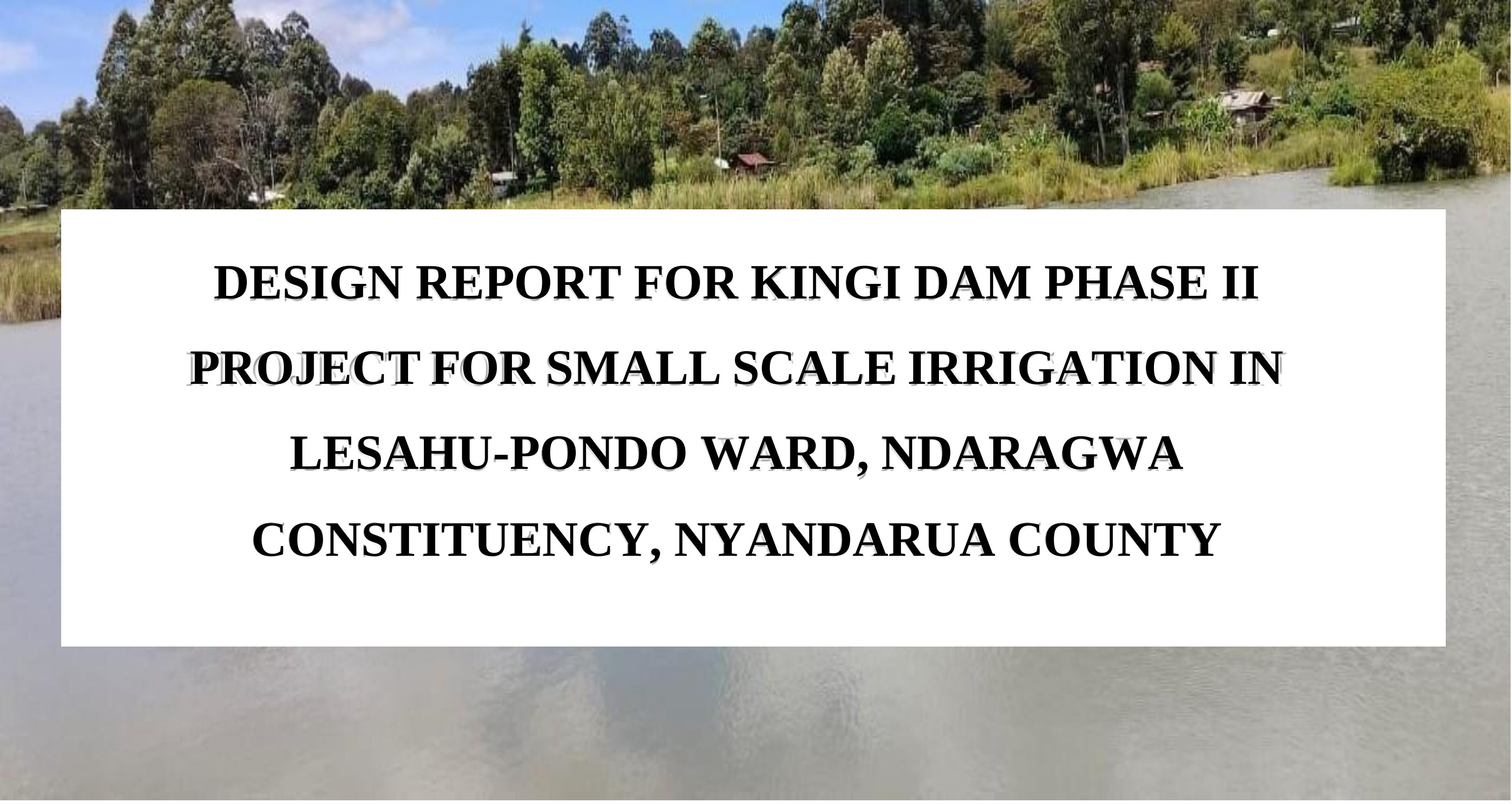

DESIGN REPORT FOR KINGI DAM PHASE II PROJECT FOR SMALL SCALE IRRIGATION IN LESAHU-PONDO WARD, NDARAGWA CONSTITUENCY, NYANDARUA COUNTY

