrigation scheme?
To analyze financial options, acceptability, and sustainability of the proposed drip irrigation technology in Djaramaya irrigation scheme.	Financial profitability, social and cultural acceptance gives farmers incentives in investing for advanced irrigation systems. Private sectors and financing institutions are ensured about the sustainability of their investment.	What are the financial feasibility options to ensure the acceptability and sustainability of the proposed advanced irrigation technologies in Chad?

I.3. Rationale for the study

Agriculture in many arid regions in Africa still relies on surface irrigation system. Poor water management and agricultural practices have led to many environmental challenges including waterlogging and salinization. The socio-economic conditions of farmers are also affected as a consequence of low productivity and other related constrains such as financial.

Many farmers in Africa practicing traditional irrigation are mainly those who do not have the technical know-how; therefore, they are not much or at all aware of the benefit of adopting an advanced irrigation technology to increase their water and crop productivity. With awareness and practical demonstration of advanced irrigation technologies and their possible adaptation to the local realities, farmers can adopt and improve their irrigation techniques. This increases farmers' wealthier and ensure food security in the locality. In parallel, key financial, economic and environmental information, as well as farmers' perceptions on the different aspect of improved irrigation technologies, will be provided to policymakers, local authorities and financial institutions in fostering appropriate planning initiatives and actions.

It is stated in the Agenda 2063 of African Union: "Africa's agriculture will be modern and productive, using science, technology, innovation, and indigenous knowledge. The hand hoe will be banished by 2025 and the sector will be modern, profitable and attractive to the continent's youths and women". This current research using advanced irrigation technologies couple with the local knowledge and practices of farmers, contributes towards the attainment of this aspiration.

This work is also vital for the Islamic Development Bank (IsDB), it contributes in transforming agriculture and rural development in IsDB member countries as highlighted in the recent published AgriBook (Agriculture, n.d.).

Furthermore, the research contributes to achieving the global agenda of the Sustainable Development Goals (SDGs) at the local level. The SDG6 target 6.4[1], SDG2: "End hunger, achieve food security and improved nutrition, and promote sustainable agriculture" and the SDG 13: "Climate action" are addressed in this current study. In overall, the research, the research addresses directly six (6) SDGs goals from the global agenda (goals 1, 2, 6, 8, 13, 17).

1.5. Scope and limitation of the study

This study focused on developing conceptual advanced irrigation technologies for their adaptability in Chad within the area of Ndjamena Fara. Even though the study was limited to these areas, the findings and recommendations from this research benefit the Chadian Agricultural and Rural Equipment Ministry (MARE) as well as the SSA IsDB member countries. The research also evaluated the challenges of the existing irrigation schemes and

[1] By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.

identified opportunities for adaptability of AIT by interviewing key informants. Furthermore, the study proposed suitable advanced irrigation technology for Djaramaya irrigation scheme by analyzing holistically the technical feasibility, socio economic acceptability as well as the financial viability of the proposed drip irrigation technology. This research has used both qualitative and quantitative methods which assessed the socio economic and technical challenges and opportunities of Djaramaya scheme as well as the financial sustainability of the scheme investment using NPV, IRR, C/B ratio and Payback method. Moreover, the study analyzed the potential of PPP adoption in Djaramaya irrigation scheme with lessons learnt from Guerdane irrigation scheme (Morocco). However, detailed engineering designing of the proposed drip irrigation technology was not conducted in this thesis hence was briefly stated.

1.6. Thesis Outline

The Master thesis is divided into five main parts. Firstly, the introduction describing the background of the study, the problem addressed, the objectives, the research questions, and hypothesis, the justification as well as the scope and limitations of the study. The second part is concerning the literature review where relevant books, official reports and peer reviewed scientific articles were used to develop the theoretical framework and review previous works done in subject area. The Third part is the materials and methods or the methodology used to guide the study. This include the data collection techniques, the method of data analysis and reporting. In the fourth part, the results of the conducted analysis were presented and discussed. The conclusions and recommendations are presented in the fifth and last part of the document.

CHAPTER II: LITERATURE REVIEW

2.1.Introduction

The research studies picked for this literature review focused on 5 major elements, (1) the advanced irrigation technologies (including Drip & Sprinkler) (AIT) used in arid regions, (2) the economic and financial viability of AIT, (3) the concept of PPP in irrigation projects, (4) the operation & maintenance of AIT and (5) the factors affecting the adoption of AIT. Credible organizational websites and online journals were reviewed for online research articles including Science Direct, Elsevier, Springer, etc. In choosing literature to review, the researcher attempted to review research that was relatively recent and no older than 10 years. Thus, the research studies reviewed ranged in average between 2009 and 2019, with the majority of studies chosen from 2013 to 2019.

The keywords used in finding these relevant literatures were: Drip & Sprinkler irrigation systems, water scarcity, Public-Private-Partnership (PPP), public irrigation schemes and arid regions.

2.2.Definition of concepts

Water Use Efficiency: Water Use Efficiency or crop water productivity as described by some scholars, is defined by the input/output ratio, this means also the crop yield per unit of consumed water.

Water scarcity: According to FAO (2012), water scarcity is defined as an imbalance between available freshwater water supply and expressed need in a specified domain, under prevailing institutional arrangements and infrastructural conditions. There are mainly two types of water scarcity according to Seckler et al. (1998), (1) physical scarcity and (2) economic scarcity. However, the World Bank (2007) has referred to three types of water scarcity: scarcity of the physical resource, organizational scarcity, and scarcity of accountability. In the current research, the two lasts where considered as part of both the physical and economic scarcity.

Physical scarcity occurs when there are insufficient water resources to respond to the various needs due to some environmental conditions (including groundwater depletion and environmental degradation) or social discrimination in the water allocation. While economic water scarcity is defined as a condition whereby the unavailability of water is governed by poor hydraulic infrastructures (including lack of investment in the sector) and inadequate human capacity development to meet all demands. Many countries in Sub-Saharan Africa suffer from economic scarcity that can be addressed by developing further hydraulic infrastructures and equitably allocating of water in order to reduce poverty (FAO, 2012).

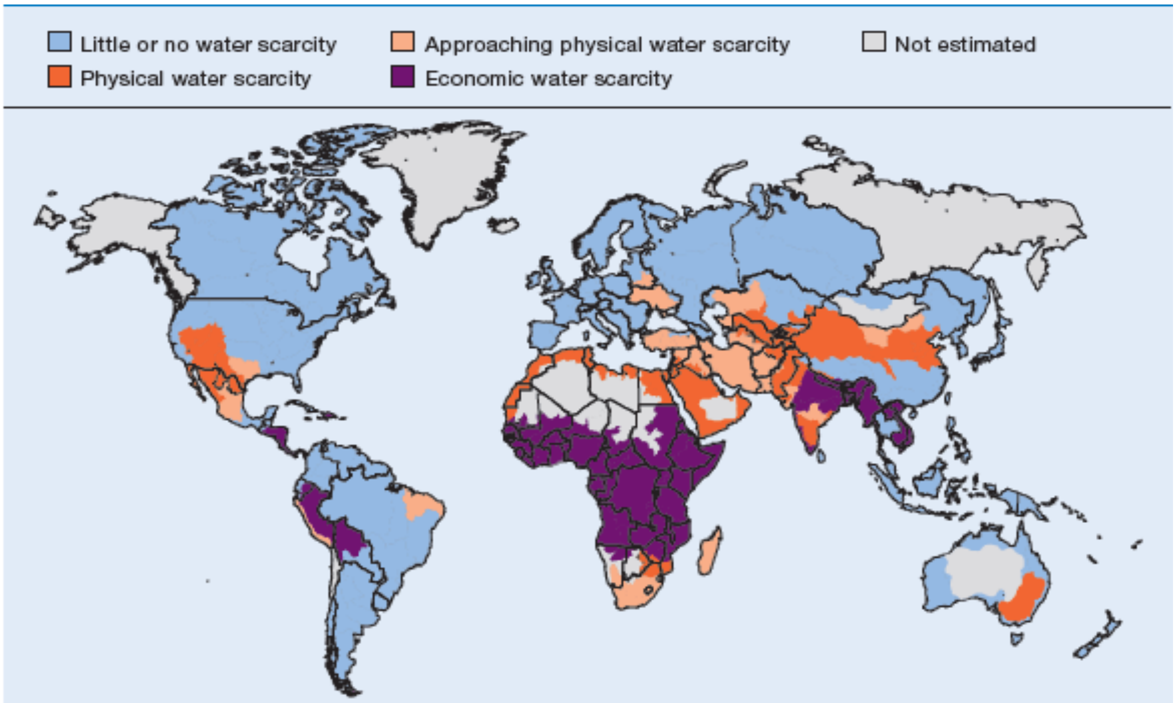


Figure 2. 1: World water scarcity map

Advanced Irrigation Technologies (AIT): AIT in the context of the current research refers to any water-saving irrigation technologies that is able to increase crop production and water productivity. Micro irrigation which is the slow application of water by surface or subsurface drip, bubbler, and micro sprinkler irrigation systems is considered among others as modern or advanced technologies for their ability to save water and increase yield (Li, 2019). *The current research refers to Drip and Sprinkler irrigation as advanced irrigation technologies or micro irrigation system.*

Public-Private-Partnership (PPP): a PPP refers to a set of long-term contractual arrangement between a public entity (State or local authority) and a private entity for providing a public asset or service (financing, building or managing the necessary works, equipment or intangible goods) in which the private party bears significant risk and management responsibility and receives in return remuneration (Mandri-perrott et al, 2016; Zawawi et al, 2014; Peter, 2005; Verma, 2012).

2.3.Irrigation technologies

Irrigation consists of an artificial application of water on agricultural land which occurs when there is lack or insufficient rainfall to supply the crop (Fereres & Soriano, 2007). There are different types of irrigation method including surface which is the oldest irrigation technique that uses an open channel that brings water by gravity to smaller canals irrigating the cultivated plots, and pressurized method (Sprinkler, Drip) which consist of pumping water from a surface or ground water then supply the crop in the form of artificial rainfall through a rotating sprinkler heads or in form of droplets at the root zone of the plant (Chris Perry & Pasquale Steduto, 2017) Pressurized irrigation systems generally seen as the most appropriate irrigation technologies if prove to be suitable with the local conditions. Compared to furrow, flood, or large-scale sprinkler irrigation systems, drip irrigation is seen as the most water-efficient and precise method (D. Li et al., 2018; Provenzano, 2007). They have the ability to supply water combine with fertilizers from the source to the plant's root without losses as well as preventing development of weeds (Tunc et al., 2019). Leakages from pipes, evaporation and illegal water uses are effectively handled in these types of technologies (Nouri et al., 2019).

2.3.1. Drip irrigation

Developed over thirty years, this technique involves bringing water under low pressure to the roots and distribute it in the form of droplets, using small pipes, placed on the soil or buried (Sharma & Suhirid, 2018). Some of the main characteristics of this technique are : "(1) water is applied at a low rate, (2) water is applied over a long period, (3) water is applied at frequent intervals, (4) water is applied near or into the root zone, (5) water is applied by a low-pressure delivery system, and (6) water is routinely used to transport fertilizers and other agricultural chemicals" (R. Lamm & R. Camp, 2007).

Drip irrigation technology, one of the recent methods of irrigation, is becoming nowadays popular in areas with water scarcity and salt problems. In these areas, the technology is used mainly for horticulture and vegetables due to its economic effects (Tunc et al., 2019).

Figure 2. 2: Drip irrigation systems, Source: ICID conference proceedings, 2018

2.3.2. Sprinkler irrigation system

Sprinkler irrigation is a versatile way to water any type of crop, soil and topography. It can be efficient in soil conditions or topographies for which surface irrigation methods are not. In general, the systems are defined according to the type of movement of the ramps on which different types of sprinklers are fixed. The ramps are fixed or mobile. In the latter case they are moved manually or mechanically. Manually moved ramps require the smallest investment but a very high labor requirement. This system can only be used on low growth crops. (Hedley et al., 2014).

Figure 2. 3: micro jet and mini sprinkler irrigation systems, **Source: ICID conference proceedings, 2018**

Many studies conducted in India have compared micro irrigation to conventional techniques of irrigation including furrow, basin, border or surge irrigation. The author revealed that micro irrigation is more efficient in many aspects of water management as compare to the conventional method. The table 2.4 below present a summary by different research workers.

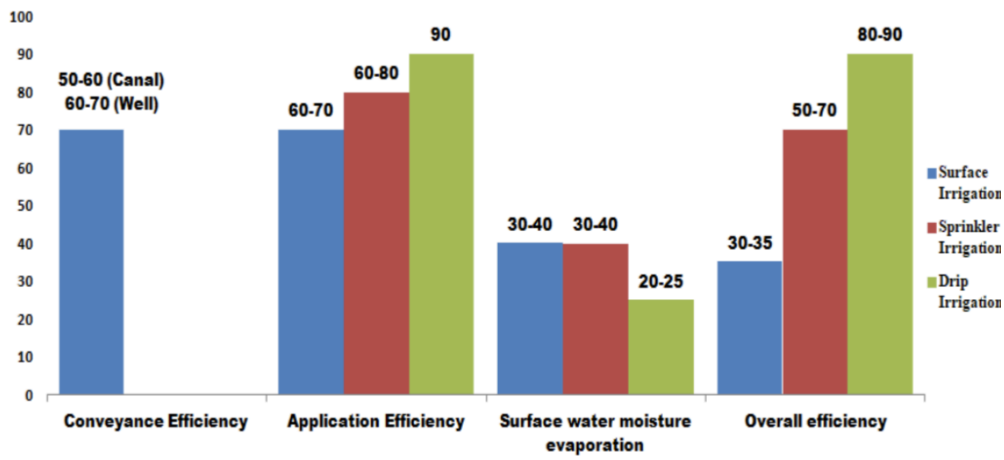


Figure 2. 4: Water use efficiency under various irrigation systems, Source: http://www.grantthornton.in

2.3.3. Global trends

According to FAO statistics (2014), 42% of the world irrigation is located in only 2 countries: China and India. In 2010 China became the country with the largest irrigation area.

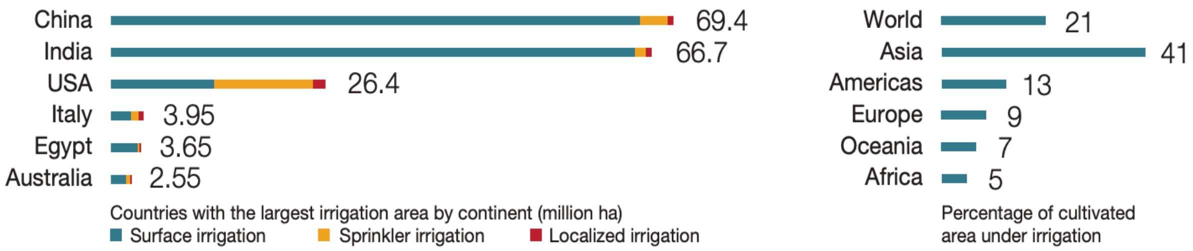


Figure 2. 5: irrigation share worldwide, Source: AQUASTAT, FAO's global water information system, 2014, http://www.fao.org/nr/aquastat

Modern irrigation technologies have shown a rapid growth in the last three decades all over the world. According to the International Commission on Irrigation and Drainage (ICID), the total acreage of micro irrigation in the world increased 25 times, reaching 14.4 million hectares (i.e. 6.2% of the total irrigated area) during the past thirty years. In India for example, area under drip irrigation has increased from 40 ha in 1960 to more than 2.7 million ha by 2000.

Table 2. 1: World drip irrigated areas

Country	**Area under cultivation, lakh hectare**	**Total irrigated area, lakh hectare**	**Drip irrigated area lakh hectare**
America	1790.00	214.00	10.50
Israel	4.37	1.99	1.61
Italy	109.75	26.98	0.80
China	1353.65	525.80	0.34
Jordan	3.90	0.75	0.38
France	194.83	20.00	1.40
India	1695	590.00	2.85(2000-01)
Egypt	33.00	33.00	1.04
South Africa	684.20	78.00	1.44
Cyprus	1.41	0.40	0.25
Spain	190.60	36.40	2.30

Source: ICID conference proceedings, 2018; ***1 lakh= 100 000.***

2.3.4. Operation and maintenance

The continuous efficiency of the AIT can be achieved only if the operation and maintenance of the system are properly maintained. This involve a proper Irrigation scheduling, determining when exactly to irrigate (evapotranspiration of the plant) and how much water is required (application rate) which is crucial for the effective operation of the system. Also, an advanced technology cannot effectively perform as designed and distribute water with a high degree of uniformity, unless the components of the systems are regularly maintained. For example, the major issues with drip irrigation is emitter clogging due to the accumulation of particulate, organic matter, and precipitates/lime. A successful operation of an AIT requires a frequent maintenance and specific attention to the following: (1) filters, (2) fertigation equipment's, (3) Submain & laterals, (4) Chemical treatments (R. K. Gupta, 2018).

2.4 Factors affecting the selection of irrigation technology

Many factors including soil, climate, topography, water source, energy, etc. are important and directly affect the selection of a specific irrigation technology.

2.4.1 Soil

The soil plays a key role in supporting the crop's development. The soil suitability for irrigation depends on the physical properties including the soil structures and texture, the geomorphological profile, the permeability, the cohesion as well as the chemical properties that consist of organic and inorganic matters (acidity and alkalinity). These soil parameters are important for a sustainable and diversified crop development (Zeng et al., 2011).

2.4.2 Climate

Temperature (minimum & maximum), sunshine intensity, humidity crop evapotranspiration and the length of the day have a significant effect on the irrigation planning (Iizumi & Ramankutty, 2015). The effective development of crops requires a certain climatic condition for an optimal growth.

2.4.3 Topography

The landscape characteristics including the slope which condition the surface water flow, as well as the parceling, are essential factors of irrigation planning. The topography determines work necessity requirement, erosion, drainage, land advancement and type of crops to be grown. For instance, plots with a uniform slope and low amplitude are suitable for irrigation because they significantly reduce the leveling cost, also some irrigation systems perform better in steep slope and vice versa.

2.4.4 Water Source and energy consumption

Constant availability of water is determinant to ensure a reliable supply to the field during drought periods. The source of water likewise helps in determining the amount of energy that can be utilized in pumping to ensure water is readily available for irrigation. The energy utilized for any irrigation system where pumping is required should be as low as possible so as to ensure that the farmer gains enough benefit from the farming activities.

2.4.5 Cropping patterns

The Rooting depth, growth stages, crop water use, ground cover, availability of market and demand frequency are the important parameters that affect the selection of the crop to be grown. In general, the cropping patterns whether it is a stable or a high value crop, dictates the type of irrigation technology to be used (Sun et al., 2015). Therefore, it is crucial to select a technology that is cost effective as compared to the selected cropping patterns.

Table 2. 2: Suitability of irrigation technologies vis a vis cropping patterns

	Crop category			
Irrigation system	1	2	3	4
Surface				
Basins, borders		x	x	x
Furrows, corrugations	x	x		x
Contour levee – rice		x	x	
Sprinkler				
Side (wheel) roll lateral	x	x		
Hand move lateral	x	x		x
Fixed (solid) set		x		x
Center pivot, linear move	x	x		
Big guns – traveling, stationary	x	x		
Micro				
Point source				x
Line source	x			x
Basin bubbler				x
Mini sprinklers & spray heads				x

Category 1. Row or bedded crops: sugar beets, sugarcane, potatoes, pineapple, cotton, soybeans, corn, sorghum, milo, vegetables, vegetable and flower seed, melons, tomatoes.

Category 2. Close-growing crops (sown, drilled, or sodded): small grain, alfalfa, pasture, and turf.

Category 3. Water flooded crops: rice and taro.

Category 4. Permanent crops: orchards of fruit and nuts, citrus groves, grapes, cane berries, bananas and papaya plantations.

Source: adopted from (Waller et al., 2015)

2.4.6 Economic Factor

In Chad, numbers of irrigation schemes failed to reach their design objective few months after the commissioning. However, in order for to achieve the desired objective of a scheme, the initial cost of the establishment of an irrigation project must be fully recovered. The revenue gain from the scheme must at least be equivalent to the cost of production. Poor harvest, low price of harvested crops in the market, high costs of input, poor irrigation management are factors that affect the economic outcome of an irrigation project. (Ali, 2010).

2.4.7 Institutional factor

Most of the irrigation schemes that collapsed in Chad have as major challenge poor institutional infrastructures and management. A sustainable irrigation project required a planned operation and maintenance, an adequate financial model and a cost effectiveness. In addition, adequate and effective institutional arrangement and policies are needed for proper designing, construction, operation and maintenance of the irrigation system.

2.5. Adoption of Irrigation Technologies

(Mango, Makate, Tamene, Mponela, & Ndengu, 2018) have investigated on the parameters influencing the applicability of small-scale irrigation farming as a climate-smart agriculture practice as well as the profit impact for smallholder farmers. The major results have shown that elements such as off-farm employment, access to irrigation equipment, access to reliable water sources and awareness of water conservation practices, access to market and farmer's age impact the establishment of a small-scale irrigation farming.

Another similar study was conducted by (Mutambara & Munodawafa, 2014) on the factors that affect the production and the sustainability of smallholder irrigation schemes in Zimbabwe. The authors used a mixed method to survey a total of 130 farmers using questionnaires, 11 key informant interviews and three (3) farmer group discussions in three (3) different schemes purposively selected. The study revealed that farmers cannot afford any extension project due to their limited resources, they can barely sustain subsistence farming. According to the results, only 40-67% of farmers had access to some agricultural inputs (Fertilizers & Pesticides) and this was mainly due to favoritism of some group of farmers over another which has resulted in the poor and unsustainable production. Unreliable electricity access for water supply, lack of access to financial services (0% of farmers had access to loan from a bank and only 17% got a loan from input suppliers) come in addition to the above factors hindering the sustainability of the schemes.

In a recent study by Fonteh, (2017), there is no universally agreed irrigation technology for a given area, many parameters like the soil characteristics, the water resources, the landscape, the seeds variability, the climate, the socio-cultural and capacity of farmers, the availability of public infrastructures, determine the type of the technology to be adopted locally. According to the same paper, small scale irrigation system if well managed are adequate due to their socio-economic profitability. However, to guarantee the sustainability of smallholder schemes, specific attention must be given to the installation, the operation and maintenance costs, the mechanisms to achieve efficient and equitable water allocation and the control of water losses.

2.6. Need of a new mode of finance for irrigation development

Beyond the famous concept of "more crop per drop", one must ask the question of the feasibility of the changes that this implies: capacity of small farmers to invest in switching from traditional irrigation to advanced irrigation systems, or the possibility of making radical shift in the cropping systems to save water. Historically, the development of irrigation in France with maize expansion, because there was a high demand from livestock and industry. In the Sahel, rice production remains dominant in irrigation because it is one of the staple foods for African cities. Changing cropping patterns to make more space for less water intensive techniques and crops also requires a review of the financing model, agricultural practices as well as the production conditions. In this context, it is up to the research to continue to analyze the different innovations that emerge in irrigated agriculture, to evaluate not only their potential but also the risks, with regard to the social dimensions on the allocation of water resources and the issues of sustainability. Therefore, it appears that there are alternatives to new financial model including Public-Private-partnership models but still, it should be precise to what extent they are socially, economically and environmentally sustainable. This will bring light on policy makers' trade-offs between different possible uses of the finite resource, food sovereignty and market-opening options.