APRIL, 2025

NAVCDP

National Agricultural Value Chain Development Project

Transitioning from Subsistence to Commercial Farming

EXECUTIVE SUMMARY

The Kingi Dam Phase II Irrigation Development Project is a community-driven initiative aimed at improving water accessibility, enhancing agricultural productivity, and strengthening climate resilience among smallholder farmers in Ndaragwa Sub-County, Nyandarua County. Building on the successes and lessons of Phase I—implemented under the Kenya Climate Smart Agriculture Program (KCSAP)—this second phase seeks to extend the benefits of irrigation to previously marginalized areas that were not reached due to technical challenges, particularly elevation differences.

The project proposes the construction of key infrastructure, including a pump chamber with solar-powered submersible pumps, a power house and control unit, solar panel support structures, and a 90mm rising main pipeline. Water will be conveyed to a 9-meter-high water tower constructed on a designated community plot at Kiriita, fitted with two 10,000-liter plastic storage tanks, from where it will be distributed via a comprehensive water reticulation system. The system is designed to support 215 households, bringing approximately 53.75 acres under irrigation in the villages of Upper Kiandege, Lower Kiandege, and Kiriita.

The primary objective is to enable consistent and reliable water supply for irrigation and livestock use, reduce dependence on unreliable rain-fed agriculture, and improve food and income security for marginalized farmers. With an average irrigable area of 0.25 acres per household, the project will facilitate year-round production of food and fodder crops, help mitigate the impacts of climate change, and promote sustainable land and water use practices. Additionally, the use of solar-powered technology ensures an environmentally friendly and cost-effective solution for long-term water management.

The project aligns with key national and county policy frameworks, including the National Irrigation Policy, the Agricultural Sector Transformation and Growth Strategy, and Kenya Vision 2030, as well as the Nyandarua County Integrated Development Plan (CIDP3). It represents a strategic investment in rural development that will not only boost agricultural productivity but also empower the community through improved livelihoods, equitable resource distribution, and enhanced resilience to environmental shocks.

In summary, the proposed Kingi Dam Phase II project is a viable, sustainable, and socially inclusive intervention that will play a pivotal role in transforming the livelihoods of farmers in Ndaragwa Sub-County and contribute meaningfully to food security and rural economic growth.

The total estimated project cost is **KES 26,755,087 equating** to **KES 1,244,422.65** per hectare which is significantly lower than the *International Water Management Institute's* benchmark of KES 1,569,305 for similar projects. Farmers' contribution is estimated at **KES. 8,000** for infield hose pipe and sprinkler.

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UNITS

mm	millimetres
m	metres
masl	metres above sea level
m3	cubic meters
m3/day	cubic metres per day
m3/hr	cubic metres per hour
km	kilometres

1.0 INTRODUCTION

1.1 Background information

Agriculture in Ndaragwa Sub-County is the backbone of the local economy, with the majority of households relying on smallholder farming for food and income. However, the sector is highly vulnerable to erratic rainfall and prolonged dry spells due to the impacts of climate variability and seasonal rainfall fluctuations, leading to low and unpredictable crop yields. The purpose of irrigation in this context is to provide a reliable and consistent water supply to support year-round farming, increase agricultural productivity, improve food security, and enhance the livelihoods of rural communities. By enabling farmers to grow crops beyond the rainy season and adopt high-value horticulture, irrigation plays a vital role in transforming subsistence farming into a more resilient and market-oriented enterprise.

Although Nyandarua County enjoys bimodal rainfall, Ndaragwa Sub-County sits at a transitional agro-ecological zone between the wetter highlands and the semi-arid Laikipia plateau. This positioning exposes the area to frequent dry spells, shortened growing seasons, and periodic crop failures, especially in the lower zones such as Shamata, Leshau Pondo, and parts of Central Ndaragwa. The result is inconsistent farm output, reduced household income, and growing food insecurity, particularly among smallholder farmers who dominate the local economy.