2.7. Public-Private Partnership in Agricultural Development

Over the years, government have been the main if not the only actor in supporting the agricultural development and providing farmers with subsidies as well cooping the changing climate(Wu, Cui, Xie, & Luo, 2018; Zhang et al., 2018). However due financial constrain, many governments in SSA cannot afford additional investment in construction of irrigation infrastructures, their management and maintenance as well as ensuring the value chain (including production harvest and market services) (NEPAD, 2013; Dittoh et al., 2010). Because of this situation, much consideration has been given to the implication of private sector jointly with the government to continue providing support to farmers with reliable agricultural services in order to achieve food security (World Bank, 2017).

The Public-Private Partnerships is a recent phenomenon in the irrigation arena in which, the major objectives of the government is to (1) increase the investment rate of the sector by attracting more capital and reducing the operation and maintenance burden by delegation the management of the schemes, (2) ensure the sustainability of the large irrigation investment (due to the high subsidy cost in the annual budget) by contracting with a private sector which can provide innovative management in the delivery of the services, (3) to create an enabling business environment for the development of a commercial agriculture rather than subsistence for local, national and international markets.

Countries around the word including Morocco, Ethiopia, Egypt, Bangladesh, Brazil and India have initiated and properly developed the PPP model, the reason being that private sector can support technically and financially part of the investment cost (Bizuhoraho, 2018; Florian, 2017). However good governance, accountability of the systems and the effectiveness of the legal and institutional framework are the major driven forces to ensure the sustainability of any PPP model. Additionally, sustainable irrigation system with advanced irrigation systems facilities coupled with adequate PPP model, will effectively work in the irrigation sector through judicious use of water resources (A. Kashem, 2009).

Considering the current trends of agricultural value chains in some developing countries and transitional economies, good opportunities emerged for new PPP models. Public entities and donor agencies have been piloting these in recent years, and the results have shown that they have effectively worked under certain conditions (FAO, 2018).

2.7.1. PPP concepts

Agricultural Value Chain. This refers to the value addition at each level of the agricultural production cycle, from the farm level up to the market or the final consumption where by the different actors and activities are identified along the process. Various steps including processing, packaging, storage, transport and distribution are involve in this “value chain” (World Bank, 2016; FAO, 2005).

Design-build-finance-operate-transfer (DBFOT). In this PPP the private sector takes full responsibility for the designing and financing of the irrigation assets. The private sector is also responsible for building, operating and maintaining the assets during the life of the contract, but at the end of the contract period the assets are transferred back to government (World Bank Group 2016).

Design-Build-Operate (DBO). It is a type of contracts in which the private sector is involved in the designing, the construction and the operation of the facilities for a certain agreed output within a period of time. In this type of PPP, the government or the public sector naturally owns and finances the construction of the facilities (Mandri-perrott & Bisbey, 2016; MoLG, 2011). In this type of contract, the operations period is long enough to allow the private company to pay off the construction costs and realize a profit (FAO, 2009).

Divestiture: In this type of PPP, the government sells all the public owned irrigation facilities to the private sector. In this situation, the private firm takes on indefinite ownership and responsibility for all aspects of the scheme including construction, rehabilitation, operations and maintenance (Mandri-perrott & Bisbey, 2016).

Concession: It is a form of project development in which the private sectors receive from the government a grant of economic rights of a public asset (including the legal ownership of the land) under a set of specified rules and regulations, that guide the operation of the project. The private sector bears the investment cost of construction, provision of services, maintenance, and management of irrigation infrastructures and receives in return revenues from users (Mandri-perrott & Bisbey, 2016) .

Lease/affermage: Similarly, to a concession, in a lease contract the private sector still partially of fully in charge of the operation and maintenance and share commercial risks with the government which is typically remains responsible for providing the capital investment for the assets (World Bank, 2014). According to Peter (2005), this kind of PPP is attractive especially when the government due to financial constraint decide to hand over the O&M to private sectors and receive back regular renting payment.

Operation, maintenance and management (OMM): OMM is a type of contract where by the private sector is responsible of the operations, maintenance and management activities of the irrigation services (water allocation, maintenance of equipment's, provision and support services including farmers training…). The assets remain the property of the government and the private sector receive back service fees from the farmers (Mandri-perrott & Bisbey, 2016)

Sustainability of the irrigation scheme: this concept implies the long-term abilities of all the stakeholders involve in the PPP contract (including the government which has granted the PPP, the private company(ies) that offers the services, and the farmers that are benefiting from the services), to benefit continuously and in a sustainable way from the project. This means for the private sector to ensure profitability of the operation and maintenance of the irrigation scheme (collection of the service fees) in order to recover the O&M and the investment cost. Sustainability is therefore strongly related to a sustainable agricultural value chain as a consequence of an increased income that will enable farmers to cover their service fees and remain profitable (World bank, 2016).

2.7.2. Type of PPP

PPP arrangements can manifest in a wide variety of forms, considering the type of contract between the entities, the shared responsibilities and the level of risks (World bank 2016, Varma et al.,2012).

Table 2. 3: Type of PPPs contract

	Type of model	Description of contract purpose	Risk assumed by private sector	Length of contract	Capital invstment	Asset ownership
	Service contrct	Infrastructure support services such as billing	Low	1–3	Public	Public
Broad definition of PPPs	Management contract	Management of a part/ whole of the operations	Low/Medium	1–5	Public	Public
Broad definition of PPPs	Lease/Affermage contract	Management of operations and specific renewals	Medium	10–15	Public	Public
Broad definition of PPPs; Core PPPs	Build Own Transfer (BOT); Build Own Operate (BOO); Design Build Operate (DBO)	Invenstment in and operations of a specific component of the infrastructure service	High	Varies	Private	Public/Private
Broad definition of PPPs; Core PPPs	Concession	Financing and operations and execution of spcific investments	High	25–30	Private	Public/Private
	Divestiture/ Privatisation	Transfer of ownership of public infrastructure to the private sector	Complete	Indefinite	Private	Private

Source: World bank 2016

Table 2. 4: Responsibilities taken by the private sector under different PPP models

<table>
<tr><th rowspan="2">Source of revenue for private firm</th><th rowspan="2">Functions to be allocated between private sector and government</th><th colspan="6">Participation of private sector in investment functions (capital expenditure)</th></tr>
<tr><th colspan="2">Yes</th><th colspan="4">No</th></tr>
<tr><td rowspan="4">Services paid to the private operator by the final users (farmers)—Public Service Delegations (PSD)</td><td>Design</td><td colspan="2" rowspan="4">Concession arrangement</td><td colspan="4" rowspan="4">Lease/Affermage arrangement</td></tr>
<tr><td>Construction</td></tr>
<tr><td>Transfer of inftrastucture after completion of construction</td></tr>
<tr><td>O&M</td></tr>
<tr><td rowspan="7">Services paid to the private operator by the Public Authority</td><td>Design</td><td rowspan="6">Build Own Transfer (BOT)</td><td rowspan="7">Build Own Operate (BOO)</td><td rowspan="2"></td><td rowspan="3"></td><td rowspan="2">Engineering Procurement Construction (EPC)</td><td rowspan="6">Design Build Operate contracts (DBO)</td></tr>
<tr><td>Construction</td></tr>
<tr><td>Management (staff of private operator in Public Entity)</td><td>Management contract</td><td rowspan="5"></td></tr>
<tr><td>O&M</td><td rowspan="4"></td><td>O&M contract</td></tr>
<tr><td>Ownership of O&M assets</td><td rowspan="3"></td></tr>
<tr><td>Transfer of inftrastucture after completion of construction</td></tr>
<tr><td>Ownership of infrastructure</td><td></td><td></td></tr>
</table>

Source: BRL (2011) PPP Options study and awareness raising for irrigation investment in Malawi.

Table 5 shows how the different responsibilities associated with irrigation schemes are allocated under the various types of PPP models, defined by: the source of revenue for the private firm; the allocation of functions between the private sector and government; and the participation of the private sector in the capital expenditure of the scheme. The shaded areas represent responsibilities taken by the private sector under each model.

2.7.3. Contractual arrangements

The form of contract agreed between the public and private party to facilitate development or operation of infrastructure will be influenced by at least three factors: (i) the degree and type of risks associated (the higher the risks, the less likely the private sector will invest in building long-term assets, and the more inclined they will be to enter lower-risk lease, management or service contracts); (ii) the level of user demand (the higher the required volumes of capital investment and the lower the user demand, the greater the need for long-term agreements in order to realize a return on investment, such as Build-Operate-Transfer (BOT) contracts; and (iii) the extent of public subsidy (the higher the level of subsidy, the more readily the private sector will invest its own resources, or leverage resources from lenders, and thus the more willing to entertain higher risk concession agreements) (FAO, 2005).

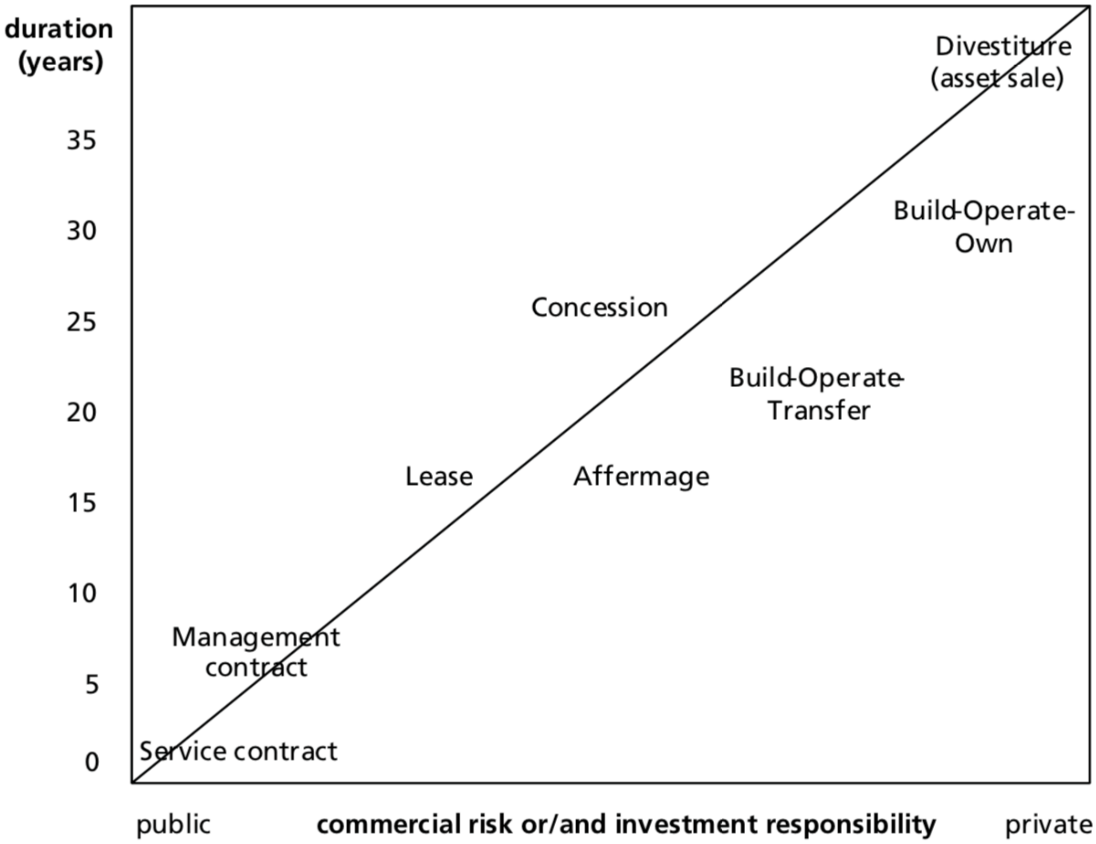


Figure 2. 6: contractual forms against duration and levels of risk and investment, Source: FAO, 2009

2.7.4. PPP in irrigation projects, between success and failure

The overall objective behind any PPP arrangement is to facilitate the development or the operation of agricultural infrastructures which includes the upgrading of the irrigation system towards advanced technologies, the strengthening of human resources capacities as well as the improving of the socio-economic conditions of farmers and the local communities.

The PPP in Agriculture development could be facilitated or hindered by government policies, the institutional arrangement, the laws and regulations. Strengthening and harmonization of this factors (quality control, monitoring, regulations and policies, institutional…) will give incentives and attack the private firm to invest in the sector (Burton et al., 2002).

There are different factors that determine the success or failure of a PPP arrangement. These factors include but not limited to: the novelty of private participation in irrigation sector, the insufficiency of long-term capital markets, and the balancing of subsistence farming's needs with those of agri-business in some emerging economies, the inefficient farmers' organizational structures (cooperatives, water use associations) and the willingness of farmers to pay water services and access to off farm services can strongly influence the design and type of PPP structure that is to be developed. Consequently, strategies and projects must be adapted to new market conditions; these should include an early focus on viability of the proposed scheme, a clear delineation of roles between the construction of assets, their maintenance, and operation, and the production of agricultural goods. Flexibility in bidding to allow financial close and, most importantly, rethinking the manner of government support (financial and regulatory) will be key to foster the development of PPPs in irrigation (World bank 2016). The status of Land ownership whether it belongs to the government or privately own is also affecting the private sector participation (OECD, 2014).

In the developing world and transition economies, there are few examples of PPPs in irrigation development that have shown different perceptions from regarding their success. Some of these PPP projects include the El Guerdane project in Southern Morocco which is the first of its kind worldwide (water mobilization, supply, and management). The PPP established in 2008, provides water to 10,000 ha of highly lucrative citrus fruit plantations. International development institutions especially IFC present this project as a success story. However, for some researchers such as Annabelle Houdret (2013) revealed that the outcome of this project in terms of local development have been mixed. While some farmers have benefited from the initiative, most small-scale farmers around the project area have experienced increased marginalization from water, fertile land, and development. The author has conducted an extensive field research between 2006 and 2013 in the El Guerdane area that identifies three critical issues posed by PPPs: (1) effects on livelihoods and socioeconomic development within and beyond the project area; (2) unequal sharing of costs, benefits and risks between public and private partners; and (3) uncertain environmental impact.

CHAPTER III: METHODOLOGY

3.1. Background profile of the country

Located in the heart of Africa, Chad, the 5th largest country of Africa (1,284,000 km^2) lies between the 7th and 24th degrees North latitude and between 14th and 24th degrees East longitude. It is limited by six countries: Libya in the North, Sudan in the East, Central African Republic in the South, and Cameroon, Nigeria and Niger in the West. Chad is characterized of three bioclimatic zones: (1) the Saharan zone in the north (47% of the area), (2) the Sahelian zone in the center (28% of the area) and (3) the Sudanian zone in the south (25% of the area).

Figure 3. 1: map of chad

The Sahelian (zone of the case study) agricultural economy is traditionally based on cereals (millet) and oilseeds (groundnuts). In this region, any significant intensification of production cannot be conceived without irrigation due to the climatic condition.

3.2. General description of the study area

Djaramaya irrigation project is located at 45 km north of the capital city of N'Djamena and is accessible via the N'Djamena - Djaramaya - Dandi National road. The project covers a total area of about 20 000 ha located on both sides of the Djaramaya - Dandi national road.

The farm unit concerned by this current study, covering an area of 3000 ha, is located within the band between the Djaramaya - Dandi national road and the Chari river, which is also the natural border between Chad and Cameroon. The location of the 3,000 hectares farm is shown in Figure 3.2.

The strip between the Djaramaya - Dandi national road and the Chari river covers an area of about 13 000 ha. This zone consists of:

- A series of depressions (pools) alimented by natural channels or by the convergence of runoff water. Vegetation in these areas is very dense due to the presence of water for a longer period of the year. Recessional sorghum crops are grown in these areas;
- Bumps and soils are almost completely bare.
- Small traditional irrigated areas developed mainly along the Chari river.
- A marigot (blue line on the satellite image below) that crosses the perimeter from South to North for more than 24 km. It is located on an average of 500 to 1000 m on the left bank of the national road Djaramaya - Dandi. A set of culverts structures along the road allows the flow of water on both sides;
- Plains suitable for development on plateaus and generally separated by areas of depression;
- Villages and hamlets bordering or within the perimeter. Large villages are usually close to existing hydro-agricultural development

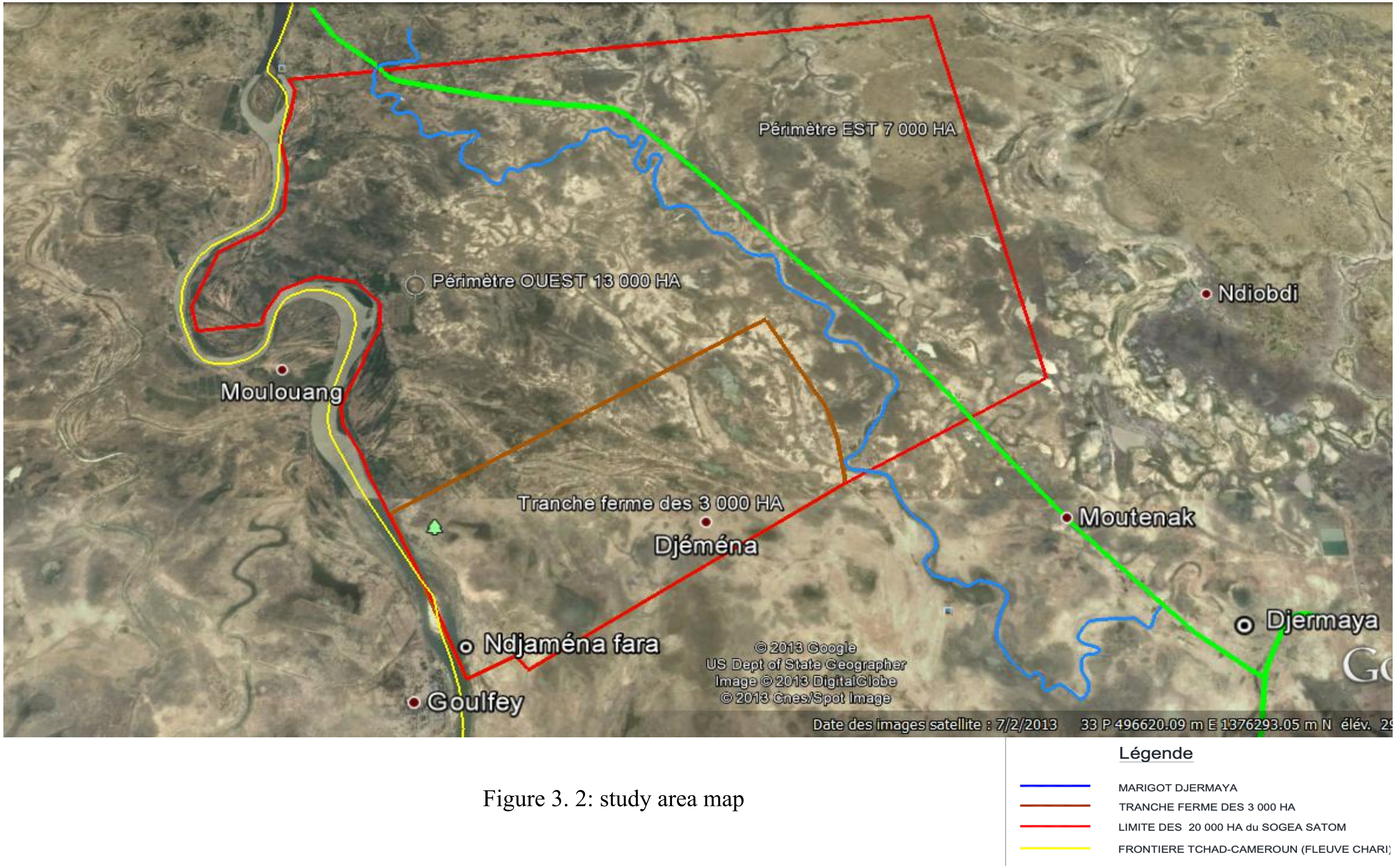


Figure 3. 2: study area map

3.2.1. Climate and rainfall

The study area benefits from a dry tropical climate that evolved from the Sudano-Sahelian type between 1951-1967 towards the Sahelian type. It is characterized by two main seasons including:

- A long dry season (7-8 months, from November to May) during which the monthly mean values of the relative humidity of the air remain below 50%, and;
- A short-wet season (3-5 months, from May to October).

The rainfalls fluctuate from 400 to 700 mm / year in the form of more or less violent storms. In recent years, the precipitations concentrate on three months (July-September). It happens that a tenth of the annual rainfall falls in a single day, flooding most of the perimeter area for several days.

3.2.2. Vegetation

The study area is characterized by a savannah tree cover, mainly consisting of Acacias species. There is also steppe vegetation, as well dense formations of Balanites aegyptiaca.
On the banks of the Chari River, in the flooded basins and ponds there are special plant formations of Acacia seyal, Acacia sieberiana, Acacia nilotica, Acacia senegal, Zizyphus mauritiaca.
In the west towards Fahd, there is alternation between the Acacia Senegal steppe, Piliotigma reticula, Tamarindus indica, Bauhinia rufescens, Acacia senegalensis, Cadaba farinosa; on sandy soils: Ziziphus mauritiaca, various Capparis, Boscia senegalensis, Bauhinia rufescens. and empty or sometimes strewn patches of Hyphaene thebaica on the levees.
In the deeply inundated lowlands, there are tall herbaceous formations of the genus: Andropogon pseudapricus, Bracharia jubata, Cyperaceae, Scleria tessellata, Scirpus supinus, Bracharia jubata and Eragrostis atrovirens, sometimes grasses of Panicun afzelii and P. anabaptistum.

3.2.3. Hydrography

The study area is located on the right bank of the Chari River, which is the main source of water supply for the hydro-agricultural perimeter of the 3,000 hectares farm. The hydrographic network consists mainly of the Chari River receiving or feeding several destroyed or rarely functioning flood channels. During floods, the water overflows from the minor river bed and invades the channels and ponds in first position and then submerge only the lower parts of the studied area. Under natural conditions, the channels also fill with runoff during the rainy season and feed all the depressions, before the flooding of the river. After the rainy season, the water disappears mainly by evaporation and infiltration. According to the design project report, observations made during the study mission show that the groundwater levels are below 40 m (perhaps 60-80 m or beyond as showed in some literatures).

3.2.4. Humidity and evaporation

The relative humidity of the air is maximum during the rainy season and minimum at the end of the dry season. It reaches 70% in August and 20% in February-March that is not exceeding an annual average of about 36%. The values of potential evapotranspiration (evaporation of a natural surface to which water is supplied without restriction: PET) are therefore maximum in April-May and minimum in August and comprising between 1800 mm / yr and 2600 mm / yr. (Brunel, Bouron 1992).

3.2.5. Water quality

The table shows very alkaline reactions for both the river and the boreholes surveyed. The water of the river is weakly mineralized, on the other hand the waters of the aquifers are rather mineralized, especially of those of Hillou Moussa. The analysis shows a dominance of anions and especially a dominance of Na^+. The dominant salts are chlorides, followed by sulphates, the carbonate contents being very low. The dominant cations are in ascending order: sodium followed by calcium, magnesium and potassium. The results of the water analyses are provided in Table 3.1.

Table 3. 1: Principal parameters of the water quality

Localization	**Source of water**	**Na^+ mg/l**	**Mg^{2+} mg/l**	**Ca^{2+} mg/l**	**K^+ mg/l**	**HCO_3^- mg/l**	**SO_4^{2-} mg/l**	**cl^- mg/l**	**$NO3^-$ mg/l**	**pH**	**SAR**	**EC µs/cm**
N'djamena Fara	River	10.77	3.3	3.41	3.01	50.2	0.975	3.472	1.144	7.79	1.8	92
Hillou Moussa	borehole	110.4	42.82	94.1	9.42	519.6	198.58	15.617	1.529	8.22	15.2	1292
Hillou Haroune	borehole	70.71	39.69	50.13	10.18	501.19	31.103	4.036	0.472	8.22	9.5	877
Fahd	Well	48.27	9.57	64.7	7.48	4.2	330.2	20.935	430.98	8.33	6.2	602

Source: Betico

3.2.6. Temperature

The temperatures observed in N'Djamena are between 14 ° C (average minimum temperature January) and 41 ° C (average maximum temperature April). The table below shows the average monthly temperatures and rainfall in Ndjamena.

a. Air temperature

In the study area located in Chari Baguirmi region, average interannual temperatures oscillate between 26 °C and 28 °C. During the hot season, average monthly temperatures range from 28 °C to 32 °C, and show a slight decrease during the rainy season, with 26 ° C to 28 ° C in August. The cold season, from November to February, presents an annual minimum temperature in January, with 21 °C to 23 °C (Roche, 1973). The diurnal difference is minimum at the middle of the rainy season (7 °C to 10 °C) and maximum from December to February (16 °C to 20 °C).

b. Rainfall:

- A long dry season (7-8 months, from November to May) during which the monthly mean values of the relative humidity of the air remain below 50%.
- A short-wet season (3-5 months. from May to October).
- The rainfalls fluctuate from 400 to 700 mm / year.

Table 3. 2: Monthly average temperature and rainfall at Ndjamena

Month	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May.**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**	**Year**
Average min temperature (°C)	14,3	16,6	21,0	24,8	25,8	24,7	23,1	22,4	22,7	21,8	17,8	14,8	20,8
Average max temperature (°C)	32,4	35,2	38,7	41,0	39,9	37,2	33,5	31,6	33,7	36,9	35,8	33,5	35,8
Rainfall (mm)	0,0	0,0	0,3	10,3	25,8	50,3	144,0	174,4	84,3	20,3	0,1	0,0	509,8

Source : Le climat à Ndjamena (en °C et mm, moyennes mensuelles) Climate-Charts.com

3.2.7. Topography

The study area is a vast plain that is presently under rough exploitation. The topography is relatively flat but with some low areas (ponds) and large mounds. The altitudes are between 290 and 297.50 m in the general leveling system of Chad. The slope of the study area is approximately 15 cm / km oriented south-north and a slight slope (5 to 10 cm / km) from east to west.

3.2.8. Agricultural activities

According to a survey conducted by Betico-Mali (engineering consulting company), agriculture is the main economic activity in the region (7 out of 8 villages practice it). It is also the activity that generates the most of the population's income except in Dazaga where this role is played by livestock. According to the agricultural seasons, between 71 and 74% of households practice rainfed sorghum / maize compared to 29 to 33% for rice. The agricultural statistics of the Haraze AL-Biar rural development sector presented in the table below highlight the important place of rice in the production systems of the region.

Table 3. 3: occupied surfaces of cereals in the Haraze Al-Biar sector from 2009 to 2012.

Cereals	**Surfaces in hectares**			
	2009	**2010**	**2011**	**2012**
Corn	13 585	15 600	14 075	14 278
Sorghum	9 563	9 700	9 009	10 599
Penicillary millet	4 635	4 950	4 480	9 631
Beré beré millet	2 000	4 200	3 500	4 108
Rice	1 100	1 200	580	1 065
Total	39 945	31 883	31 644	39 681

Source : Adopted from « Rapports bilans 2010-2011 et 2012-2013 du secteur de Haraze Al-Biar ».

Regardless of the year of observation, dry cereals account for more than 95% of the area planted:

- Maize accounts for 35 to 50% of the area;
- Sorghum accounts for 25 to 30% of the area;
- The penicillary represents 10 to 25% of the areas;
- Beré beré millet represents 5 to 15% of the areas;
- And rice represents 2 to 4% of the areas with 1000 to 1200 hectares for the whole area of haraze al-biar.

3.3.Research design

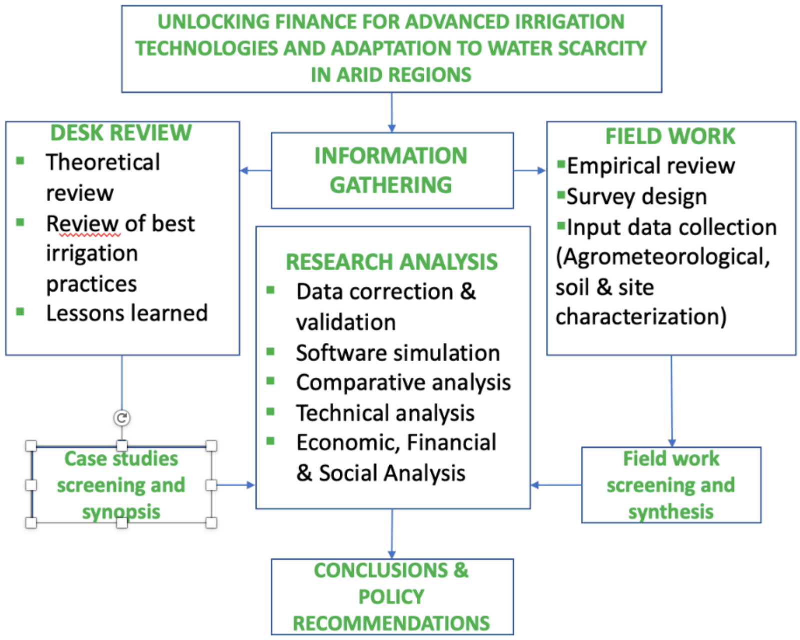


Figure 3. 3: Proposed research design, source: author construction

3.4. Data collection and analysis

3.4.1. Data collection and sampling method

This study has adopted both quantitative and qualitative method or a mixed method design. The research was based on primary and secondary data as input. For the primary data, a series of in-depth interviews were conducted with senior experts, project coordinators and directors in the Ministry of Production, Irrigation and Agricultural Equipment as well as the Agricultural Bank of Chad. A questionnaire was developed based on these interviews and relevant literature from publication. The structured questionnaire included fixed- choice questions. A seven-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree) was used as a quantitative measure. The quantitative questionnaire was divided into 6 main sections assessing the farmers perception of their current irrigation systems. The first section was designed to gather information about social and demographic characteristics of respondents. The second section was designed to assess the agricultural input factors, the third part was designed to evaluate the economic factors, the fourth touched the technical factors, the fifth part was concerning the institutional arrangement factors. The respondents were asked to indicate their agreements with statements by marking their response on a seven points Likert- type scale. The variables are presented in Table 3.5.

Table 3. 4: Items used in the quantitative survey

Socio Demographic Factors	Economic Factors	Financial Factors
Gender	Annual crop production	Cost of the system
Age	Labor use	Water tariff
Education level	Annual income (on farm)	O&M of the system
Farming experience	Annual income (out farm)	Access to credit
Household size		

Technical factors	Institutional factors
Irrigation Technology	Awareness
Water use efficiency	Information access
Water accessibility	Capacity building
Water quality	Degree of participation
Fertilizers and pesticides access	Market accessibility
Crop grown	Government subsidy

The survey was conducted with the household head or the key farm decision maker, as well as any other members of the household that were regarded as key informants. When multiple respondents were relevant, the survey was conducted with all respondents at the same time.

The first author and a team of experienced bilingual enumerators carried out data collection. The team participated in a one 3 hours training workshop to be familiarize with the questionnaire and to ensure consistent data collection. Subsequently, the questionnaire was field-tested in a sample size of 15 farmers located in Klessoum and Linia, and further refined, before implementation. At Ndjamena Fara, the aim was to survey all the farmers in the 3000 hectares farm unit. However, due to time constrained and unavailability of some farmers during the administrated period of survey (April 2019), 60 farmers were interviewed. The sample were purposively selected using a random sampling technique. For the qualitative survey, 12 key informants from the Ministry of Production, Irrigation and Agricultural Equipment (7), the Agricultural Bank of Chad (1), Economic and Monetary Community of Central Africa (CEMAC) Regional Research Centre Applied to the Development of Agricultural Systems (1), Ministry of the Environment, Water and Fisheries, the Regional agronomic research center for Sahel zone (3), Ndjamena Fara Irrigation Project (2).

The secondary data was concentrated on scientific and peer reviewed publications, agrometeorological & soil data, reports and lesson learned from international agencies in the thematic area, case studies and best practices from different perspectives.

3.4.2. Data collection techniques & Source

Table 3. 5:Research objectives, data sources and collection techniques

Research objectives	Sources of Data	Data Collection Techniques
To investigate the current socio economic and environmental setups of the Djaramaya irrigation scheme	○ Location sites ○ Agriculture and Water Resources Authorities	○ Questionnaire design ○ Interviews ○ Direct Observations
To assess the environmental and technical adaptability of drip irrigation technology under high value crop development in Djaramaya irrigation scheme.	○ Agriculture and Water Resources Authorities ○ National and International Agencies ○ Agrometeorological Stations ○ Environmental agencies ○ IsDB experts, consultants	○ Survey ○ Document Analysis ○ Desk review ○ Internet-based ○ Physical collection
To analyze financial options, acceptability, and sustainability of the proposed drip irrigation technology in Djaramaya irrigation scheme.	○ Farmers ○ National & International Agencies ○ Agriculture and Water Resources Authorities ○ IsDB experts, consultants ○ Environmental agencies ○ Research centers	○ Questionnaire ○ Document analysis ○ Market Analysis

Source: Authors elaboration

3.4.3. Data Analysis and reporting

a. Statistical analysis

To analyze the primary data generated from the field survey, both the Statistical Package for Social Sciences (SPSS) software version 25 and Microsoft Excel software version 2019 were used. To facilitate the data reporting and analysis an automated online google form was used to collect the information. The data were then introduced into the SPSS with respect to software parameters and following the Likert scale style. Finally, the formatted data were converted into an excel format for the detailed analysis and outputs.

Records	Gender	Age	Education_level	Farming_experie...	Household_size	Irrigation_technology	Water_use_efficiency	Water_accessibility
1	Female	45-60	No formal educati...	10-15	5-7	Strongly disagree	Disagree	Disagree
2	Female	25-44	No formal educati...	5-10	3-5	Strongly disagree	Strongly disagree	Disagree
3	Female	45-60	No formal educati...	10-15	5-7	Strongly disagree	Disagree	Strongly disagree
4	Female	25-44	No formal educati...	5-10	3-5	Strongly disagree	Disagree	Disagree
5	Female	25-44	No formal educati...	5-10	3-5	Somewhat disagr...	Strongly disagree	Neither agree or ...
6	Female	15-24	No formal educati...	5-10	<3	Strongly disagree	Disagree	Somewhat agree
7	Female	25-44	No formal educati...	5-10	3-5	Disagree	Somewhat disagr...	Somewhat agree
8	Female	45-60	Primary	10-15	5-7	Strongly disagree	Disagree	Somewhat agree
9	Female	45-60	No formal educati...	10-15	5-7	Strongly disagree	Disagree	Neither agree or ...
10	Female	45-60	Primary	10-15	5-7	Strongly disagree	Strongly disagree	Neither agree or ...
11	Female	45-60	No formal educati...	>15	5-7	Strongly disagree	Disagree	Disagree
12	Female	45-60	Primary	>15	>7	Disagree	Disagree	Neither agree or ...
13	Female	45-60	Primary	>15	>7	Disagree	Disagree	Neither agree or ...
14	Female	45-60	Primary	>15	5-7	Disagree	Disagree	Somewhat agree
15	Female	45-60	No formal educati...	10-15	5-7	Strongly disagree	Somewhat agree	Disagree
16	Female	45-60	No formal educati...	10-15	5-7	Somewhat disagr...	Neither agree or ...	Neither agree or ...
17	Female	45-60	No formal educati...	10-15	3-5	Somewhat disagr...	Somewhat disagr...	Somewhat disagr...
18	Female	25-44	Primary	10-15	5-7	Disagree	Somewhat disagr...	Neither agree or ...
19	Female	45-60	No formal educati...	10-15	3-5	Disagree	Somewhat disagr...	Agree
20	Female	45-60	No formal educati...	10-15	3-5	Disagree	Somewhat disagr...	Somewhat agree
21	Female	15-24	Primary	<5	<3	Disagree	Somewhat disagr...	Somewhat agree
22	Female	60+	No formal educati...	5-10	>7	Disagree	Disagree	Strongly agree
23	Female	45-60	No formal educati...	5-10	5-7	Disagree	Disagree	Neither agree or ...

Figure 3. 4: SPSS data analysis view, Source: author

	Irrigation_technology	Water_use_efficiency	Water_accessibility	Water_quality	Fertilizers_pesticides_access	Crop_grown	Annual_crop_production	Labor_use	On_farm_Annual_income	Out_farm_Annual_income	Cost_of_the_system
Likert scale	I am satisfied with my current irrigation system	I use less water with the current irrigation technology	I have continuous and reliable access to water	The water use to irrigate has good quality	It is easy to have access to fertilizers and pesticide in enough quantity	I have experience in growing crop such as tomato, cabbage, onion, pepper (green, red)	I am satisfied with the annual crop production under the current irrigation	I used less labor under the current irrigation system	I am satisfied with the average annual income from agriculture	I receive enough revenue from other activities than agriculture	I usually pay less to install the system
Strongly disagree (%)	25%	12%	3%	2%	73%	10%	7%	3%	0%	5%	2%
Disagree	52%	55%	12%	3%	18%	2%	30%	30%	22%	17%	8%
Somewhat disagree (%)	23%	25%	8%	5%	7%	12%	42%	58%	65%	28%	15%
Neither agree or disagree (%)	0%	5%	28%	15%	0%	32%	18%	3%	13%	25%	18%
Somewhat Agree (%)	0%	3%	32%	27%	0%	28%	2%	0%	0%	20%	47%
Agree (%)	0%	0%	10%	33%	2%	12%	2%	2%	0%	2%	7%
Strongly Agree (%)	0%	0%	7%	15%	0%	5%	0%	3%	0%	3%	3%
Total (%)	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure 3. 5: Data analysis and results in Excel software, Source: author

b. Financial Analysis modelling

the Net Present Value (NPV), the Cost-Benefit Ratio (C/B ratio) Internal Rate of Return (IRR) and Payback period using discounted cash flow technique were examined to simulate the financial viability of AIT investment in Djaramaya scheme. The following indicators were used in the current study.

Project period

The project period is set for five (5) years for two main reasons. Firstly, the life span of the drip irrigation technology is estimated between 5-10 years. Secondly, the current analysis is designed to look for external funding, therefore a shorter period of 3-5 years is more interesting and attractive to private sector. Thus, the selected project period is the minimum interval of the drip system and maxim um interval for the time second time horizon

Present value

The Present Value (PV) is defined as the present worth (gross margin) of the project (FAO, 2002). The formula to calculate the PV is given below. The values of the PV for the scheme analysis are shown in the table 4.10.

$$PV = FV * \frac{1}{(1+i)^n}$$

Where:

FV = Future value (total amount payable)

PV = Initial amount borrowed (present value)

i = Interest rate

n = Number of years

$\frac{1}{(1+i)^n}$: Discounting factor (DF)

Net Present Value (NPV):

The NPV is present worth of the net benefits (= benefits - costs) of the project. In order to calculate the NPV, a discount rate must be determined for the analysis. The rate of interest from commercial credit banks in chad is currently around 14%. However, this discount rate should be revised and set with regards to the borrowing financing institution. This could be for instance the rate used by Multilateral Development Banks such as the World Bank (WB), the Islamic Development Bank Group (IsDB) or the African Development (AfDB). The NPV at 14% discount rate is therefore, the sum of all the PV for the project duration. The results of the NPV calculation were shown in the last column of appendix 10

Benefit/Cost (B/C) ratio (BCR):

The B/C ratio is the ratio between the PV of the benefit stream and the PV of the cost stream (FAO,2002). It tells how much the benefits exceed the costs.

Internal Rate of Return (IRR)

The IRR is simply defined as the rate at which the NPV of the project is equal to zero. It is also called the rate of the investment growth, that is where the project will start making benefit. The investment condition is that the IRR should be greater than the discount rate. In order to be more attractive to financial institution, this rate should be two times greater than the discount rate. Below is the formula used to calculate the IRR.

$$\mathrm{IRR} = \mathrm{Idr} + \frac{(\mathrm{hdr} - \mathrm{Idr})\ \mathrm{x}\ \mathrm{NPV\ at\ Idr}}{(\mathrm{NPV\ at\ Idr}\ -\ \mathrm{NPV\ at\ hdr})}$$

Where:

IRR = Internal Rate of Return

hdr = Higher discount rate

ldr = Lower discount rate

NPV = Net Present Value

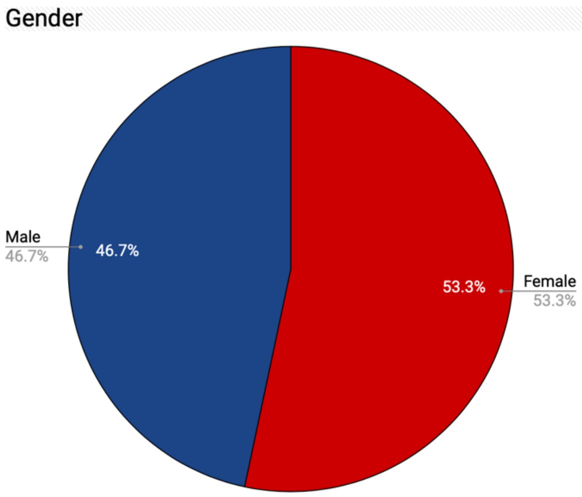
CHAPTER 4: RESULTS AND DISCUSSIONS

4.1. Diagnosis of Djaramaya irrigation scheme

4.1.1. Socio-Demographic factors of the respondents

Gender and Age

The total household in the study area were 120 among which 60 famers were randomly interviewed, the results showed that the proportion of female is 53.3% while the male represent 46.7% (Figure 4.1). This is mainly due to the design of the project which is prioritizing the most vulnerable persons including the widows in the first farm unit of 80 hectares. The result is not fare from the general statistics of the national and regional level with a ratio of 97.58% (M/F) and 99.96% (M/F) respectively at the national level and at Hadjer-Lamis region. The high proportion of woman in Djaramaya scheme can be also linked to the effect of the politico military conflicts. Also, Woman in Chad mostly take care of the family daily activity which include securing water and maintaining the farming activity. 81.7% of the surveyed sample have an average age ranging from 25 to 64 years with more than a half between 45 to 64 years (56.7%) (figure 4.1).



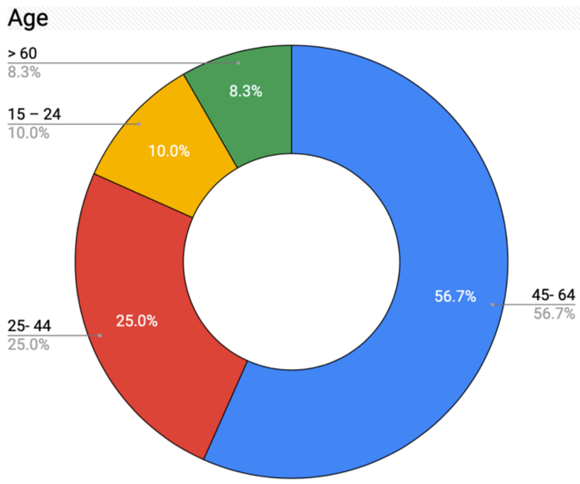


Figure 4. 1: Figure: gender and age characteristics of the respondents

Household size & Farming experience

The figure 4.2 Showed that the average household size is between 3-7 persons representing 68.3% (in which 40% of them has an average of 5-7 persons). More than 66% of the surveyed farmers have an average farming experience of at least 10 years with the majority beyond the 15 years experiences. Traditionally, farmers in the village of Ndjamena Fara have been practicing agriculture for long period, however starting 1996 the government has established through funding from the European Union the firsts agricultural perimeters in Ndjamena Fara as well as other villages around. There are also some small perimeters developed by private individuals in these localities. The table 4.1 Showed the existing agricultural schemes before the establishment of the Djaramaya irrigation scheme of 3000 ha.

Table 4. 1: existing irrigation schemes in Haraze Al-Biar sector

Scheme	**Establishment date**	**Surface (ha)**	**Distance (km) to N'Djamena City**
1- Mara	1988	27ha	15km
2- Drogona	1996	29,5 ha	20 km
3- N'Djamena-Fara	1996	39,25 ha	35 km
4- Sagour –Djibrine	1988	34 ha	45 km
5- Médekhin	1988	30,75 ha	62 km
6- Anbédane	1988	30,25 ha	82 km
7- Zofaya	1996	30,5 ha	89 km

Source: Douguia Agricultural sector

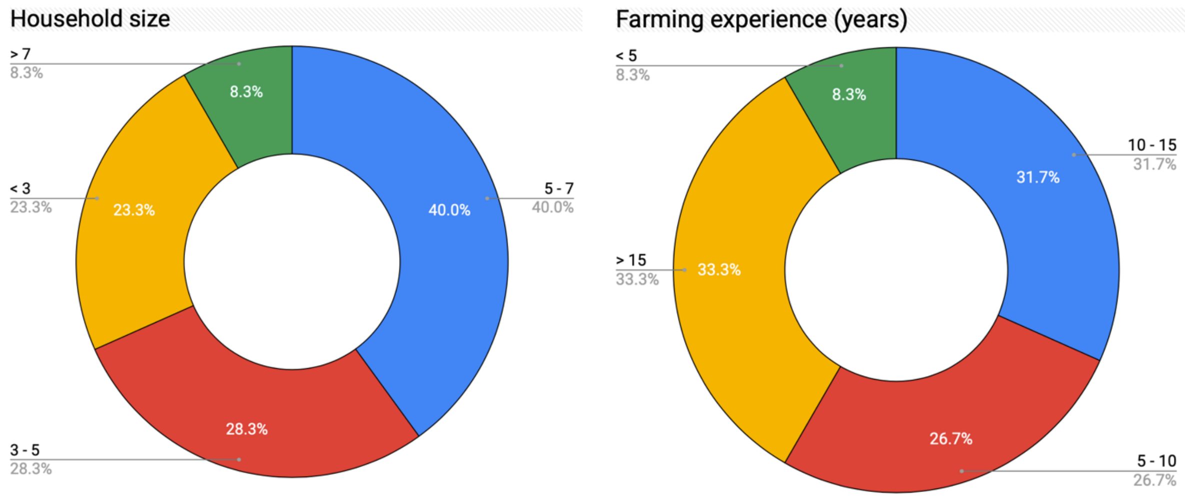


Figure 4. 2: Household size & Farming experience of the respondents

Education level

The education of the surveyed sample is very low. According to the results 70% of farmers (n=60) did not received any formal education while only less than 27% reached the primarily level and 3.3% the secondary (figure 4.3). Most of them has dropped the school after engaging with the farming activities as well as other out farm activities including general business, livestock… The formal education as mentioned in this research is the normal cursus following the national academic program, however farmers in the study area have been traditionally educated through the "koranic school" which is the most common in the Muslim rural communities in Chad.