Agriculture in the Kingi area, like much of the surrounding region, is predominantly dependent on rain-fed farming. While the area benefits from fertile soils and a strong agricultural tradition, the productivity of local farms is increasingly threatened by erratic rainfall patterns, unpredictable onset of rains, and prolonged dry spells. These climatic stresses have become more frequent and severe in recent years due to the effects of climate change, leading to reduced crop yields, crop failure, and increased food insecurity among smallholder farmers.

In the financial year 2021/2022, the project benefited from the Kenya Climate Smart Agriculture Program (KCSAP) with the scope of works including the desiltation of the dam reservoir (increasing the water-holding capacity of the reservoir area), construction of a pump intake structure, pump house, water kiosk with 1 No. 10m3 plastic tank mounted on it, installation of a solar-powered submersible pump, erection of a solar support structure with (102 No. 340 Watts Photovoltaic Modules), construction of a 6-metre high water tower with 2 No. $10m^3$, fencing of the dam area, supply of 331 No. 2,300 litres plastic tanks and laying of 17km HDPE pipeline of assorted diameter. This infrastructure has enabled 150 households to benefit from small-scale irrigation system. These members are drawn from the Southern and Southeastern part of the dam area.

The targeted farmers in the proposed Phase II project solely depend on rain-fed agricultural production and fetch water from the dam using donkey-drawn carts and motor bikes for livestock and domestic use. This is because the KCSAP funded Phase I project was not able to supply water to the area due to technical challenges arising from ground elevation. To overcome this challenge, the community has identified a public piece of land where a water tower can be constructed to supply the Phase II beneficiaries with water through gravity. This piece of land has a community water tank that supplies domestic water to the community and has ample space that can accommodate the proposed water tower. Kingi Dam Phase II is therefore conceived as a strategic intervention to enhance the region's climate resilience and support sustainable agricultural development. This second phase of the project will focus on:

- Substantially increasing water storage capacity to meet year-round irrigation demand
- Establishing a pressurized water distribution network to reach farmlands efficiently
- Implementing water-efficient irrigation technologies such as drip and sprinkler systems, which reduce water losses and improve crop yields
- Empowering farmers through training and institutional support to manage water sustainably and adapt to climate-smart agricultural practices
- Boosting local food production, incomes, and livelihoods, thereby reducing reliance on food aid and increasing economic resilience.

This project directly contributes to the goals outlined in the Ministry of Agriculture's Irrigation Development Strategy, which prioritizes the expansion of irrigated agriculture to enhance food security, reduce poverty, and create rural employment. It is also aligned with the broader national development agenda under Kenya Vision 2030, which identifies irrigation as a key enabler for transforming agriculture from subsistence to a commercially viable sector.

Through the implementation of Kingi Dam Phase II, the project aims to unlock the agricultural potential of the area, enhance water resource management, and provide a replicable model for small-scale irrigation development across other semi-arid regions in Kenya.

1.2 Problem statement

Despite the implementation of Phase I of the Kingi Dam project under the Kenya Climate Smart Agriculture Program (KCSAP), which provided critical water infrastructure benefiting 150 households, the system failed to serve farmers located in the southern and southeastern parts of the dam area due to ground elevation challenges. As a result, targeted Phase II beneficiaries continue to rely solely on rain-fed agriculture and must fetch water manually from the dam using donkeys and motorbikes for both livestock and domestic use, limiting their agricultural productivity and resilience. There is an urgent need to extend the irrigation system to these underserved areas by constructing an elevated water tower on a strategically located public plot to enable gravity-fed water distribution.

1.3 Objective

1.3.1 General objective

The objective of the proposed Kingi Dam Phase II irrigation project is to enhance agricultural productivity and climate resilience among smallholder farmers in the southern and southeastern parts of the Kingi Dam service area by providing reliable, year-round access to water for irrigation and domestic use.

1.3.2 Specific objectives

- Install solar-powered infrastructure for sustainable and cost-effective water pumping;
- Construction of a powerhouse and laying of rising pipeline from the pump to the water tower
- Construct of water tower and a gravity-fed water distribution system from water tower to overcome elevation-related supply challenges
- Improve household food security and income through expanded small-scale irrigation;
- Reduce reliance on rain-fed agriculture and manual water-fetching methods;
- Promote equitable access to water resources across the broader Kingi Dam beneficiary community.