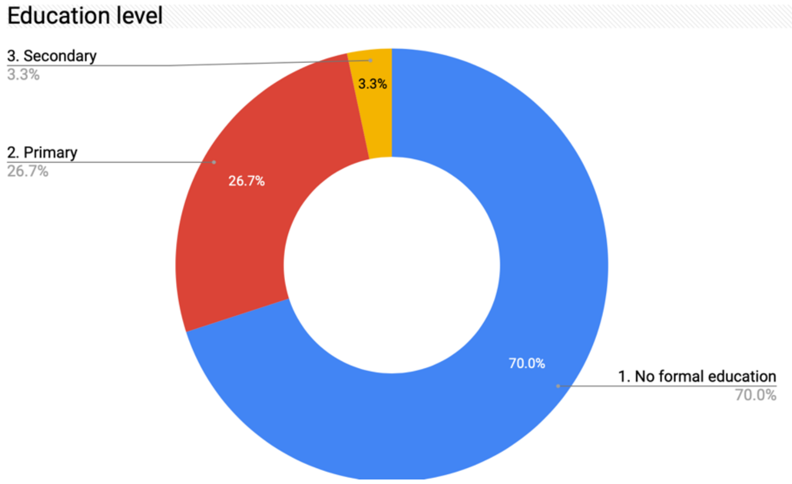


Figure 4. 3: Education level of the respondents

4.1.2. Perception of respondent about the Environmental & Technical factors

The results in table 4.4 showed that 100% of the respondents were not satisfied with their current irrigation system which is still traditional, using surface method. Farmers have to dedicate most of their time in the farming activities in addition to the physical burden. Similarly, more than 92% of the respondents reported to not be using efficiently water, they water their farm 3 to 4 times in a week or whenever the pumping system is running, they irrigate till saturation or till the pump is stopped. The drainage canals usually have excessive water after each irrigation activity. This situation of unwise use of water create environmental challenges including salinization and water logging knowing the soil characteristics of the study area. When it comes to the agriculture input such seeds, fertilizers and pesticides, almost 91% of the sampled farmers expressed that they do not have reliable access to such input. There are many reasons including the lack of access to quality seeds within the Chadian market. ITRAD is the institution in charge of supplying farmers with quality seeds from its respective experimental site, however during the visit we observed the challenges faced by this institution in playing its expected role due to financial challenges (Figure 4.4).

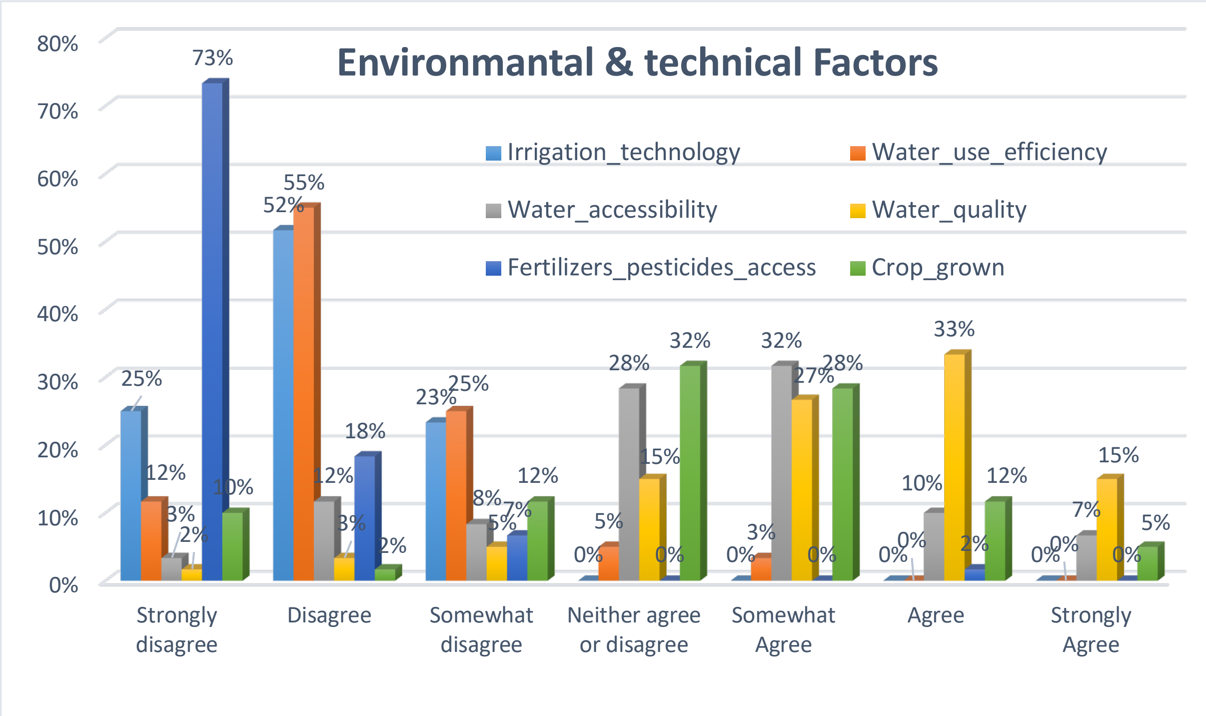


Figure 4. 4: Environmental and technical factors

According to a study conducted by Betico, access to inputs is generally characterized by the low availability of fertilizers and pesticides within the Chadian market that is poorly supplied with such input. In most of the cases, farmers in this locality turn to the Cameroonian market to get supplied with fertilizers. Therefore, plants receive whether less input or experience delays in the right application time (usually fertilizers were applied when there are less needs). This result in a decrease in the crop productivity as well as the quality of the products.

In parallel, the result of the survey indicated that the majority of the interviewed famers did not report major challenges in the accessibility and the quality of water used. This can be explained by the fact that Djaramaya irrigation scheme is directly supplied from Chari river which is flowing throughout the year with no significant pollution. Even though there is abundance of water in acceptable quality, yet some farmers (22%) complained for not having timely access to water because of the high operation cost of the diesel generator that have to pump water from the river and supply the open gravity canals. When asked about their perception in growing high value crop, majority of farmers showed great willingness for such crops that frequently required in the local and national market. The only challenges according to them is the availability of the equipment's and the necessary input.

4.1.3. Farmers perception on the economic factors

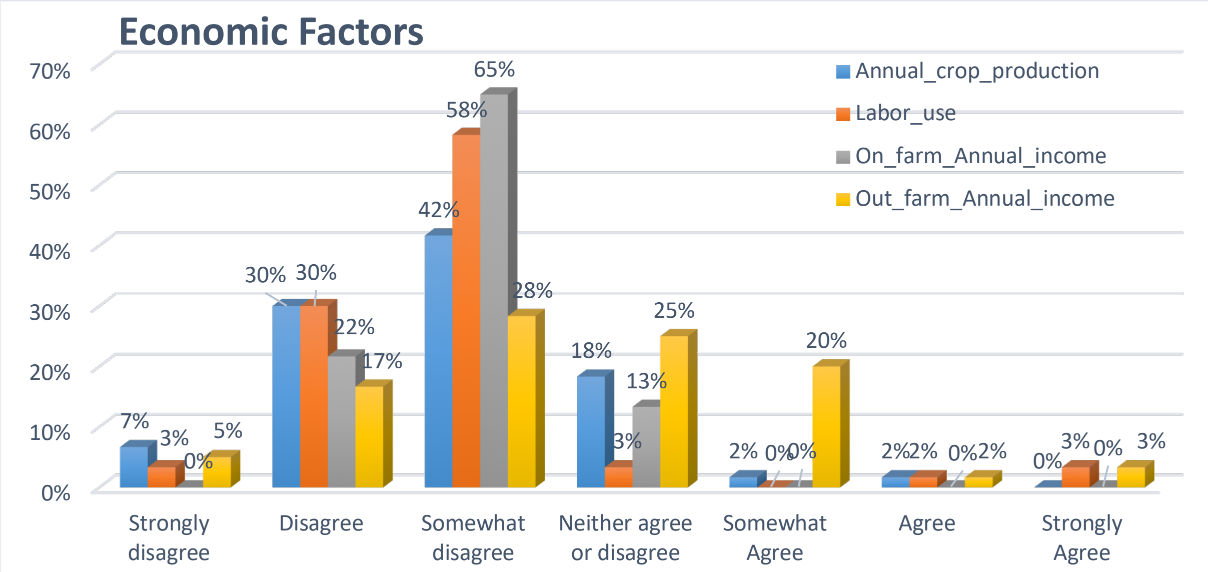


Figure 4. 5: Economic factors

The findings revealed that respectively more than 79% and 87% of the farmers are not satisfied with their annual crop production and their "on farm annual income" which considered not being enough to meet the family expenses. In most of the cases, member of the family is involved in "out farm activities" (48%) to increase their annual income and prepare for the next growing season. Given the scarcity and high cost of the outside labor (91% indicated insufficient labor), the work is mainly done in family. A comparison of the average cultivated area per household (i.e. 5.53/ha) and the average number of farm workers per household (i.e. 3-5 persons) stipulated that there is a shortage of agricultural labor in the study area coupled with the lack of individual equipment.

4.1.4. Farmers perception on the financial factors

Almost half of the surveyed farmers indicated that the initial investment cost their current irrigation system (surface) is quite low. However, 93% reported that the operation and maintenance cost associated with the system is somewhat high due to the inefficiency of most of the infrastructure used from the main canal up to the farm level. For example, during the period of the survey (March-April 2019), the scheme was out of operation because of financial challenges (unpaid bill of the contracting company and high maintenance cost of the diesel generator). The findings showed also the majority (93%) of farmers in the Djaramaya scheme can afford to pay for the water tariff as fixed by the project terms. During the first growing season where only paddy rice was grown in the 80 hectares, farmers have paid at the end of the season four bags of rice of 80kg per 1/4 of hectare as water fees in accordance with the agreed terms. This was confirmed by the project coordinator during the face to face interview conducted in Ndjamena. The farmers with unanimity reported that they did not have access to any credit system as to support their farming activities especially during the start of the campaign.

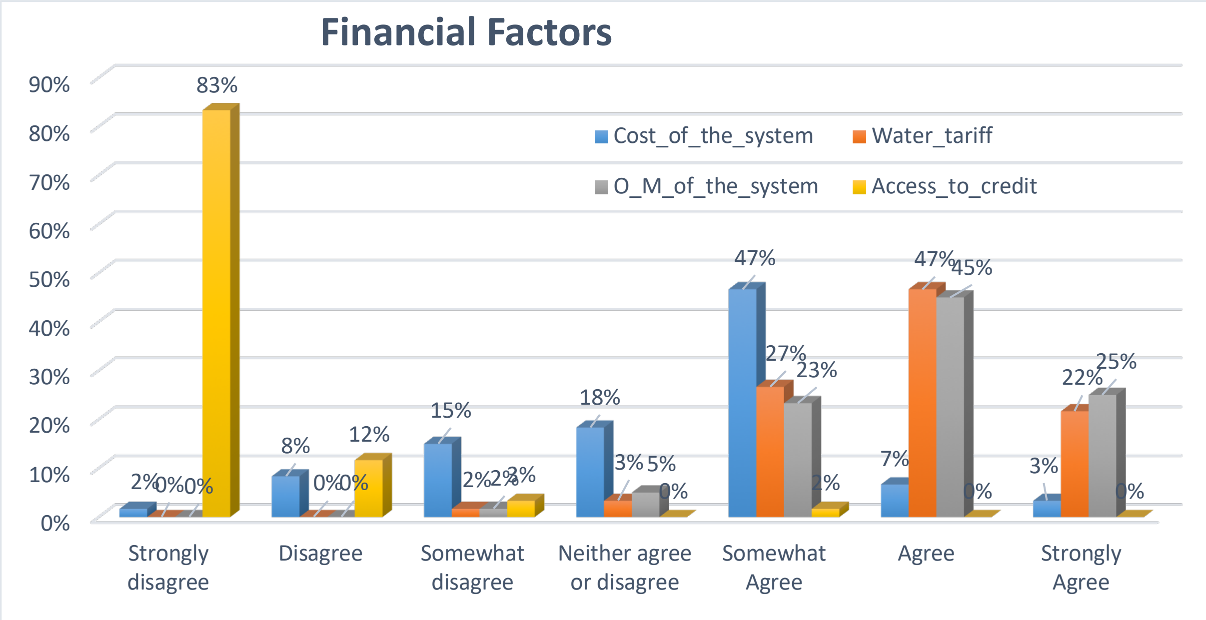


Figure 4. 6: Financial factors

4.1.5. Farmers perception on the institutional factors

Factors such as awareness, information access, capacity building, farmers participation, market accessibility and government subsidy were strongly described among the biggest challenges faced by almost all the surveyed farmers. Farmers were not aware of the advantage and disadvantages of their agricultural practices; they barely receive the right information concerning their activities. They do not receive frequent training whether from the Ministry of agriculture or the NGOs. In general, they were left with one traditional knowledge. The National Food Security Program (PNSA) subsidizes fertilizers and pesticides for 60%. But the quantities supplied are very insufficient (usually unavailable) and most of the time in poor quality.

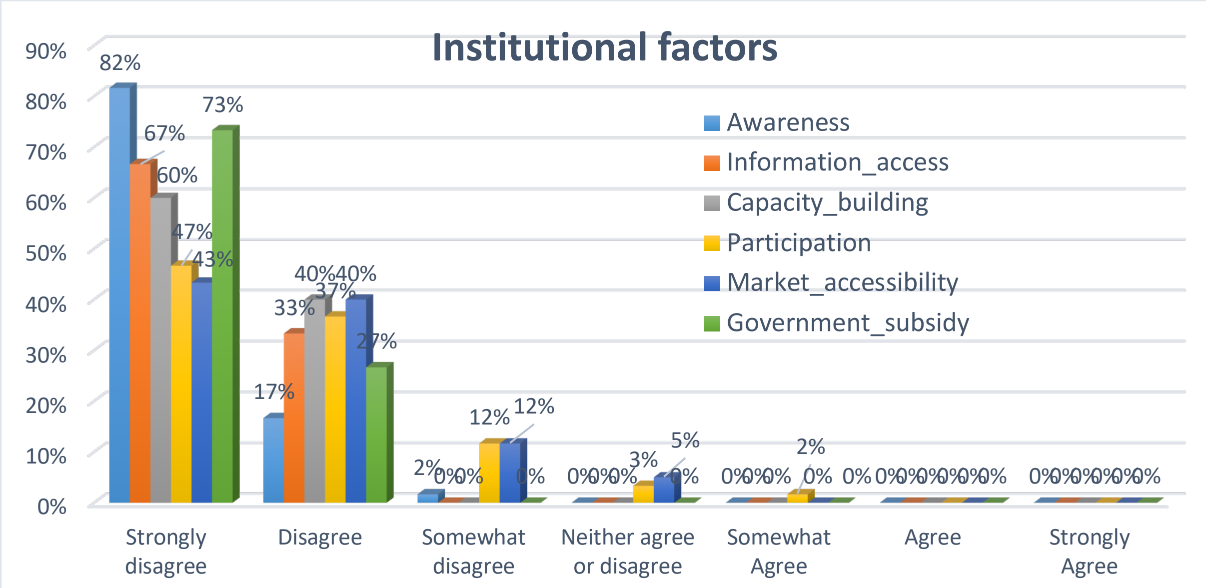


Figure 4. 7: Institutional factors

4.2. Adaptability of advanced irrigation technology in Djaramaya irrigation scheme

4.2.1. Assessment of production factors

a. Climate condition

The climatic data collected are those of the N'Djamena station over a period of 30 years (1983-2012) for rainfall and over a period of 6 years (2006-2011) for monthly averages of the minimum and maximum temperatures as well as for Evapotranspiration (ET0). The results of the climate data analysis are shown in the figure below.

The climate is Sahelian with a rainy season from May to October. An average of 543 mm is recorded for this period. This rainfall is rather low, apart from few crops including millet and cowpea, growing any other crop without supplemental irrigation is not possible.

Average monthly temperatures range from 16°C in December to 27°C in May for the minimum and from 23°C in December to 34°C in March for the maximums. Over the whole year temperatures are optimal for a large number of crops and for normal growth conditions. Low minimum temperatures below 14 ° C are noted only during the month of December. Maximum temperatures rarely exceed 35 °C even in April and May, which reduces the risk of infertility due to high temperatures.

The reference Evapotranspiration varies for the region from 5mm/day in August to 9mm/day in March. It remains lower than the rainfall during all the year except between November and April.

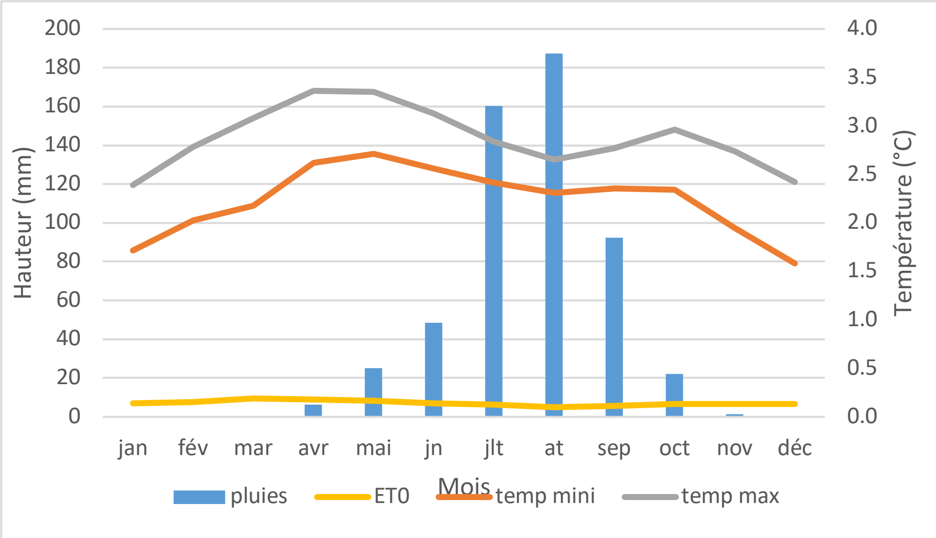


Figure 4. 8: Monthly Evapotranspiration

b. Water ressources :

The study area is located on the right bank of the Chari River (main source of water supply for the irrigation scheme).

The analysis of the table below shows that in the average year:

- During the period from August to December (flood period), there is a high availability of water in N'Djamena flowing into the Chari River,
- During the months of April and May, the river crosses a period of low water corresponding to low water levels.

Table 4. 2: Average monthly flows (in m3 /s)

Month	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Q, m^3/s	170	215	443	1073	2014	2760	2532	1292	579	347	219	163

Average monthly flows (in m3 / s) over the last 15 years in N'Djamena Station (Chari River)

Figure 4. 9: General view of Djaramaya scheme showing the water source (Chari river), source google earth.

The precipitations in the study area range from 400 to 700 mm / year in the form violent averse sometimes. In the recent years, the rainfalls are concentrated on the three months (July-September). It is not unusual that a tenth of the annual rainfall falls in a single day, flooding most of the perimeter for several days. The project design has considered this environmental factor and built a digue to protect the whole 3000 hectares

c. Land and soil suitability :

Soils in the study area consist of fluvial alluvial deposits of Chari. A report on the soil study conducted in the area showed more details on the status of these soils and their agricultural potential. Eight soil units were identified with different soil types for each unit according to the grain size and mineral distribution. Soils with very sandy texture are found in high altitude and fine textured soils in basins and ponds bottoms. Five soil classes of different varieties were identified to be adequate for irrigation (see appendix 1). Previous studies have reported signs of salinization. Therefore, a careful selection of crops to be grown associated with the suitable irrigation technology and an adequate agricultural management practices will significantly increase the land and crop productivity.

The summary of the results for the five (5) class of soil aptitude is given in the table 4.2 (refers to appendix 1 for more details).

Table 4. 3: Soil suitability classes

Class of soils	Soil suitability
S1	Suitable soils
S2	Moderately suitable
S3	Marginally fit
N1	Unsuitable soil (for economic reason, fertility)
N2	Unsuitable soil (for physical reason, drainage issues)

d. Cropping patterns

The soil aptitude results indicate which crop to be selected for a specific soil type with a given characteristics. Several parameters were considered in the selection of crops to be grown including the soil fertility and the economic profitability. Therefore, for the optimal use of the soil in Djaramaya scheme, a mix of cropping options depending on the season is proposed (vegetable, cereals, fodder, horticulture) in considering the above-mentioned parameters as well as the intended objective of the Chadian Government in achieving food security in the region.

- Fodder crops in rotation with cereal crops (rice, sorghum) can be grown on **2136 ha** (71% of the area) during the wet season;
- Vegetable crops (tomato, onion, potato, pepper, cabbage) in rotation with cereal crops (other than rice) can be practiced on **708 ha** (23.6 % of the total area);
- **443.50 ha** (14.78% of the total area) are not suitable for irrigated cereal crops, the best option in this soil type is to grow horticulture crops (Mango and Citrus);
- Rice was found as major and staple crop for many of farmers in Djaramaya scheme that should not be neglected. During the field survey, the researcher observed that rice was the only crop grown in the 80 ha that was made available from the project implementation. The cultivation of rice is possible in approximately **641 ha** (i.e. 21.35% of the total area) during the wet season. Table 4.3 shows the summary of the agricultural land use in accordance to the cropping patterns.

Table 4. 4: soil occupation vs cropping patterns

Cops varieties	Wet season		Dry season	
	Area (ha)	Percentage	Area (ha)	Percentage
Rice	640.55	24.8%	–	–
Vegetables (tomato, potato, onion, pepper, cabbage)	–	–	708.50	27.5%
Fruits crops (Mango, citrus, orange)	443.50	17.2%	443.50	17.2%
Fodder	786.80	30.5%	–	–
Cereals excluding rice (maize, sorghum)	708.50	27.5%	–	–
Total	**2 579.35**	**100.0%**	**1 152.00**	**44.7%**

It can be observed from the table 4.3 that, all the lands are 100% occupied during the wet season and about 45% during the dry season, that is a cropping intensity of 145% over the year. The land use maps for the two seasons with the different cropping options are presented in appendix 4.

4.2.2. Potential of advanced irrigation technologies in Djaramaya scheme

After looking at the potential of advanced irrigation technologies in the second chapter of this document, it is worth to note that, advanced irrigation technologies are needed but they cannot be applied everywhere due to many factors including environmental, technical and economic. However, if the conditions are found to be adequate that is, suitable soil, adequate cropping patterns especial possibility of growing high value and cash crops, then the best choice is to prioritize the AIT because of their high production output and environmental adaptability. In addition to the production input, the selection of an AIT as solution for water scarcity and high crop output should also consider holistically some external factors such as the market availability, the access to loans and subsidy, the post-harvest, etc. as to ensure the farmer about the sustainability of his investment.

Table 4. 5: Suitability of irrigation technologies

Cops varieties	**Wet season**		**Irrigation technologies**	**Dry season**		Irrigation technologies
	Area (ha)	Percentage		Area (ha)	Percentage	
Rice	640,55	24,83%	**Basin**	–	–	
Vegetables (Onion, potatos. etc.)		0,00%		708,5	27,47%	**Drip**
Fruits crops (Mango, citrus, orange)	443,50	17,19%	**Drip**	443,5	17,19%	**Drip**
Forager/Fodder	786,80	30,50%	**Furrow**	–	–	
Cereals excluding rice (maize, sorghum)	708,50	27,47%	**Furrow**	–	–	
Total	**2 579,35**	**100,00%**		**1 152,00**	**44,66%**	

The picture is much clear from the above table 4.4 that, advanced technology such as drip can be attractive to farmers and stakeholders only if proven to be profitable. In one hand, it can be observed from the results that during the wet season drip irrigation (17,19% of the total cultivated area) was only propose for the horticulture crops (Mango & Citrus) that are highly profitable in the region. It was also recommended in dry season for both horticulture (since they are permanent crops) and vegetable crops that are also found to be economically profitable for farmers. In addition, during the dry season, the water abstraction from the Chari river, one of the lake Chad tributaries, should respect the environmental flow of 45m3/h. Thus, drip irrigation is the only proposed technology during this period for sustainable water management. In the other hand, the findings indicate that, there is still need for surface irrigation system in Djaramaya irrigation scheme for numbers of reasons including the farmers education level (figure 4.3), Age (figure 4.1) water availability during the wet season and the cropping patterns as well as other external parameters that are not favorable for advanced technology. Though farmers can maintain the surface irrigation system (basin or furrow) but however a proper agricultural management practice should be incorporated to ensure sustainable farming system. The table 4.4 shows the suitability of irrigation technologies.