1.4 Scope of the project

The proposed Kingi Dam Phase II irrigation project will involve the construction and installation of key infrastructure to support small-scale irrigation and domestic water access in Upper Kiandege, Lower Kiandege, and Kiriita villages. The scope includes:

- Construction of a **pump chamber** and **installation of a solar-powered submersible pump** at the Kingi Dam site;
- Construction of a **power house** and installation of a **control panel** to manage the pumping system;
- Erection of a **solar panel support structure** and installation of **solar photovoltaic modules** to provide sustainable energy;
- Installation of a **90mm diameter rising main pipeline** from the dam to the **Kiriita Community Water Point plot**;
- Construction of a **9-meter high water tower** fitted with **two 10,000-litre plastic storage tanks** to enable gravity-fed distribution;
- Installation of a **water conveyance and reticulation system** to supply water to targeted farms and homesteads.

The project targets **215 households** as direct beneficiaries, serving approximately **53.75 acres of irrigable land**. The beneficiaries reside within **three villages**—Upper Kiandege, Lower Kiandege, and Kiriita—and all landowners possess valid **freehold title deeds**, which ensures secure land tenure and enhances the project's sustainability and community ownership.

1.5 Project justification

The justification for the proposed Kingi Dam Phase II irrigation project stems from the urgent need to expand access to reliable water supply for agricultural and domestic use in underserved areas of Ndaragwa Sub-County. While Phase I of the project, supported by the Kenya Climate Smart Agriculture Program (KCSAP), established vital infrastructure, it was unable to extend services to communities in the southern and southeastern parts of the dam area due to elevation-related technical limitations. As a result, households in Upper Kiandege, Lower Kiandege, and Kiriita villages continue to rely on unreliable rain-fed agriculture and labor-intensive water collection methods, limiting their productivity, food security, and resilience to climate shocks.

The proposed Phase II seeks to address these gaps by developing a gravity-fed irrigation system powered by solar energy, which will enable efficient and sustainable water distribution. This will directly support 215 households and bring approximately 53.75 acres of land under irrigation. By leveraging renewable energy and efficient water conveyance infrastructure, the project promotes climate-smart agriculture, reduces vulnerability to drought, and enhances the adaptive capacity of smallholder farmers.

Furthermore, the project is aligned with national and county development priorities, including Kenya Vision 2030, the Agricultural Sector Transformation and Growth Strategy, and the Nyandarua County Integrated Development Plan (CIDP3). It supports key policy objectives such as improving rural livelihoods, increasing food production, promoting environmental sustainability, and reducing rural poverty. The presence of secure land tenure through valid title deeds among the beneficiaries further strengthens the feasibility and long-term viability of the intervention.

Ultimately, the Kingi Dam Phase II project represents a strategic and socially inclusive investment that will unlock the agricultural potential of the region, reduce dependence on rain-fed farming, and transform the lives of the beneficiary communities through improved water access and enhanced agricultural productivity.

1.6 Benefit of the project

The Kingi Dam Phase II irrigation project is expected to deliver significant social, economic, and environmental benefits to the local community and the broader region. These include:

- **Improved Agricultural Productivity**: By providing consistent water supply for irrigation, the project will enable year-round cultivation, reduce crop failure, and increase yields, especially for high-value crops and horticulture.
- **Enhanced Food Security**: With expanded irrigation coverage of approximately 53.75 acres, the project will boost household food production, reduce dependency on seasonal rainfall, and improve nutrition among beneficiary families.
- **Increased Household Incomes**: Reliable irrigation will allow farmers to diversify into market-oriented farming, access new markets, and generate higher incomes from surplus produce.
- **Climate Resilience**: The project will reduce the vulnerability of local farmers to erratic weather and prolonged dry spells, aligning with climate adaptation strategies and promoting sustainable agriculture.
- **Time and Labor Savings**: By eliminating the need for manual water-fetching using donkeys and motorbikes, the project will save time and labor, especially for women and children, allowing them

to engage in other productive activities.