Table 4. 6: Percentage share of irrigation technologies in Djaramaya scheme

Type of Irrigation technology	Cropping patterns	Percentage	
		Wet season	Dry season
Surface Irrigation technologies	Staple crops	82,81%	0
Advanced irrigation technologies	High value crops	17,19%	44,66%
Total		100%	45%

a. Drip irrigation technology

Determinant factors

The previous table 4.4 showed the potential for different varieties of crops in different soil types. The crop suitability couple with the triple bottom line that is the social, economic, and environmental including the technical feasibility dimensions have motivated the selection of the irrigation technology. The analysis showed that the selection of a technology can be favored or disadvantaged by the legal and institutional arrangements in place. This was also supported by numbers of researchers ((Fanadzo & Ncube, 2018; Moyo, van Rooyen, Moyo, Chivenge, & Bjornlund, 2016; Nyagumbo & Rurinda, 2012). Figure 4.11 presents the key components for adopting a sustainable AIT.

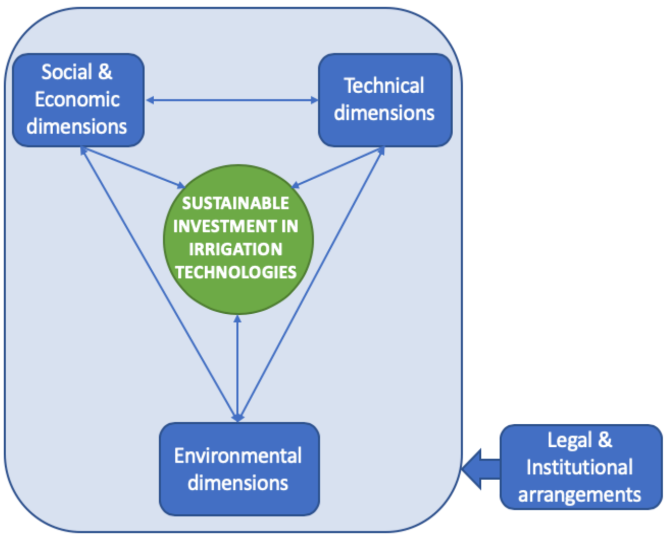


Figure 4. 10: determinant factor in the selection of an AIT

Main component of the system

A drip irrigation technology mainly consists of a Pump unit, control head, main and submain lines, Laterals, emitters or drippers. The following figure 4.12 describe the components of a typical drip irrigation system.

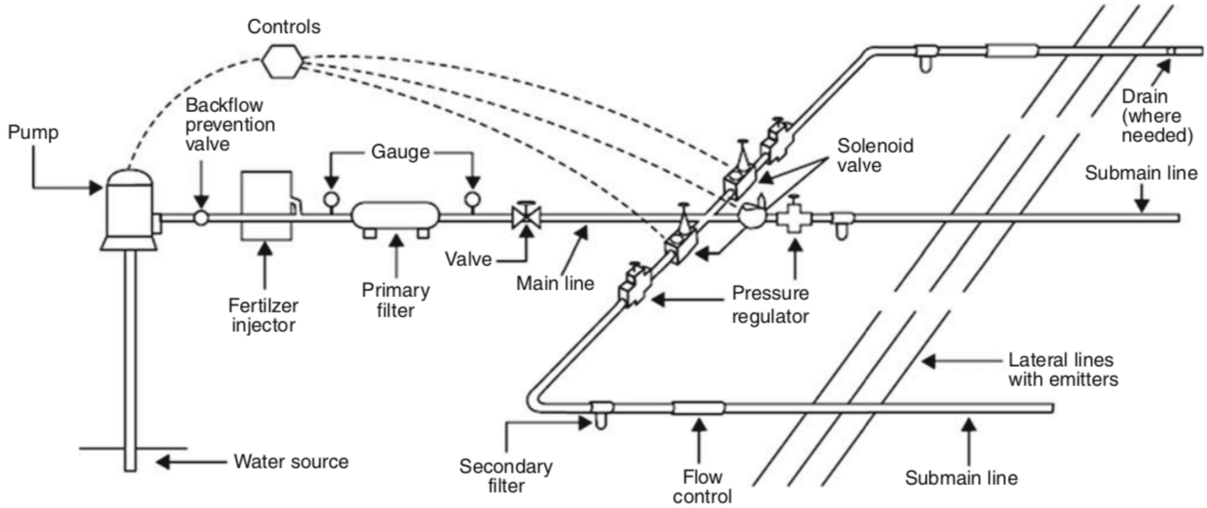


Figure 4. 11: Components of drip irrigation system, Source: (Waller & Yitayew, 2015)

4.3. Financial analysis modelling of the drip irrigation technology

The financial analysis modelling of the drip irrigation system has looked at the scheme profitability and benefit based on the capital investment cost, operation and maintenance costs as well as the gross margins costs for a unit of 1ha of tomato grown crop. The financial viability/worthiness of the farm investment in drip irrigation was measured using the indicators such as the Net Present Value (NPV), the Benefit/Cost (B/C) ratio, the Internal Rate of Return (IRR) and the Payback Period (PP). In order to estimate the cash inflows and outflows for the investment in drip irrigation technology, some realistic assumptions were made due the absence of observed temporal information on benefits and costs.

4.3.1. Investment costs

The investment cost refers to the cost of establishment or construction of the irrigation scheme. In the context of the current research this cost refers to the acquisition of the drip irrigation technology for 1 ha unit. The estimated investment costs are shown in the table 4.6.

Table 4. 7: Estimated investment cost for drip irrigation technology

Items	Cost
Dripper line	2 800
Mainline and sub-mainline	350
Controller & Fertilizer house	450
Installation (Contractors/Labor)	410
Pump, motor and VFD[2]	525
Controller	275
Valve assemblies (including filters)	325
Injection unit	160
Miscellaneous	225
Total	**5 520**

The prices used are based on different quotation from national international suppliers as well as advice from irrigation specialist. The total cost of the technology ranges between 2000 and 5000 USD according to suppliers from countries such as China, India, Turkey, Australia and Israel. The overall total investment cost required to install the drip system is approximately 5500 USD (this may include the cost of logistics since it will be installed in Chad). Figure… showed that the most expensive components is **dripper line** which shares the largest investment cost.

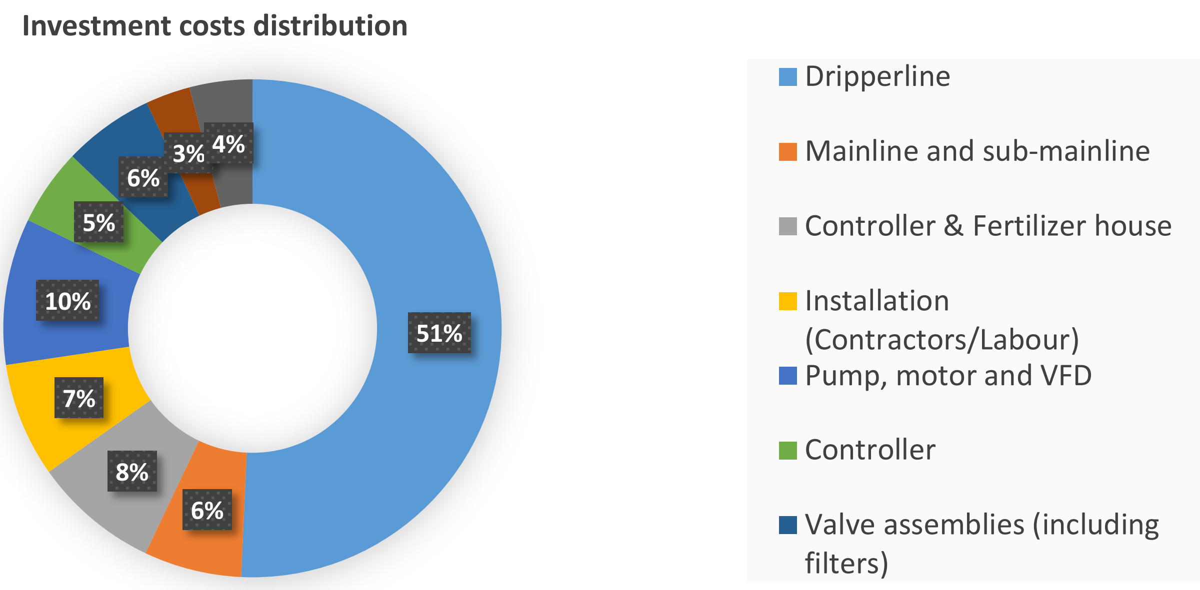


Figure 4. 12: Share of the Investment costs

[2] A variable frequency drive (VFD), or variable speed drive, can be used to optimize the speed and torque of a water pump's motor by changing input frequency and voltage. Such adjustments may enhance energy use efficiency, thus reducing input costs

4.3.2. Operation & Maintenance costs

The operation and maintenance costs include the replacement costs, the energy costs, the costs of repairs and maintenance, the technical costs, the water charges and other related costs such as sunk costs.

a. Replacement costs

In order to calculate the replacement costs, the following assumption were made:

- Emitters, valves, controllers and other small devices should be replaced every 5 years
- The dripper lines and pipe infrastructure should be replaced every 10 years
- The pumping unit should be replaced every 15 years

N°	Items	Replacement period (year)	Estimated cost
1	Emitters and small devices[3]	5	237,5
2	Dripper line and pipe infrastructure (incl. Labor)	10	496,8
3	Pumping unit	15	566,8
	Total		**1301,1**

Table 4. 8: estimated replacement costs

In the context of the current analysis only the first cost was considered since the investment analysis was run for the period of five (5) years.

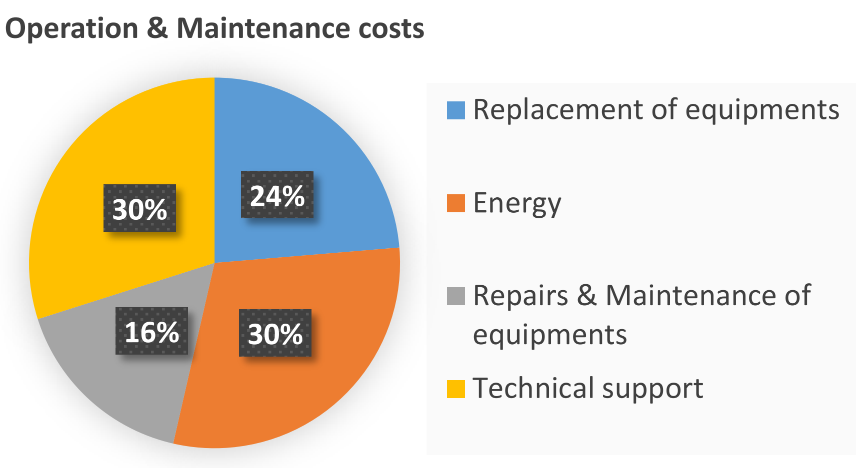


Figure 4. 13: Share of the operation & maintenance costs

[3] Valves, meters, gauges, regulators, connections, risers and fittings

b. *Energy costs*

This refers to the diesel cost of the daily water pumping depending on crop water requirement. The cost was established based on the field data gathered from the current fuel consumption of surface vegetable growers as well through various literature (energy consumption of drip system for tomato growth). A fixed assumed cost of approximately **300 USD** for the growing season was considered. However, real costs from similar schemes should be known for further details analysis.

c. *Repair and maintenance costs*

These are the costs of the utilization of the equipment. A percentage ranging from 1.5-5% of the overall cost of the equipment is used as repair and maintenance. For the current case a 3% annual repair and maintenance was assumed. usually assumed to depend on the cost of the equipment utilized. However, real costs from similar schemes should be known for further details analysis.

d. *Technical support*

Using advanced irrigation technology for such large irrigation schemes like Djaramaya, required at least one full-time agricultural extension officer/technician to advise farmers on their agricultural activities. The estimate is made for a salary of 300 000 FCFA shared by a group of 20 farmers for a period of 12 months that is an annual total of 300 USD by farmer and hectare which the cost of the technical expertise.

e. *Water charge*

In the case of Djaramaya irrigation scheme, farmers are only charge for the diesel consumption and the laws regarding the water abstraction is yet to be implemented in Chad. This cost is not included in the current analysis since the energy costs is already considered as operation cost.

f. *Other related costs (Sunk costs)*

The sunk cost is the cost associated with previous infrastructures, for example, an existing dam or other assets in the project area. In the case of Djaramaya scheme, there a several infrastructures that are already established (Intake infrastructure, supply canals, drainage systems…). Therefore, this cost is not included in the analysis. Table 4.7 shows the summary of the operation and maintenance costs.

Table 4. 9: Summary of the operation and maintenance costs

Items	Estimated cost ($)
Replacement of equipment's	237,5
Energy	300
Repairs & Maintenance of equipment's	165,6
Technical support	300
Water charges	0
Sunk cost	0
Total	**1003,1**

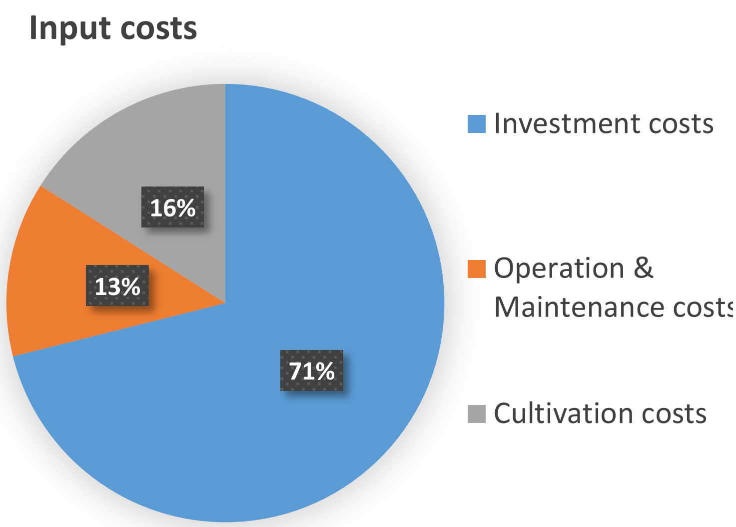
4.3.3. Cultivation/Variable costs

This refers to the costs related to the production. The values in the table 4.8 were collected from the Djaramaya scheme, others from similar irrigation schemes including Linia and Klessoum. The cost of cultivation and income generated using drip technology is assumed constant during the entire life period of the drip system.

Beside its ability to both save water and increase the crop productivity, drip technology reduces the cost of cultivation especially in the following irrigation activities: weeding, ploughing and preparatory works (laser leveling), quantity of labor needed to operate the system. The costs of cultivation are presented in Table 4.8.

Table 4. 10: Cultivation costs

Items	Unit	Costs
Preparatory works	US$	30
Seed and seed sowing	US$	90
Fertilizers	US$	500
Farm yard manure	US$	41,25
Pesticides	US$	56,25
Weeding and intercropping	US$	4,35
Hired labor (90 days, unit=2.5)	US$	225
Transport of products to market	US$	225
Harvesting/Packaging (15kg box)	US$	20
Other	US$	50
Total costs	**US$**	**1241,85**



Items	Costs
Investment costs	5520,00
Operation & Maintenance costs	1003,10
Cultivation costs	1241,85
Total	7764,95

Figure 4. 14: Summary of the share of input costs Source: author analysis

4.3.4. Gross margin benefits

The gross income generated from the production income is calculated based on average estimate of the harvest which the yield by the area and the unit market price of the product (Considering the season and the market conditions). The data used in the calculation of the gross margin benefits were obtain from different sources including the suppliers of agricultural inputs, the marketing boards, the prices observed in local markets as well as various peer reviewed literatures. However, for further more accurate analysis major markets may be monitored closely to provide average prices for each month. Table 4.9 shows the gross margin benefits.

Table 4. 11: Gross margin benefits

Items	Unit	Year 1	Year 2	Year 3	Year 4
Area (1)	ha	1	1	1	1
Yield (2)	t/ha	15	20	25	25
Harvest (3) = (1)x(2)	t/ha	15	20	25	25
Price (4)	US$/t	200	200	200	200
Gross income (5) = (3)x(4)	US$	**3 000**	**4 000**	**5 000**	**5 000**
Preparatory works	US$	30,00	30,00	30,00	30,00
Seed and seed sowing	US$	90,00	90,00	90,00	90,00
Fertilizers	US$	500,00	500,00	500,00	500,00
Farm yard manure	US$	41,25	41,25	41,25	41,25
Pesticides	US$	56,25	56,25	56,25	56,25
Weeding and intercropping	US$	4,35	4,35	4,35	4,35
Hired labor (90 days, unit=2.5)	US$	225,00	225,00	225,00	225,00
Transport of products to market	US$	225,00	300,00	375,00	375,00

Harvesting/Packaging (15kg box)	US$	20,00	26,67	33,33	33,33
Other	US$	50,00	50,00	50,00	50,00
Variable/cultivation cost (6)		**1241,85**	**1323,52**	**1405,18**	**1405,18**
Gross margin benefit (7) = (5)-(6)		**1 758,15**	**2 676,48**	**3 594,82**	**3 594,82**

Yield assumption: the tomato yield is expected to increase by 5 tones yearly till the 4th year as a result of advanced irrigation technology and good agricultural practice.

4.3.5. Financial analysis of the project worthiness

Having introduced methods to deal with the time dimension, the viability or worthiness of the project that takes the timing of costs and benefits into account can now be measured, using the following indicators:

a. Net Present Value (NPV) :

The NPV is present worth of the net benefits (= benefits - costs) of the project. In order to calculate the NPV, a discount rate must be determined for the analysis. The rate of interest from commercial credit banks in chad is currently around 14%. However, this discount rate should be revised and set with regards to the borrowing financing institution. This could be for instance the rate used by Multilateral Development Banks such as the World Bank (WB), the Islamic Development Bank Group (IsDB) or the African Development (AfDB). The NPV at 14% discount rate is therefore, the sum of all the PV for the project duration. The results of the NPV calculation were shown in the last column of appendix 11.

The result showed a positive NPV, that means at the chosen discount rate, the investment will be more than recovered and it will be profitable to invest in this advanced irrigation technology. Since the NPV does not give an idea about the relative return of capital, it just tells if the project is profitable to initiate. Other financial indicators including BCR and IRR are required.

b. Benefit/Cost (B/C) ratio (BCR):

The B/C ratio is the ratio between the PV of the benefit stream and the PV of the cost stream (FAO,2002). It tells how much the benefits exceed the costs. The total of the PV of the benefits **(17 872 ,67 USD)** divided by the total of the PV of the costs **(9 512,57 USD)** gives the B/C ratio of 2.11. The ratio is greater than 1; it means that, at the current interest rate, the benefits exceed the costs. Table 4.10 presents the results of BCR calculation.

c. Internal Rate of Return (IRR)

The financial analysis results suggest that the proposed irrigation investment is viable since the IRR is 60% which is exceeding two times the discount rate of 10%.

d. Payback period

The payback period is defined as the time taken to recover the initial investment or when the annual net benefits become equal to the investment cost. In the case of the current analysis, the result showed a payback period of 2 years using discounted costs and benefits. From the table 4.10, it can be seen that after the second year the cumulative discounted net benefit is **5 919.21 USD**, which is more than the investment cost **5 520 USD.** This means that all the costs are paid back in about 2 years.

Table 4. 12: Summary of the financial analysis

Financial Indicators	Values
Net Present Value (USD)	8 360,57
Present value of benefits (USD) at 10%	17 872,67
Present value of costs (USD)	9 512,11
Benefit/Cost (B/C) Ratio	1,88
Internal Rate of Return (IRR)	24%
Payback period	3 years
Discount rate	10%

Table 4.12 shows details results of the financial analysis modelling. While reading the appendix 11, it can be seen that year 2 is the first accounting period in which increases in operating costs as well as increases in income occur.

4.4. Sustainability analysis of Djaramaya irrigation scheme

After looking at the financial viability of the AIT investment, it is therefore, crucial to ensure the sustainability of the whole irrigation scheme. The previous investment analysis was conducted on the high value crop (a case of Tomato) which represents 61,85% (145% cropping intensity) of the 3000 ha of Djaramaya scheme while around 83% is cultivated using conventional rainfed agriculture. However, the income generated from the conventional surface irrigation mainly during the wet season contribute to the overall benefit of the scheme. This was not included during the financial analysis modelling.

Though, the financial analysis suggests a rapid return of investment just after the second year, adopting an AIT like drip requires a significant initial investment that can be difficult to access by the poor farmer without a well-functioning credit system. Just like the other irrigation schemes in Chad, farmers in Djaramaya scheme do not have access to any kind of financial services as was strongly supported the field survey conducted. Thus, in order to maintain the viability of the scheme and meet the vision of the Chadian government on ensuring food security and well-being in the region, the researcher explores different financial options including the PPP model.

4.4.1. Role of the private sector in financing advanced irrigation technologies in Djaramaya scheme

Private sector plays key role today in creating values in place where the governments were fails to ensure sustainability of the investments. Worldwide, the performance of the private sector in financing public assets in the sectors such as energy, transport, mining, etc. through PPP is known as the most effective and successful financing option. In irrigation projects, few PPP models exist as compared to the other sectors and where few successes have been recorded so far. This is the case of Guerdane irrigation project in Morocco (2004), the first of its kind, which can be used as benchmark for Djaramaya irrigation scheme as well as other similar projects in Chad. The potential of this case was explored in this current research.

Table 4. 13: Guerdane PPP irrigation project

Underlying features (Financial Close date for I&D PPP)	Guerdane Morocco	Megech- Seraba Ethiopia	Chiansi Zambia	Muhuri Bangladesh
Close date	2004	2012	2014	2016
Project cost	$85 million	$47 million	$2.5 million (pilot) + $32 million	$58.0m
Farming activity	Cash-crops	Subsistence	Subsistence	Mixed
Size and scope	Up to 10,000 ha	4,040 ha	300-2,600 ha	17,000 ha
PPP model	Design Build Operate	Operate & Maintain	Build Operate Transfer	Management & Lease
Scope of Private contract	Irrigation only	Irrigation only	Irrigation only	Both Irrigation and Agriculture
Adopted from world bank report (103346-REVISED-PUBLIC-Irrigation-PPP-toolkit-Final-3-March-2016.pdf)				

4.4.2. Guerdane irrigation scheme

Morocco has developed a solid, concrete and multi-sector experience of private sector participation in infrastructure projects such as energy production (Jorf Lasfar coal-fired power plant, Tahaddart gas-fired power plant, Tarfaya wind power project, Safi power plant, Ouarzazate solar projects), agriculture (Guerdane irrigation project), ports (Tangier-Med), urban transport, urban water and electricity distribution.

The Moroccan government has chosen a private partner for the planned public private partnership (PPP) irrigation project in the citrus-growing area of Guerdane, Taroudant province. The project's financial concept was innovative in that it was the first irrigation system worldwide to be built and operated in a PPP model.