- **Equitable Water Access**: Phase II will address the elevation-related service gaps from Phase I, ensuring that underserved communities in Upper Kiandege, Lower Kiandege, and Kiriita villages have equitable access to water resources.
- **Environmental Sustainability**: Use of solar-powered pumping reduces reliance on fossil fuels, minimizes the project's carbon footprint, and supports green energy solutions in rural development.
- **Community Empowerment**: Through participatory planning, infrastructure ownership, and capacity-building, the project will strengthen community structures such as Water User Associations (WUAs), enhancing local governance and sustainability.

2.0 CHARACTERISTICS OF THE PROJECT AREA

2.0.1 Geography

The Kingi Dam Phase II Project for Small Scale Irrigation is located in the Leshau-Pondo ward, Kiriita Location, Leshau Pondo Ward, Ndaragwa sub-county, Nyandarua County. GPS location Latitude, Longitude (0.0537310, 36.4204750) and altitude of 2280 M asl. It is approximately 4.5km from Mairo-Inya town (off Nyahururu - Nyeri Road).

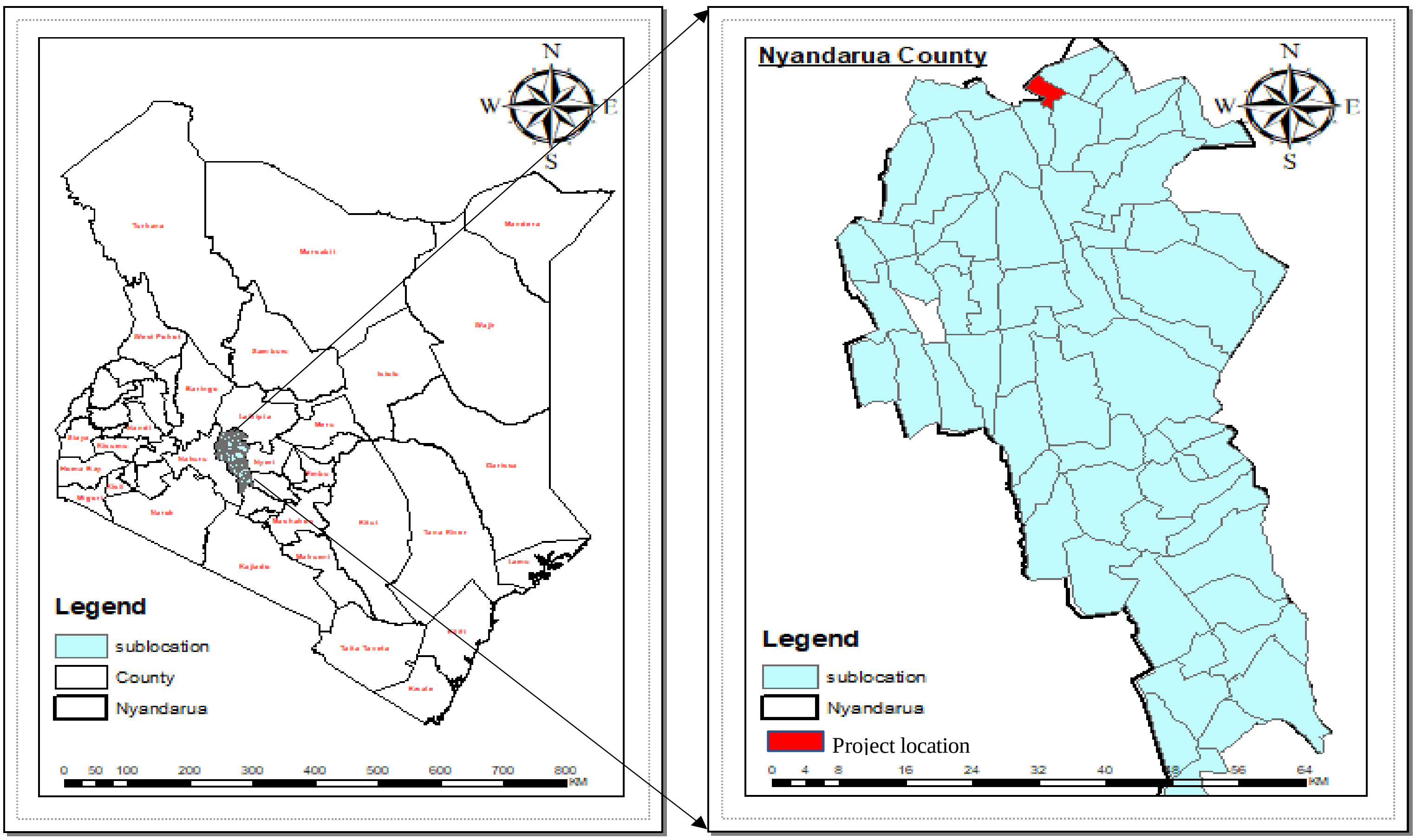

Figure 2:1 Project proposed area map

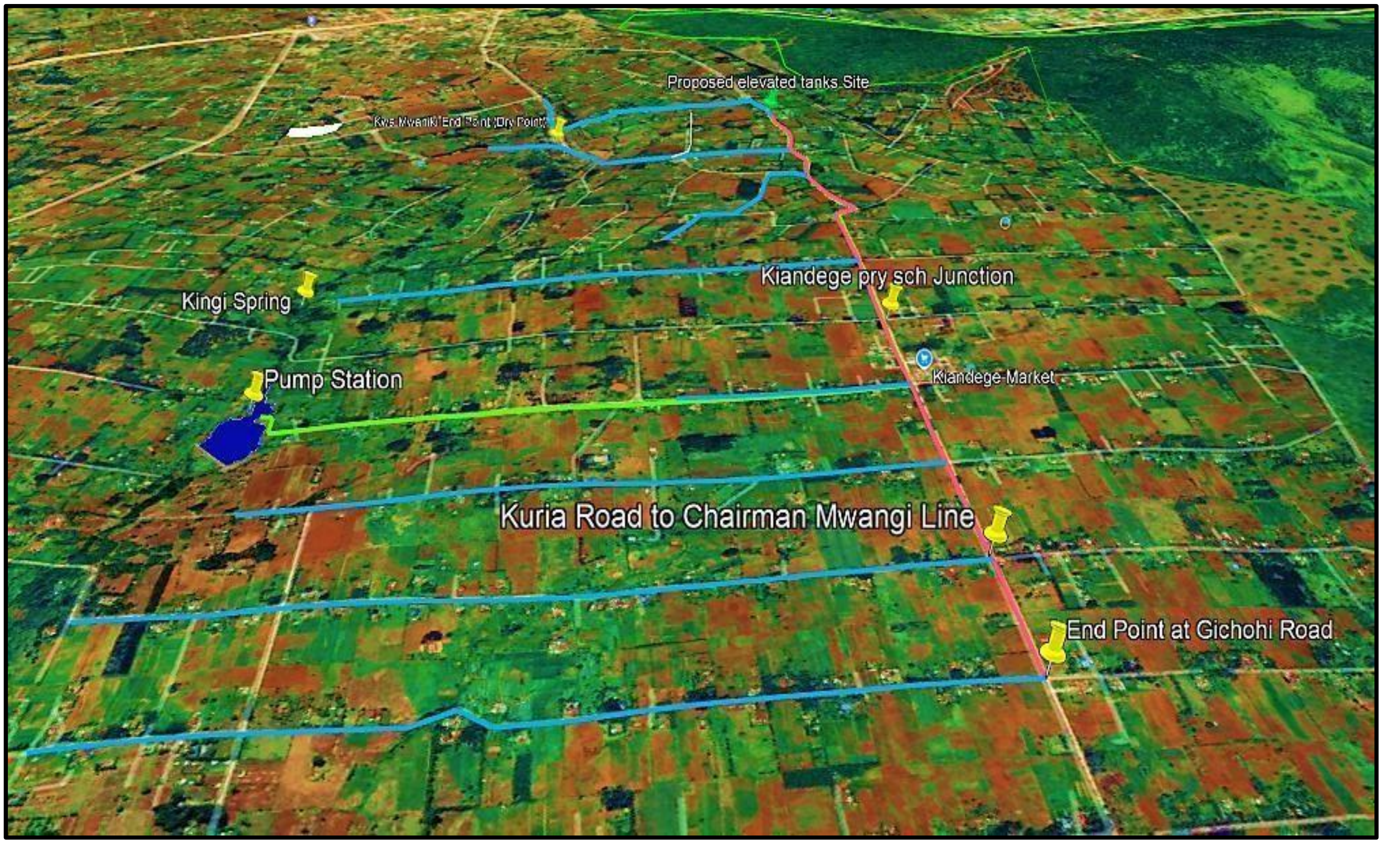

Figure 2:2 Proposed project area (Adapted from google earth)

2.0.2 Climate

The project area experiences bimodal rainfall seasons -: long and short rains. The long rain starts between March and May while the short rain comes between October and December. The area experiences on average rainfall of between 1000mm and 2000mm. The two rainy seasons are separated by season of dry spell and no reliable rainfall. The driest period is January-February and the coolest is July-august. Precipitation here is about 1872 mm per year. The least amount of rainfall occurs in February with its average be 61 mm. In April, the precipitation reaches its peak, with an average of 245 mm.