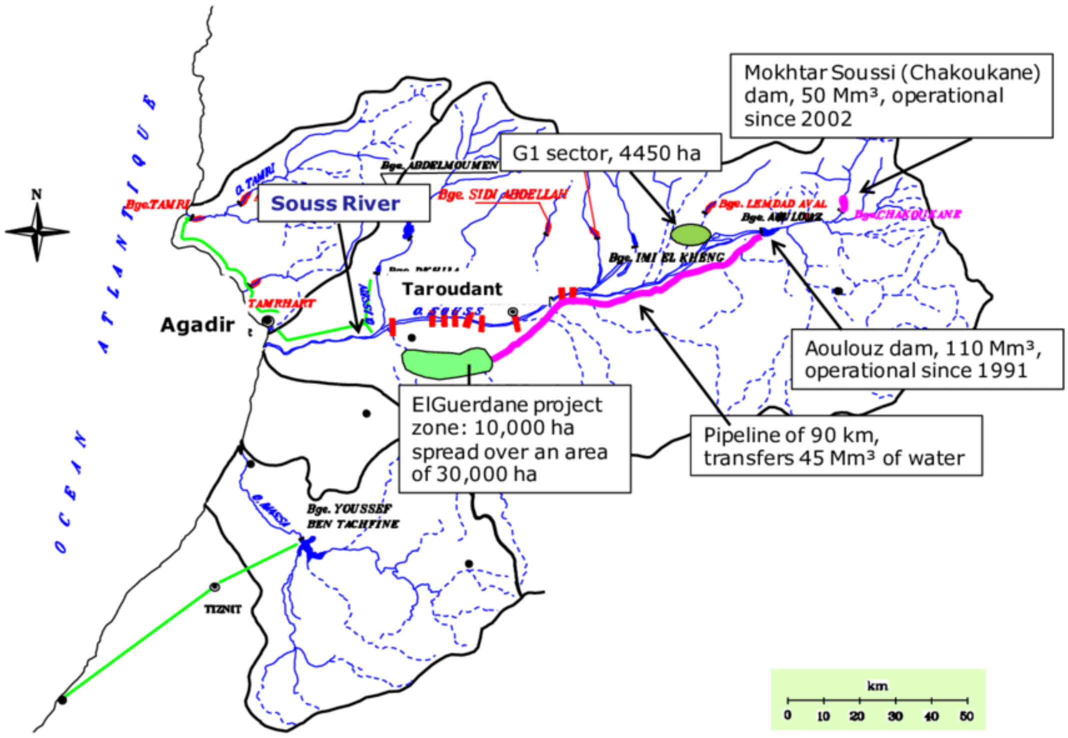


Figure 4. 15: Map of Guerdane irrigation scheme

a. Guerdane project structure & characteristics

In Morocco, major irrigation schemes are managed by the public irrigation agencies (Offices Régionaux de Mise en Valeur Agricole, ORMVAs). For 10 years, the government has been driving a reform with the World Bank's support to restore financial sustainability. This is to attract the private sector in financing, implementing, and managing new investments in irrigation projects.

b. Guerdane project characteristics

The following are the characteristics of the Guerdane irrigation project:

- A 70 km–long pipe transferring 45 million m3 from the Chakoukane Dam to a gravity-pressurized network of 10,000 irrigated ha at Guerdane for 600 farmers growing irrigated high-value crops with well-organized marketing arrangements
- The total project cost was estimated at $85 million, with the government providing $50 million, half as a grant and half as a subsidized loan. The private partner provided the balance.
- It is a concession contract, which includes all the transferable functions.
- The final price is estimated by International Finance Corporation (IFC) experts at between $0.15/m3 and $0.20/m3, close to the current costs of pumping underground water.

c. Project impact

According to IFC, the impact of the project is quite significant and contributed to boost the economy of the region:

- Safeguarded a citrus industry that provides direct and indirect jobs for an estimated 100,000 people.
- Made surface water available to farmers at an affordable price.
- Mitigated the risk of depleting under-ground water resources.
- The financial valorization increased from a negative level of - 0.637 DH /m3 in 2009 to a positive level of 2.19 DH /m3 in 2016.
- The water productivity has improved from 2.59 Kg / m3 in 2009 to 3.65 Kg/m3 in 2016.

d. Cross check comparison between Guerdane and Djaramaya projects

A cross check comparison between the two irrigation schemes that is Guerdane and Djaramaya was established in order to understand the success of the PPP model and borrow lessons to Djaramaya scheme. Both schemes are located in arid region and have similar size.

Table 4. 14: Cross check comparison between Guerdane and Djaramaya projects

	Country	**Morocco**	**Chad**
Project details	Project size (hectares)	10 000	10 000
	Cost of project	$85 million for infrastructure	$88 million[4]
	Number of farmers targeted	600	840
	Irrigation technology employed	Pressurized for drip	Surface irrigation
	Crops covered	Citrus	Multiple crops
	Type of PPP	30-year concession	N/A
	Private sector service provider	A consortium led by ONA[5]	N/A
	Public sector institutions	Government of Morocco	Government of Chad
	Current Status of Project	Ongoing contract signed in 2004	Project in stop

[4] This cost concerns only the 3000 ha where up to 36 million USD was already disbursed accounting for 40% of the implemented infrastructures. However, the Ministry in charge has requested a reevaluation of the project cost which was found to be overestimated.

[5] Omnium Nord-Africain, a Moroccan industrial conglomerate.

Allocation of Irrigation scheme functions	Investment	IDSP[6]	MARE[7]
	Governance	Water monitoring: Basin agency	LCBC[8]
		Maintenance and pricing control: ORMVA Souss-Massa	Agricultural division/ SOGEA SATOM[9]
	O&M and management	Management: IDSP (between irrigators); basin agency (between users)	PMU[10] Djaramaya & Agricultural division
		O&M: IDSP	
	Agricultural production	Farmers	Farmers

e. Lessons learned from Guerdane irrigation project

The Guerdane irrigation scheme, a 30 years concession structure, have a veritable and clear transfer of investment responsibilities. The Moroccan government has largely contributed to the project which has made the PPP arrangement financially viable and attractive. This contribution to the financing costs was in the form of subsidies and a soft loan in order to keep the tariffs the low and affordable to farmers while improving the quality of the service. The risks associated with the scheme sustainability including payment of fees (up-front payments techniques were used to cover the connection costs) were critically identified and mitigated. Among the key success of this scheme is that farmers, who grow high value crops (citrus crop), had access to a well-organized market facility for the flowing of their products. This was a convincing arrangement for the farmers to pay for the agricultural services. Djaramaya irrigation scheme have all the potential to learn from such best practices in Africa and around the world.

4.4.3. Djaramaya irrigation scheme

a. Description of the scheme

Djaramaya scheme with his surface of 10 000 hectares is among the largest scheme in chad and the biggest in both regions of Hadjer Lamis and Chari Baguirmi where Ndjamena, the capital city, is located. Currently, 3000 ha is being implemented including the upstream

[6] Irrigation and Drainage Service Provider.
[7] Ministry of Agriculture and Rural Equipment.
[8] Lake Chad Basin Commission in charge of transboundary water management.
[9] The contracting French company in charge of constructing the scheme and operating/maintaining the scheme for 2 years which is included in the project cost.
[10] Project Management Unit

infrastructures which are the major infrastructures (intake infrastructure and the conveying canals). The following is the inventory of the completed works on the 3000 ha:

- Development of 80 ha for surface basin irrigation;
- A pumping station designed for 10,000 ha;
- 01 main supply canal;
- 01 primary canal equipped with geomembrane;
- 02 secondary canals lined with geomembrane;
- 10 tertiary earth canals;
- 10 quaternary earth canals;
- 01 earth collector drain;
- 02 earth secondary drains;
- Dissipation basins and control structure in concrete.

The completed 80 hectares consist of 300 plots of 0.25 hectare each. During the first season (October to January), rice was the only crop grown.

Figure 4. 16: Djaramaya irrigation scheme intake infrastructure

Source: field survey

b. Djaramaya irrigation project costs

In the first Block of 409 ha, 80 ha are 100% completed with an average yield of 6t/ha for rice production. Currently, the implementation work of the 3000 ha is estimated at 40% where total of 18 billion FCFA (i.e. 36 million USD) was disbursed on a planned budget of 44 billion FCFA (i.e. 88 million USD). The remaining cost to finalize the 3000 ha is estimated at 24 billion FCFA (around 52 million USD). However, during the field survey, the project coordinator highlighted that, the MARE, in charge of the project, has requested a reevaluation of the project cost to know the exact volume of the constructed infrastructures as well as the ones remaining. It can be seen from the table 4.12 that the project costs were overestimated, because with about the same cost of Djaramaya phase 1 (3000 ha), the Moroccan government has contributed to established a successful PPP arrangement in Guerdane (10 000 ha).

Table 4. 15: Djaramaya irrigation project costs

Items	Phase 1: 3000 hectares	Phase 2: 4000 hectares	Phase 3: 3000 hectares
Project cost (without taxes) (FCFA)	37 436 103 432	42 297 737 046	33 274 191 654
VAT (FCFA)	6 738 498 690	7 613 592 668	5 989 354 498
Project total cost (FCFA)	44 174 602 122	49 911 329,714	39 263 546 152
Project total cost (USD)	88 349 204 24	99 822 659	78 527 092

Source: author construction & field survey

c. *Challenges and opportunities of PPP arrangement in Djaramaya irrigation scheme*

Challenges

The example of PPPs project in Chad are very rare apart from the Renaissance Hospital which was funded in a kind of concession partnership with a French company. In the field of irrigation projects, there is no concrete model in place. However, recently (June 2019), many private individuals have presented projects small scale irrigation project during the Chad-Arab World Forum and are open to PPP arrangements. For example, the PADLFIT program financed by BADEA and to be implemented by UNDP plans for the construction of 8,000 hectares of irrigated perimeters per Province. Yet, a feasibility study remains crucial to accurately identify the arable areas with investment potentialities.

Regarding the institutional status of PPP, a decree defining the PPP regime in Chad was signed on the 25th August 2017 just before round table of the National Development Plan (NDP) organized in Paris.

The Agricultural Bank, the main financial institution that has the mission of supporting farmers agricultural activities, faces several challenges according to the interview conducted with the management team. The following are the highlights of some of the challenges:

- Weak Institutional capacity
- Lack of legal framework & policies guiding the bank activities in Chad
- Unprofessionalism
- Lack of political will (the bank does not receive much attention from the government in ensuring its sustainability)
- Misunderstanding of the Islamic finance by the stakeholders (the concept of Agricultural bank was borrowed from Sudan, which is using Islamic finance with rules and regulation binding guiding the bank activity. However, this is not the case in Chad and the bank was establish without prior deep study of the Chadian context)

- Farmers willingness to pay back the loan (since there are not strict laws and sanction binding the users, many persons transform themselves into farmers with fake project to benefit from the weak structure of the Bank)
- Poor decentralization (the bank is supposed to be close to the farmers and potential agricultural regions, instead it is located in the capital)

Opportunities:

Djaramaya irrigation scheme has all the potential in accommodating a PPP arrangement in financing Advanced Irrigation Technologies which is going to be the first of its kind in Chad. The failure in the operation and maintenance of existing large-scale irrigation scheme in Chad as presented in chapter 3, suggests that a new innovative approach that involve the private sector is needed. Ensuring all the stakeholders (Farmers, Private sectors, Government) of their investment is key for the success of any PPP arrangement. For this reason, this current study has developed a clear picture of the Agricultural Value Chain showing the potential of private sector involvement in the different process. Figure 4.20 shows that the process starts from the beginning by holistically looking at key components of the AVC: the research & development, the upstream as to ensure an enabling environment, the midstream (production factors) to create a business environment and the downstream (post-harvest & market) in order to establish the condition for a competitive environment. In chad like the other SSA countries, it is challenging for the private sector to invest in sector such as agriculture. However, by developing this AVC, it gives to all the stakeholders the confidence and incentive to invest. The scope of this current research was limited to midstream level where the AIT are focused. In the context of Djaramaya scheme, the government have created an enabling environment by putting in place the major infrastructures conveying water from the Chari River up to the farm level. In addition, the analysis has shown a favorable condition for the production factors at the midstream level at least for the most important factors (water availability, soil fertility). At the downstream level, there is a high potential of availability of an important market (i.e. Ndjamena the capital city at around 40km). Thus, by learning from the Guerdane PPP case in Morocco, the Chadian government can build its capacity through the support of its MDBs (WB, IsDB, AfDB, etc.) partners and develop an attractive PPP arrangement for Djaramaya scheme and other agricultural development projects in the country.

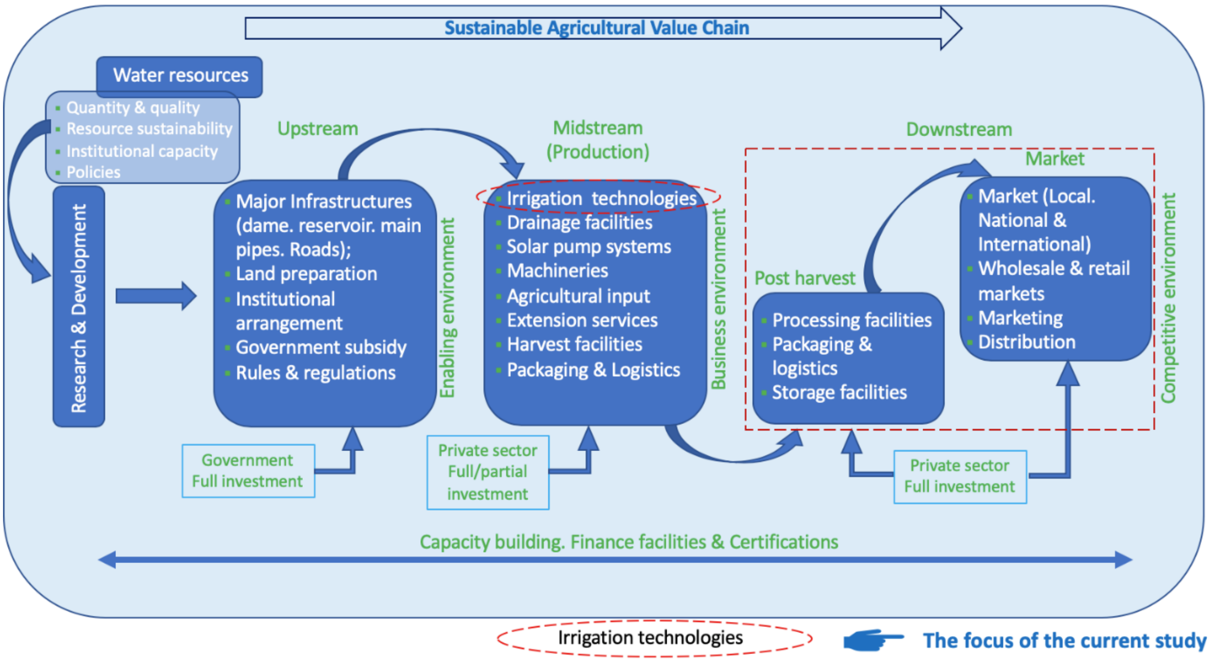


Figure 4. 17: Sustainable Agricultural Value Chain, source: author construction

CHAPTER 5: CONCLUSIONS & RECOMMENDATIONS

5.1. Conclusion

The present report examined the potential of advanced irrigation technologies (mainly drip) in Djaramaya irrigation scheme. The main objective was to propose an advanced irrigation technology for adaptability in arid region in Africa. The study focused on the socio economic and environmental characteristics of Djaramaya scheme, the technical feasibility as well as the financial profitability of the proposed advanced irrigation technology. Moreover, this present research analyzed the sustainability of the scheme and proposed a viable financial model through private sector implication and by learning from best practices including the PPP arrangement of Guerdane irrigation scheme in Morocco. Therefore, the study concluded that AIT can be highly profitable when the key factors including the soil suitability, cropping patterns and market are found favorable. The use of drip irrigation technology can highly increase the water use efficiency (up to 95%) while optimizing the nutrients and pesticides application through fertigation. This significantly reduce the water logging and salinization and thus no drainage system (additional cost) will be required as compared to furrow irrigation system.

In addition, the report has carried out financial analysis using the NPV, C/B ratio, the IRR as well as the payback to evaluate the viability of the investment. The results of the estimated NPV and C/B ratio using discounted cash flow method suggest that the investment in drip irrigation technology under high value crop (tomato) is economically viable. Furthermore, the study found that farmers would be able to recover the cost of the initial investment from the profit generated at the end of the second year. In the conventional irrigation system (surface), farmers can barely recover the cost of crop cultivation as well the operation of the system due to low yield and poor quality of products. The research confirmed that even though AIT are needed for sustainable water management they cannot be economically viable everywhere and for this reason improved surface irrigation can still be maintained for the staple crops. Thus, the findings of the current research suggest that 82.2% (145% cropping intensity) of the cultivated area in Djaramaya scheme would be economically viable under surface irrigation system. However, best irrigation management practices should be maintained in order to ensure high crop and water productivity with less environment degradation.

Furthermore, the study concluded that private sector implication in Djaramaya irrigation scheme is a key success factor to ensure sustainability where 57% (n=23) of the public irrigation scheme in Chad are poorly performing and threatened to close due to several challenges including financial. Therefore, a sustainable financial model through private sector participation was found to be suitable for the viability of Djaramaya irrigation scheme. For this reason, Guerdane PPP arrangement in Morocco stands out as a best practice among others and a benchmark that lessons can be borrowed for Chad in a detailed feasibility analysis for further study.

5.2. Policy Recommendations

There many potentials for the Chadian government to promote the use of Advanced Irrigation technologies to cope with the growing water scarcity challenges. 60% of total area of the country is desert and the Sahelian zone (case study zone) is already threaten by a serious advancement of the Sahara. This situation will lead to some series of droughts in the coming years if proper water management practice is not established. Certainly, Chad has abundant water resources, however these resources are not adequately distributed. There areas with both physical scarcity (mostly the northern part with less than 50mm of rainfall) and economic scarcity (southern part with around 1200 mm of precipitation and where there are insufficient hydraulic infrastructures). In the two cases, AIT can be the appropriate solution to cope with this growing water scarcity challenges and the Chadian Government has all the potentials to promote such technologies. Thus, the findings of this research have several policy recommendations:

- The Chadian government can promote the AIT for sustainable agricultural development by establishing regional programs promoting the use of AIT for sustainable agricultural development. The government can decide to prioritize areas with physical water scarcity in the first phase of the program since the funding may be a constrain.
- The Government while planning its various agricultural programs, could also allocate a portion of the planned budget to promote AIT under high value crop in the different region of Chad.
- Through effective policies, government can help farmers have incentives to invest in AIT by reducing the initial investment through various subsidy.
- Government extension policies and technical services are key in ensuring the sustainability of the investment. Therefore, a full-time presence of technical assistance in the various schemes are required. This will increase the farmers adoption of AIT and reduce problems including the operation of the technology and breakdown of equipment.
- Strong institutional arrangement can highly attract and give confidence to private sector to involve in the country's irrigation development programs.
- Access to timely accurate and reliable information is crucial to facilitate the transition from convention irrigation method to AIT. Therefore, the government should ensure that farmers have the right information concerning their agricultural activities.
- Farmers capacity building can play a pinnacle role in improving the communication gap and fulfilling the government vision toward the agricultural sector. This can be achieved

through farmers on farm training programs and demonstration activities to improve their crop and water productivity as well as their ability to use innovate agricultural practices.

- The government should structure the WUAs as well as institutionalizing them in order to drive the farmers participation in WUAs activities. The research found that less than 5% of the interviewed farmers in Djaramaya scheme effectively participate in community work.
- The WUAs that will be legally established should timely ensure the monitoring of the quantity of water used by famers which is not accurately known in the case of Djaramaya scheme. The intake infrastructure in Djaramaya abstract water directly from the Chari which is also feeding the lake Chad in downstream, therefore the LCBC should instantly monitor the volume withdrawal as well ensuring the environmental flow is respected. This monitoring should not just be limited to Djaramaya but along the Chari river by multiplying the measurement station.
- Agro meteorological station including soil moisture sensors are critical for any irrigation scheme that intend to go for modernized agriculture. Djaramaya scheme should have such weather station which quite helpful to farmers.
- The government should encourage the local private sectors to diversify their activity by making available the spare part of farmers breakdown equipment's and highly skills contractors. This can be accomplished by building the capacity of small and medium company through a national program.
- The establishment of a PPP framework in the irrigation sector requires a consistent technical assistance in putting in place the enabling environment for the private sector participation including policies, institutional and legal framework, risk assessment and their mitigation, bank guarantees as well insurance, etc. The government of Chad has all the opportunities to have such assistance from its various MDBs partners including the WBG, The IsDB or the AfDB that can provide support to create the necessary conditions for a PPP framework in Chad.
- In the framework of ongoing irrigation scheme of Djaramaya, the government of Chad through the ministry of agriculture can learn from the Guerdane PPP model in Morocco or the Megesh-Seraba in Ethiopia by initiating some capacity building programs with the support of its development partners. This will help in analyzing various PPP model and select the most adequate financial structure to adopt for irrigation projects implementation in Chad.
- The elaboration of a rural Land Code that mapping the potential agricultural zones with total control of water where PPP can be set up for irrigation development (10 000 to 100

000 hectares) should be established. The government can create the condition for the private sector participation in all the agricultural value chain including putting in place the upstream infrastructures (Dams, main canals) as well as the downstream which include the market (local, regional and international).

- The introduction of a favorable tax arrangement are also conditions to better boost private agricultural investments including PPPs.

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APPENDIX

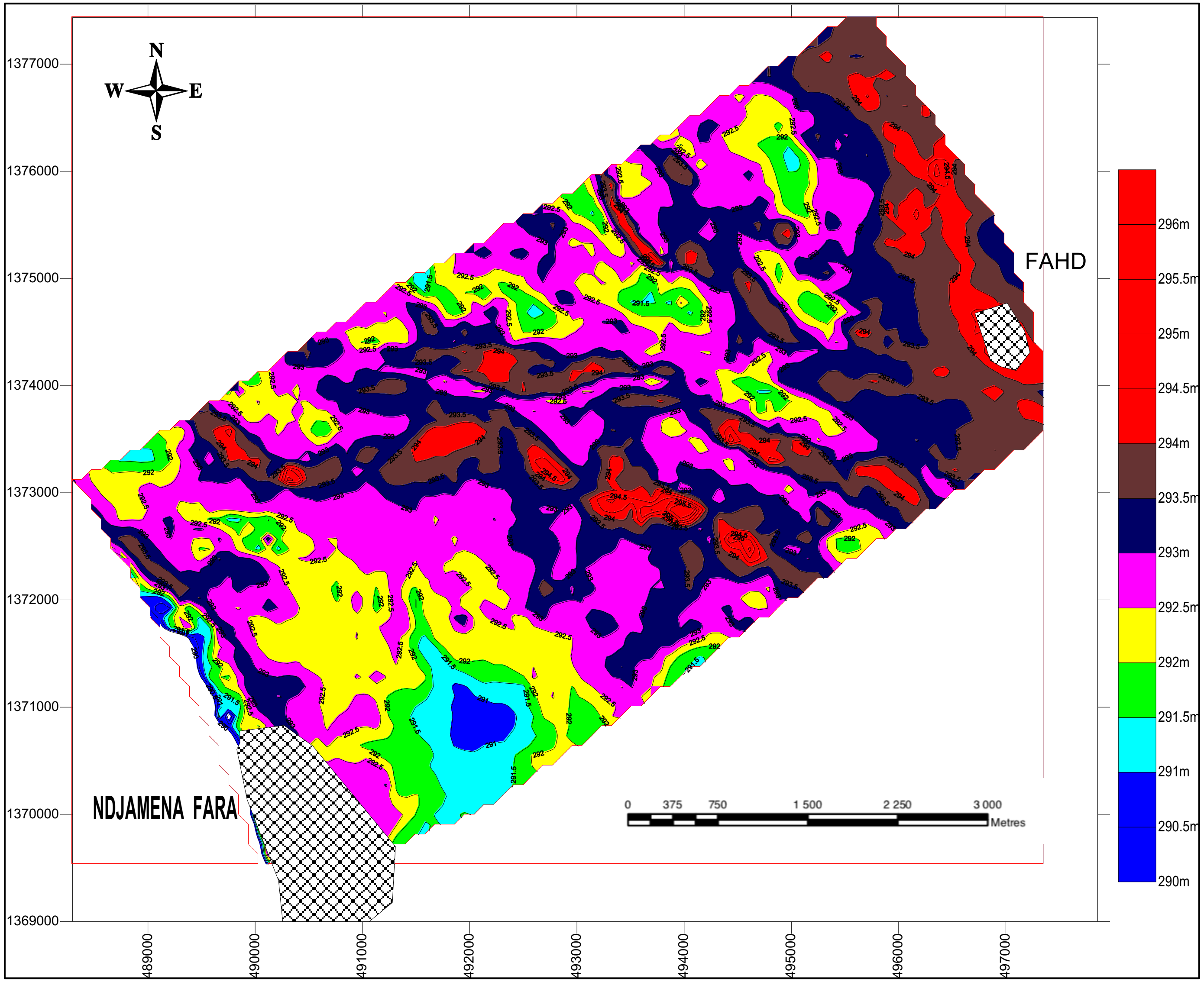
Appendix 1: Results of excel data analysis

Items	Label	Total	Strongly disagree (%)	Disagree	Somewhat disagree (%)	Neither agree or disagree (%)	Somewhat Agree (%)	Agree (%)	Strongly Agree (%)	Total (%)
Irrigation_technology	I am satisfied with my current irrigation system	60	25%	52%	23%	0%	0%	0%	0%	100%
Water_use_efficiency	I use less water with the current irrigation technology	60	12%	55%	25%	5%	3%	0%	0%	100%
Water_accessibility	I have continuous and reliable access to water	60	3%	12%	8%	28%	32%	10%	7%	100%
Water_quality	The water use to irrigate has good quality	60	2%	3%	5%	15%	27%	33%	15%	100%
Fertilizers_pesticides_access	It is easy to have access to fertilizers and pesticide in enough quantity	60	73%	18%	7%	0%	0%	2%	0%	100%
Crop_grown	I have experience in growing crop such as tomato, cabbage, onion, pepper (green, red)	60	10%	2%	12%	32%	28%	12%	5%	100%
Annual_crop_production	I am satisfied with the annual crop production under the current irrigation	60	7%	30%	42%	18%	2%	2%	0%	100%
Labor_use	I used less labor under the current irrigation system	60	3%	30%	58%	3%	0%	2%	3%	100%
On_farm_Annual_income	I am satisfied with the average annual income from agriculture	60	0%	22%	65%	13%	0%	0%	0%	100%
Out_farm_Annual_income	I receive enough revenue from other activities than agriculture	60	5%	17%	28%	25%	20%	2%	3%	100%
Cost_of_the_system	I usually pay less to install the system	60	2%	8%	15%	18%	47%	7%	3%	100%
Water_tariff	I can afford to pay for the water cost	60	0%	0%	2%	3%	27%	47%	22%	100%
O_M_of_the_system	The cost associated with the operation & maintenance of the system is quite higher	60	0%	0%	2%	5%	23%	45%	25%	100%
Access_to_credit	I have access to financial services to support my agricultural activities	60	83%	12%	3%	0%	2%	0%	0%	100%
awareness	I am informed of the advantages and disadvantages of my current irrigation system	60	82%	17%	2%	0%	0%	0%	0%	100%
Information_access	I frequently have access to the right information concerning my agricultural activities	60	67%	33%	0%	0%	0%	0%	0%	100%
Capacity_building	I frequently receive training from agricultural extension services	60	60%	40%	0%	0%	0%	0%	0%	100%
Participation	I am actively participating in community projects and activities	60	47%	37%	12%	3%	2%	0%	0%	100%
Market_accessibility	I have easy access to the market (infrastructure)	60	43%	40%	12%	5%	0%	0%	0%	100%
Government_subsidy	The agricultural input (seeds, fertilizers, and pesticides) receive a subsidy from the government	60	73%	27%	0%	0%	0%	0%	0%	100%

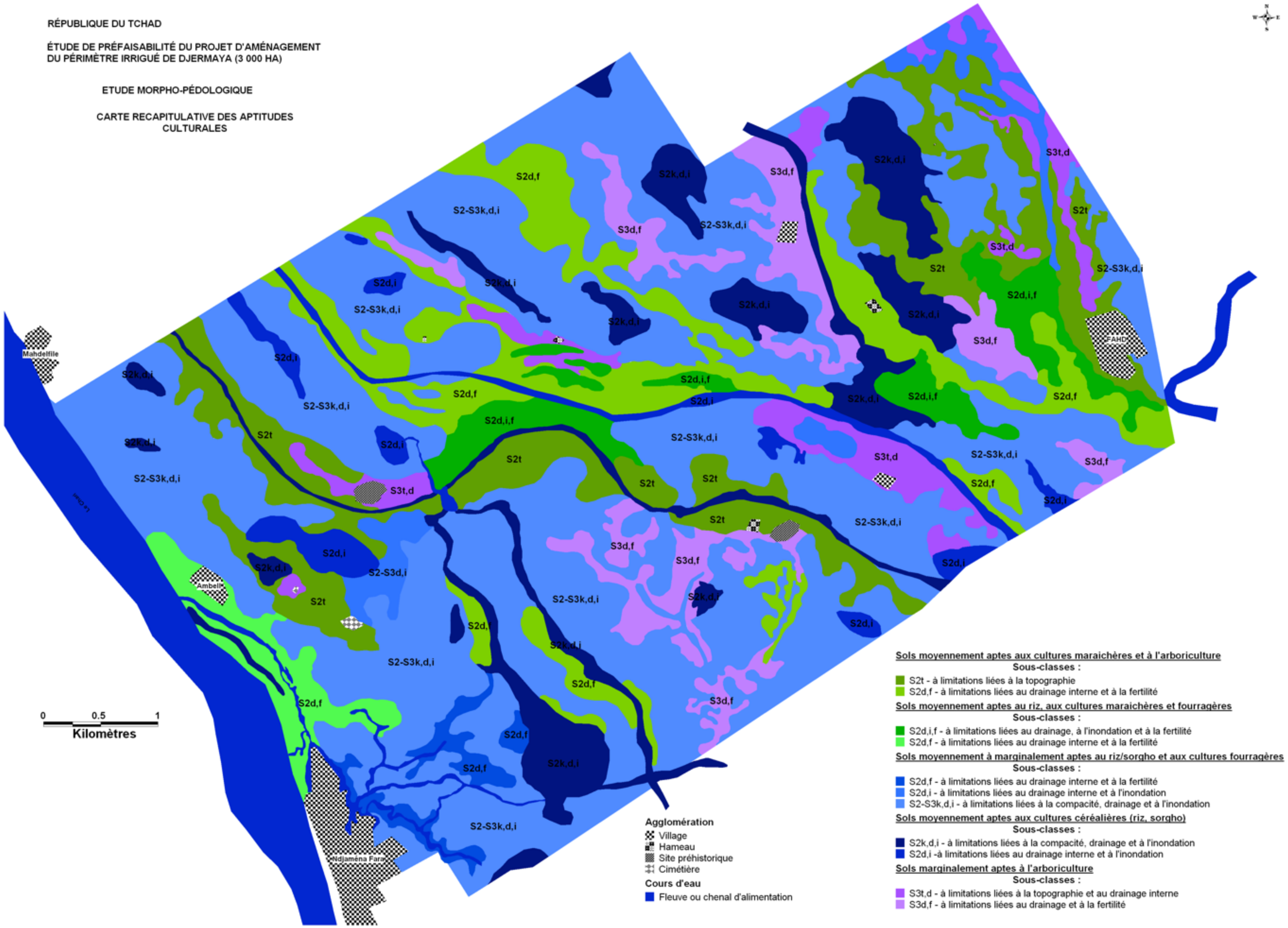
Appendix 2: Crop suitability

Id	Surface (ha)	Crop suitability			
		Cereals crop (Rice, Sorghum)	Fodder crop	Vegetable crops (tomato, onion, potato, pepper, cabbage)	Horticulture
L-g	159.3	N2	N2	N2	S3
L-g/m	445.7	N2	N2	S2	S2
ld-g	147.6	N2	N2	N2	S3
ld-g/m	401.1	S3	S3	S2	S2
ld-m/tf	49.1	S2	S2	S3	N2
ld-m/g	15.3	S3	S3	S2	S2
le-g	102.3	N2	N2	N2	S3
ed-m	85.7	S2	S2	S2	S2
C-tf	1606	S2	S3	N2	N2
C-f/tf	446.1	S2	S3	N2	N2
C-m/tf	44.3	S2	S2	S3	N2
C-g/tf	45.8	S2	S2	S2	N2
C-m/f	134.0	S2	S2	S2	S2
C-f/g	34.7	S2	S2	S2	S2
Ch-tf	33.7	S2	N2	N2	N2
Ch-f/tf	62.5	S2	N2	N2	N2
Ch-m/tf	92.6	S2	N2	N2	N2
M-tf	282.8	S	N2	N2	N2
M-f/tf	13.8	S2	N2	N2	N2
M-m/tf	65.1	S2	N2	N2	N2
M-f	16.8	S2	N2	N2	N2
M-m/g	6.4	S3	N2	N2	N2

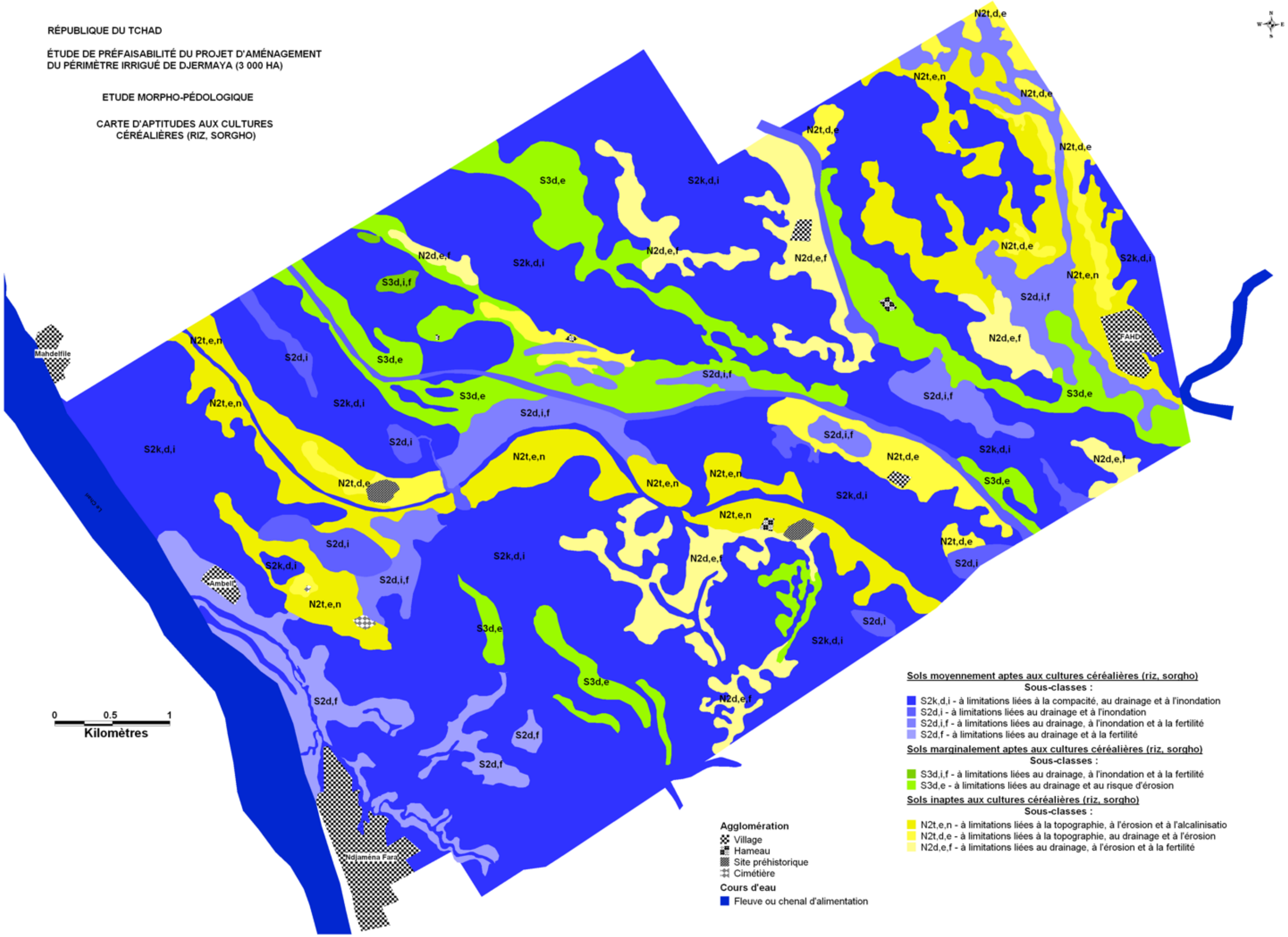
Appendix 3: topographic map



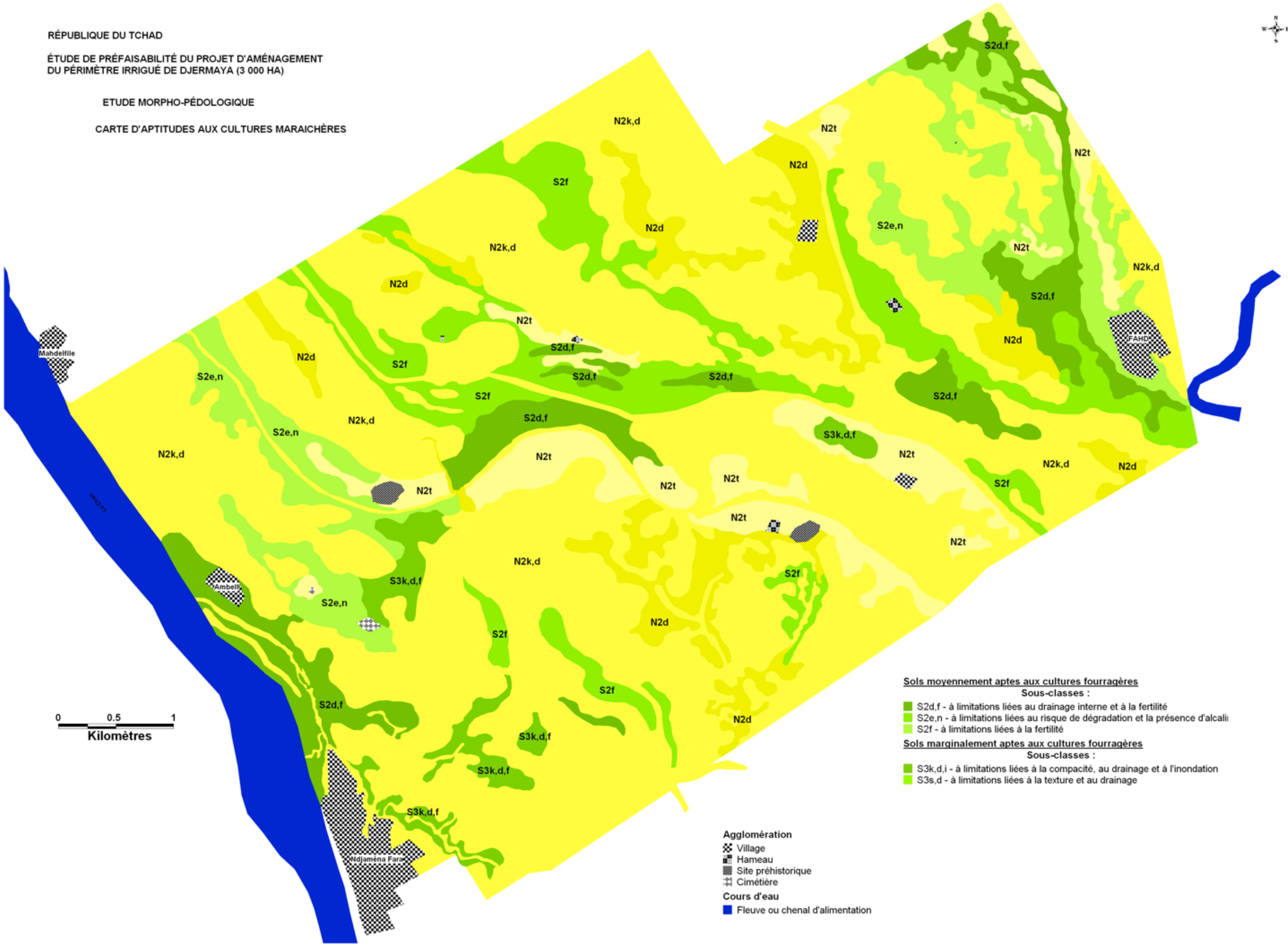
Appendix 4: Soil suitability map



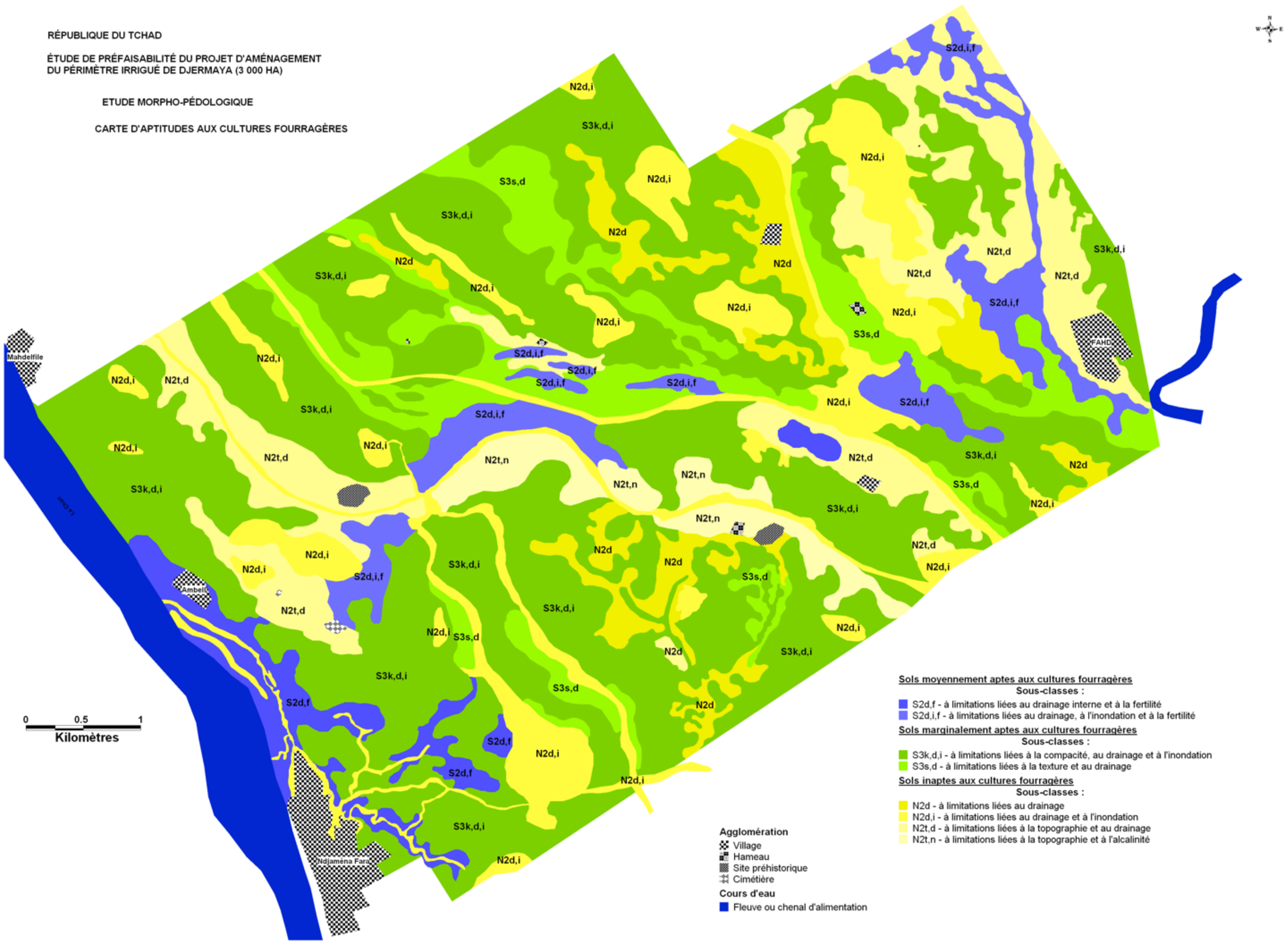
Appendix 5: soil suitability map for cereal crops



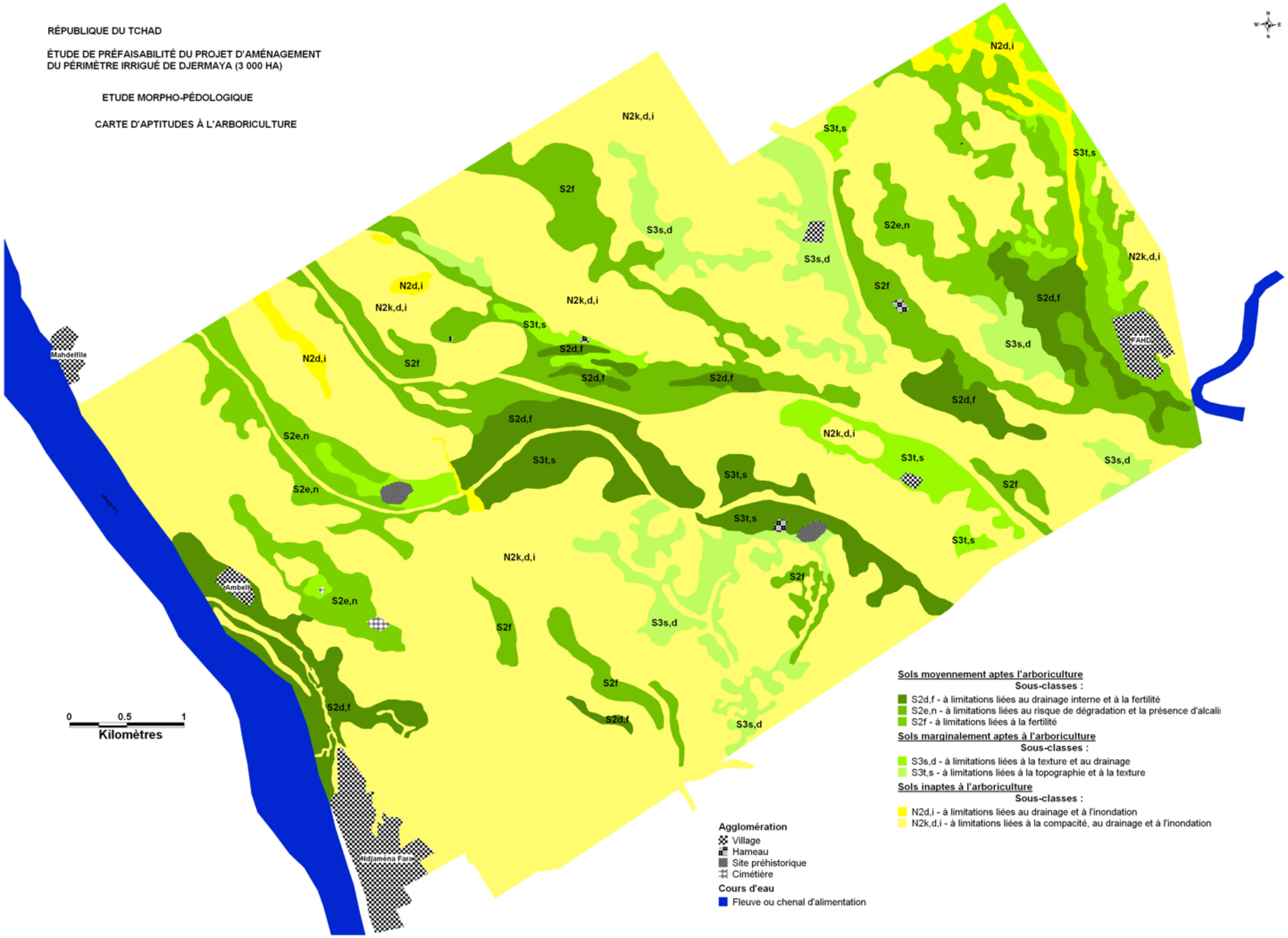
Appendix 6: soil suitability map for vegetable crops



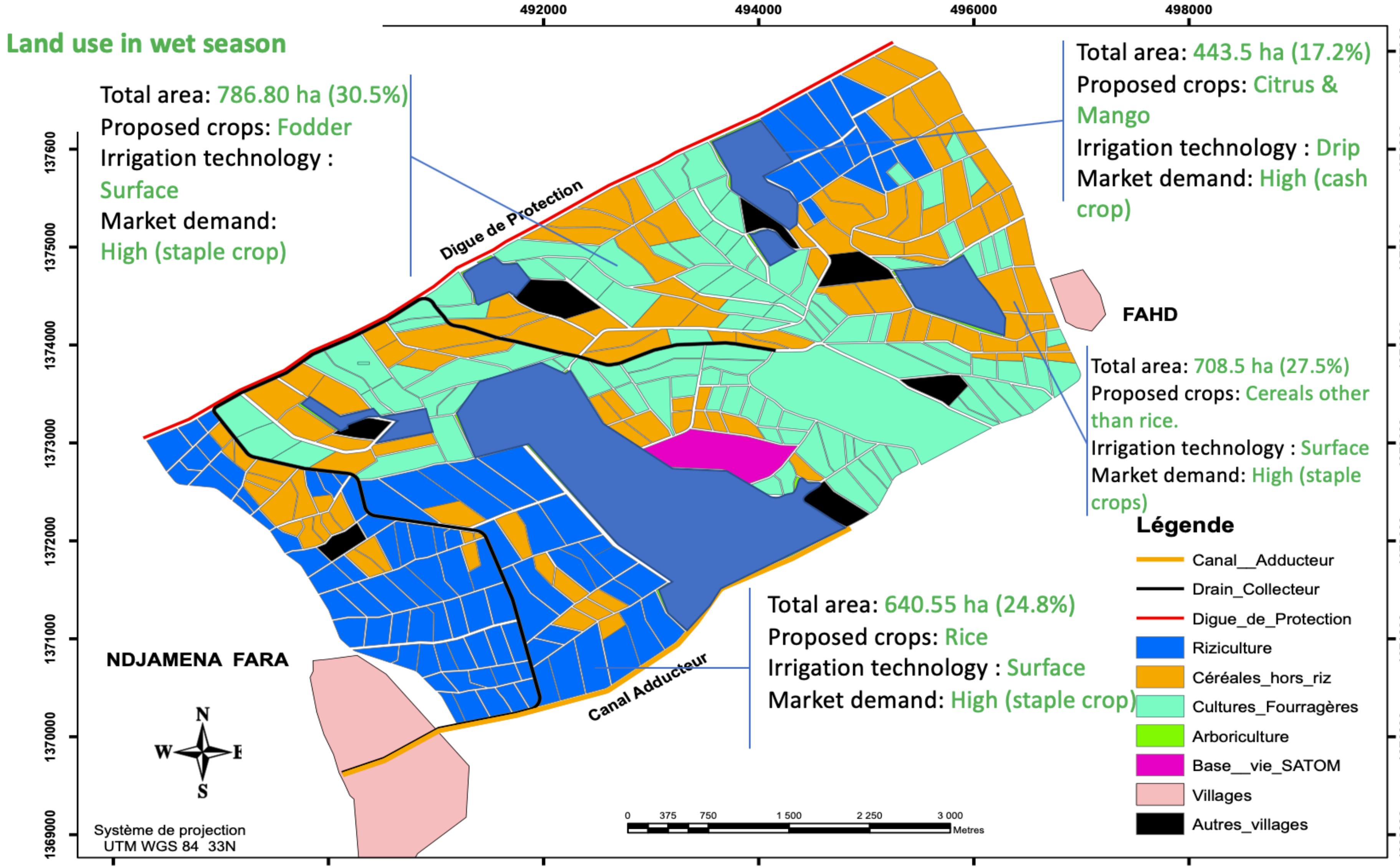
Appendix 7: soil suitability map for vegetable crops



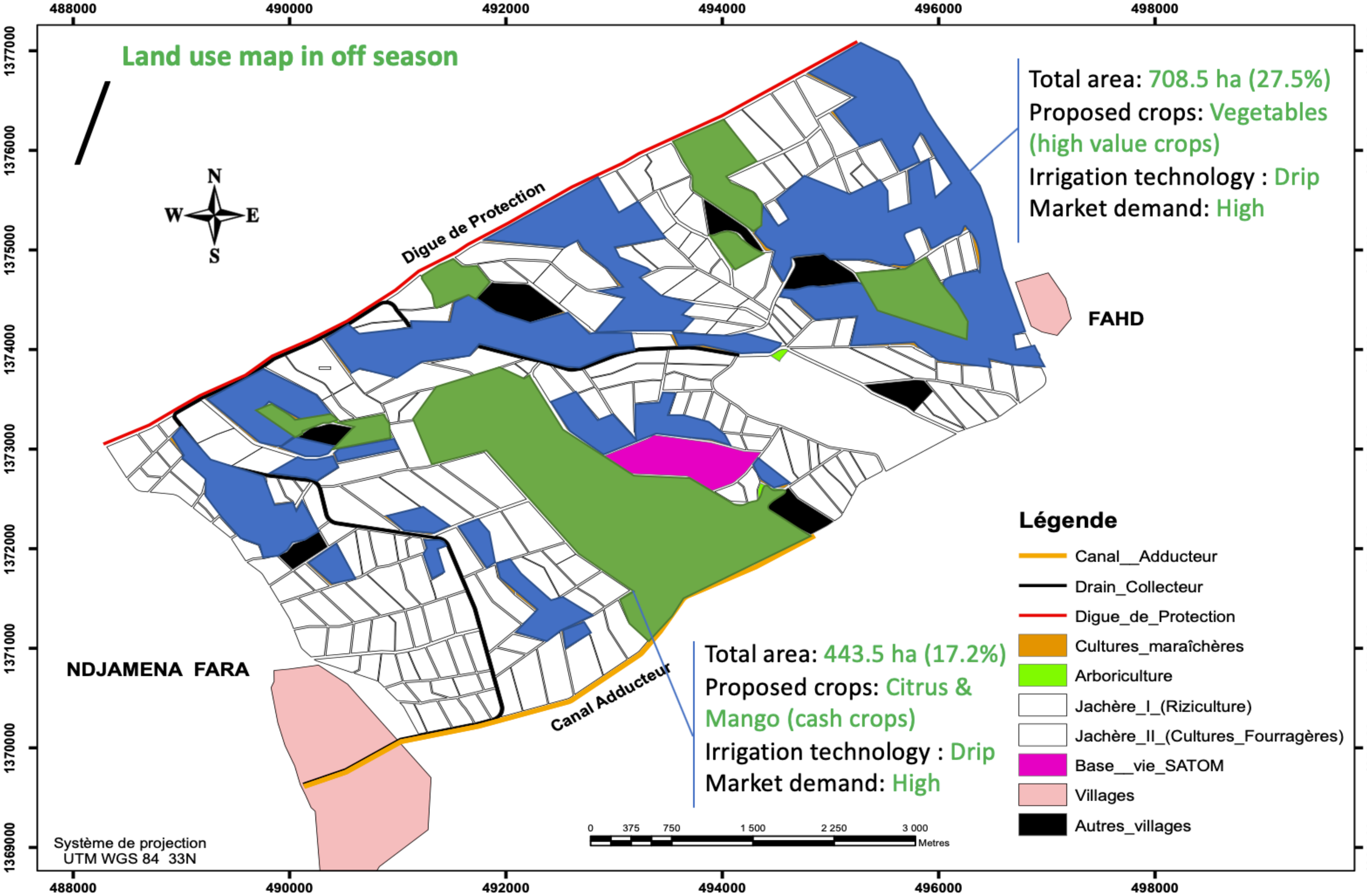
Appendix 8: soil suitability map for vegetable crops



Appendix 9: cropping patterns vs irrigation technologies map (wet season)



Appendix 10: cropping patterns vs irrigation technologies map (dry season)



Appendix 11: Financial analysis of the investment

Year	Investment costs	Replacement costs (a)	Energy costs	Repairs and Maintenance costs (b)	Technical support	Total project cost (c)	Gross Margin benefit	Net benefit (d)	Discount factor (10%)	Present Value of cost (e)	Present Value of benefits (f)	Present Value of Net benefits (g)
1	5520		0	0	0	5520	-	- 5 520	0,9091	5 018,18	-	- 5 018,18
2			300	165,60	300	765,60	1 758	992,55	0,8264	632,73	1 453,02	820,29
3			300	165,60	300	765,60	2 676	1 910,88	0,7513	575,21	2 010,88	1 435,67
4			300	165,60	300	765,60	3 595	2 829,22	0,6830	522,92	2 455,31	1 932,39
5			300	165,60	300	765,60	3 595	2 829,22	0,6209	475,38	2 232,10	1 756,72
6		237,5	300	165,60	300	1003,10	3 595	2 591,72	0,5645	566,22	2 029,18	1 462,96
7			300	165,60	300	765,60	3 595	2 829,22	0,5132	392,87	1 844,71	1 451,84
8			300	165,60	300	765,60	3 595	2 829,22	0,4665	357,16	1 677,01	1 319,85
9			300	165,60	300	765,60	3 595	2 829,22	0,4241	324,69	1 524,55	1 199,86
10			300	165,60	300	765,60	3 595	2 829,22	0,3855	295,17	1 385,96	1 090,79
11		237,5	300	165,60	300	1003,10	3 595	2 591,72	0,3505	351,58	1 259,96	908,38
	5520,00	**237,50**	**1500,00**	**828,00**	**1500,00**	**9585,50**	**15219,08**	**5633,58**		**9 512,11**	**17 872,67**	**8 360,57**

Net Present Value (NPV)	8 360,57
Present value of benefits at 10%	17 872,67
Present value of costs	9 512,11
Benefit/Cost (B/C) Ratio	1,88
Internal Rate of Return (IRR)	24%
Payback period	3 years
Discount rate	10%

Appendix 12 : Quantitative Survey questionnaire

INTRODUCTION :

Dear Sir/Madam

I'am Oumar Alfaroukh Brahim Mahamat, a 2nd (final) year MSc. student in Water Policy, from Pan African University Institute of Water and Energy Sciences (including climate change) (PAUWES) in Algeria. The aim is to fulfil my MSc. Thesis program, my topic of focus is; "**Advanced Irrigation Technologies and adaptation to water scarcity in arid region: case study of Chad**" (Suburban areas of Ndjamena). I would appreciate your answering these questions as the information you provide will be much useful to my study, and I assure you, all information will be treated confidential, will only be used for the study purpose. I would like to emphasize that your responses will be extremely valuable to me and my PAUWES University at large, hence I would greatly appreciate your inputs by answering

1- The specific objectives of my visit are:
- To gather information on current irrigation technologies and practices in Chad,
- To assess the adaptability of advanced irrigation technologies for sustainable water management in Djaramaya irrigation scheme.

2- The questions should take less than 15 minutes.

Socio-demographic characteristics

I. What is your gender?

1. Male
2. Female

II. Level of formal education?

1. No formal education
2. Primary
3. Secondary
4. University

III. What is your age?

1. 15 – 24
2. 25- 44
3. 45- 64
4. 60+

IV. Farming experience (years)?

1. < 5
2. 5 – 10
3. 10 – 15
4. > 15

Items	Technical/ Environmental Factors	Strongly disagree	Disagree	Some what disagree	Neither agree or disagree	Somew hat Agree	Agree	Strongly Agree
		1	2	3	4	5	6	7
Irrigation technology	I am satisfied with my current irrigation system							
Water use efficiency	I use less water with the current irrigation technology							
Water accessibility	I have continuous and reliable access to water							
Water quality	The water quality is good							
Water use efficiency	I use less water with the current irrigation technology							
Fertilizers and pesticides	It is easy to have access to fertilizers and pesticide in enough quantity							
Crop grown	I have experience in growing crop such as tomato, cabbage, onion, pepper (green, red).							
Items	**Economic factors**							
Crop production	I am satisfied with the annual crop production under the current irrigation							
Labor	I used less labor under the current irrigation system							
Annual income (on farm)	I am satisfied with the average annual income from agriculture							
Annual income (out farm)	I receive enough revenue from other activities than agriculture							

Items	Financial factors	1	2	3	4	5	6	7
Cost of the system	I usually pay less to install the system							
Water tariff	I can afford to pay for the water cost							
O&M of the system	The cost associated with the operation & maintenance of the system is quite higher							
Access to credit	I have access to financial services to support my agricultural activities							
Items	**Institutional factors**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
awareness	I am informed of the advantages and disadvantages of my current irrigation system							
Information access	I frequently have access to the right information concerning my agricultural activities							
Capacity building	I frequently receive training from agricultural extension services							
Degree of participation	I am actively participating in community projects and activities							
Market accessibility	I have easy access to market (infrastructure)							
Government subsidy	My agricultural input (seeds, fertilizers and pesticides) are subsidized							

Appendix 12: Qualitative Survey questionnaire

INTRODUCTION :

Dear Sir/Madam

I'am Oumar Alfaroukh Brahim Mahamat, a 2nd (final) year MSc. student in Water Policy, from Pan African University Institute of Water and Energy Sciences (including climate change) (PAUWES) in Algeria. The aim is to fulfil my MSc. Thesis program, my topic of focus is; "**Advanced Irrigation Technologies and adaptation to water scarcity in arid region: case study of Chad**" (Suburban areas of Ndjamena). I would appreciate your answering these questions as the information you provide will be much useful to my study, and I assure you, all information will be treated confidential, will only be used for the study purpose. I would like to emphasize that your responses will be extremely valuable to me and my PAUWES University at large, hence I would greatly appreciate your inputs by answering

3- The specific objectives of my visit are:
- To gather information on current irrigation technologies and practices in Chad,
- To assess the adaptability of advanced irrigation technologies for sustainable water management.

4- The interview should take less than 45 minutes.

Ministry of Production, Irrigation and Agricultural Equipment

Interviewer

Name :…………………………………………………………………………………………………..

Occupation :..………………………………………………………………………………………………..

Email address :……………………………………………………………………………………………………

Telephone :…………………………………………………………………………………………………

1- What do you think are the major irrigation challenges in chad?

2- what in your view represents good and poor irrigation system?
3- Do you think farmers are aware of the benefits of improved irrigation practices?
4- What do you think could be the factors that encourage farmers to invest in the improvement of their irrigation system?
5- What do you think could be the main challenging factors in implementing and maintaining the sustainability of irrigation projects?
6- From your experience how does the decision-making process work in your organization?

Regional agronomic research center for Sahel zone (Centre régional de recherche agronomique pour la zone sahel)

Interviewer

Name :……..

Occupation :..………………………………………………………………………………………………..

Email

address :……………………………………………………………………………………………………

Telephone :……………………………………………………………………………………………………

1. Briefly describe your organization?
2. What are the activities of your organization? Tell me specifically about the one related to irrigation?
3. What are the objectives behind each research project?
4. What is the type of irrigation technologies adopted in your organization?
5. Tell me about the operation and maintenance that you have employed to ensure sustainability?

Ministry of the Environment, Water and Fisheries

Interviewer

Name :……..

Occupation :..……………………………………………………………………………
……………………………..
Email
address :…………………………………………………………………………………
……………………
Telephone :………………………………………………………………………………
………………………………

1. Briefly describe your organization?
2. What are the activities of your department?
3. What do you think could be the factors that encourage farmers to cooperate regarding the improvement of their irrigation system?
4. Do you think farmers should pay for water abstraction and services?
5. Tell me more about the operation and maintenance adopted in your past and current projects?
6. From your experience how does the decision-making process work in your organization?

Economic and Monetary Community of Central Africa (CEMAC)
Regional Research Centre Applied to the Development of Agricultural Systems

Interviewer
Name :……………………………………………………………………………………
……………..
Occupation :..……………………………………………………………………………
……………………………..
Email
address :…………………………………………………………………………………
……………………
Telephone :………………………………………………………………………………
………………………………

1- Briefly describe your organization?
2- What are the activities of your organization? Tell me specifically about the one related to irrigation?

3- What are the findings related to irrigation of the research conducted in your organization? How are they disseminated among the stakeholders?
4- What do you think could be the main three (3) challenging factors in implementing and maintaining the sustainability of irrigation projects?
5- What do you think could be the three (3) major factors that encourage farmers to cooperate regarding the improvement of their irrigation system?
6- How the capacity building component is integrated in the different projects? If No, what were the challenges?

Agricultural Bank of Chad

Interviewer

Name :………………………………………………………………………………………………
……………..

Occupation :..……………………………………………………………………………………
……………………………..

Email

address :………………………………………………………………………………………………
……………………

Telephone :…………………………………………………………………………………………
………………………………

1- Briefly describe your organization?
2- What are the activities of your organization? Tell me specifically about the one related to irrigation?
3- What are the projects financed by the bank? What is the cost of investment? What is the return period of the investment? What is the profit?
4- Tell me about the operation and maintenance of your past and current project? What is their cost?
5- What do you think could be the main three (3) challenging factors encountered by your organization in implementing and maintaining the sustainability of your funded projects?
6- What do you think could be the three (3) major factors that encourage smallholder farmers to invest in advanced irrigation system?

Ndjamena Fara Irrigation Project

Interviewer

Name :………………………………………………………………………………………………………..

Occupation :..……………………………………………………………………………………………………..

Email

address :………………………………………………………………………………………………………

Telephone :……

1- What is your organization performance during project implementation?
2- What do you think are the major irrigation challenges?
3- what in your view represents good and poor irrigation performance?
4- According to you what is an ideal irrigation system for Chadian context?
5- How do you foresee project sustainability in Chad?
6- What are the design and construction cost, operation & maintenance cost of an irrigation system?
7- Tell me more about the operation and maintenance adopted in this project?
8- what factors do you think could facilitate the improvement of irrigation systems and their sustainability?

Lake Chad Basin Commission (LCBC)

Interviewer

Name :………………………………………………………………………………………………………..

Occupation :..……………………………………………………………………………………………………..

Email

address :…………………………………………………………………………………………

……………………

Telephone :………………………………………………………………………………………

………………………………

1. Please tell me about yourself and your role in the organization?
2. What are the irrigation projects sponsored by LCBC?
3. What do you think are the major irrigation challenges in chad?
4. what in your view represents good and poor irrigation system?
5. According to you what is an ideal irrigation system for the Chadian context?
6. Tell me more about the operation and maintenance adopted in your past and current projects? How do you foresee project sustainability in Chad?
7. Tel me about the implication of local farmers in the project cycle? How LCBC ensures the capacity building of local farmers and their resiliency?

National Office for Food Security (Office Nationale de Sécurité Alimentaire)

1. From your experience what is the production performance of small-scale irrigation schemes compare to the medium and large one?
2. what are the performance expectations from farmers and water user association in term of crop production? What about the decision-making process?
3. What do you think could be the factors that encourage farmers to cooperate regarding the improvement of their irrigation system?
4. Do you think farmers should pay for water abstraction and services?
5. What are the strategies of your organization in ensuring farmers resiliency?

Pan African University
Institute of Water
and Energy Sciences

Assessment Grid for Master Thesis Proposal

Name of the Student: OUMAR AL-FAROUKH BRAHIM MAHAMAT

Track: Master

Title : DEVELOPMENT OF A CONCEPTUAL ADVANCED IRRIGATION SYSTEM FOR SUSTAINABLE WATER MANAGEMENT IN ARID REGIONS IN AFRCA

No	Criteria	Evaluation	Numerical Grade	%
1	Aim, Research Questions and/or Hypotheses	This research will seek to develop an appropriate irrigation technology in the selected case studies within the Islamic Development Bank members countries in Africa. The aim of this thesis carries a meaning that covers the study will carry out. Four research questions and hypotheses are proposed and all of them are very close with the subject.	09	10
2	Relevance to the research priorities of the research agenda and practical contribution to Agenda 2063	Student has identified an area of study that has relevance to the research priorities of the research agenda and practical contribution to Agenda 2063 and in which an original contribution can be made. Now, remains how to convince the decision-makers and the authorities accepted this type of study by the concretization and the financing.	18	20
3	Logical Structure	The structure used for this thesis is clear and logic	10	10
4	Literature review and Bibliography	The literature review is well written and balanced and the references used in this research are reliable	09	10
5	Quality of the methodology and its implementation	Both quantitative and qualitative methods were chosen. The proposed research will be based on primary and secondary data as input. Well, both proposed methods are adequate for meeting objective of study	19	20
6	Risk analysis and Practical feasibility of research	Problem of timing (not be enough) and the reliability and validity of collected data. Another possible challenge may arise regarding the planned budget.	08	10
7	Work plan and deadlines	The work plan and deadlines chosen are logic	10	10
8	Budget appraisal	The presented budget is largely sufficient for the execution of this research work.	10	10
	Summary	This is a very interesting research proposal that deserve funding and support.	93	100

Date: **Name and Signature of the Examiner**

15/02/2019

OUMAR AL-FAROUKH BRAHIM MAHAMAT

Master Program: Water Policy

Date: 14/05/2019

TOPIC:

ADVANCED IRRIGATION TECHNOLOGIES AND ADAPTATION TO WATER SCARCITY IN ARID REGIONS IN AFRICA

UPDATED BUDGET:

S/No.	Item	Unit	Quantity	Rate (Unit price)	Amount ($)	Link to Research Activity	Month	Comment (For Evaluator Only)
(A) Material and Supplies								
2	Internet recharge	Month	3	100	300	Required for collection of secondary information	From March to May	
	Sub Total				**300**			
(B) Equipment								
5	**Agro meteorological Data**						March	
5.1	Topographic data	N/A	1	180	180	Secondary input data required for the research		
5.2	Soil data	N/A	1	200	200			
5.3	Temperature min,max (minimum 10 years)	N/A	1	250	250			
5.4	Rainfall data (minimum 10 years)	N/A	1	250	250			
5.5	Stramflow data (minimum 10 years)	N/A	1	210	210			
	Sub Total				**1090**			
(C) Travel + Visa Costs								

7.0	**International flight**	N/A	1	1 000,00	1000,00		May	
7.1	**Travel insurance**	N/A	1	80,00	80,00			
7.2	**Field trip**						March	
7.2.1	Ndjamena - Klessoum (return ticket)	N/A	1	104,55	104,55	Required to collect primarily data from both urban and rural areas		
7.2.2	Ndjamena - Djarmaya (return ticket)	N/A	1	120,00	120,00			
7.2.3	Ndjamena - Linia (return ticket)	N/A	1	110,00	110,00			
7.2.4	Ndjamena - Gassi (return ticket)	N/A	1	95,45	95,45			
7.2.5	Ndjamena - Gaoui (return ticket)							
7.2.6	Ndjamena - Mandjafa (return ticket)	N/A	1	100,00	100,00			
	Sub Total				**1610**			
	Total Grant				**3000**			

Monthly Costs ($)	
March	2000
April	0
May	1000
June	0
July	0
August	0
Total	3000