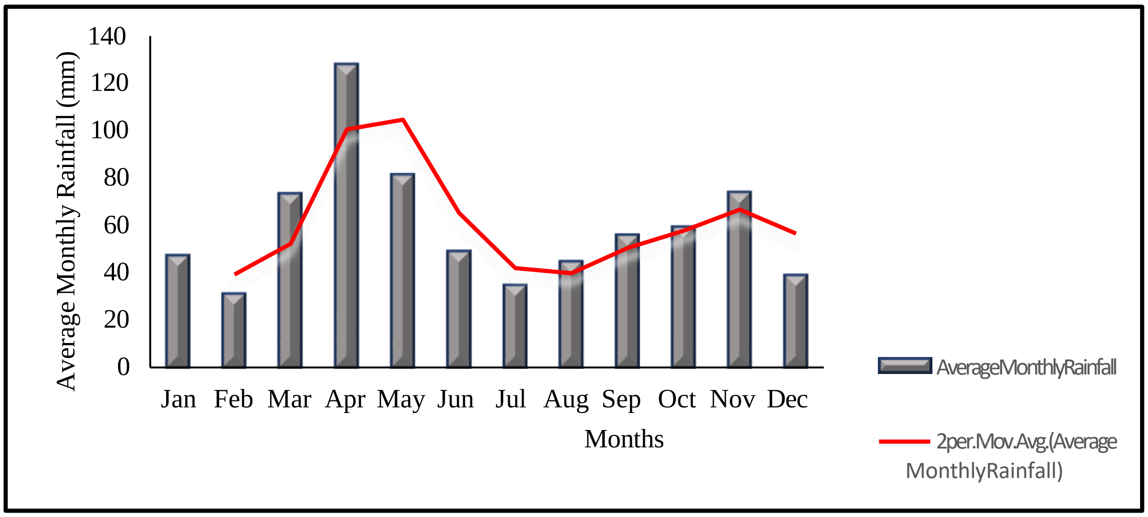

Figure 2:3 Study area annual climate data (Nyokabi et al., 2021)

The climate is warm and temperate in Ndaragwa sub-county, a place that receives significant amount of rainfall. This climate is considered to be Cfb according to the Köppen-Geiger climate classification. The average annual temperature is 13.6°C in the area. Potential evaporation is between 1,800 and 2,000 mm per year and these losses are exacerbated by frequent high winds in the area. Temperatures are highest in the months January to March; Annual mean daily minimum and maximum temperatures are from 16°C to 20°C. The month with the highest relative humidity is November (84.04 %). The month with the lowest relative humidity is February (64.65%). Ndaragwa are in the middle and the summers are that easy to define.

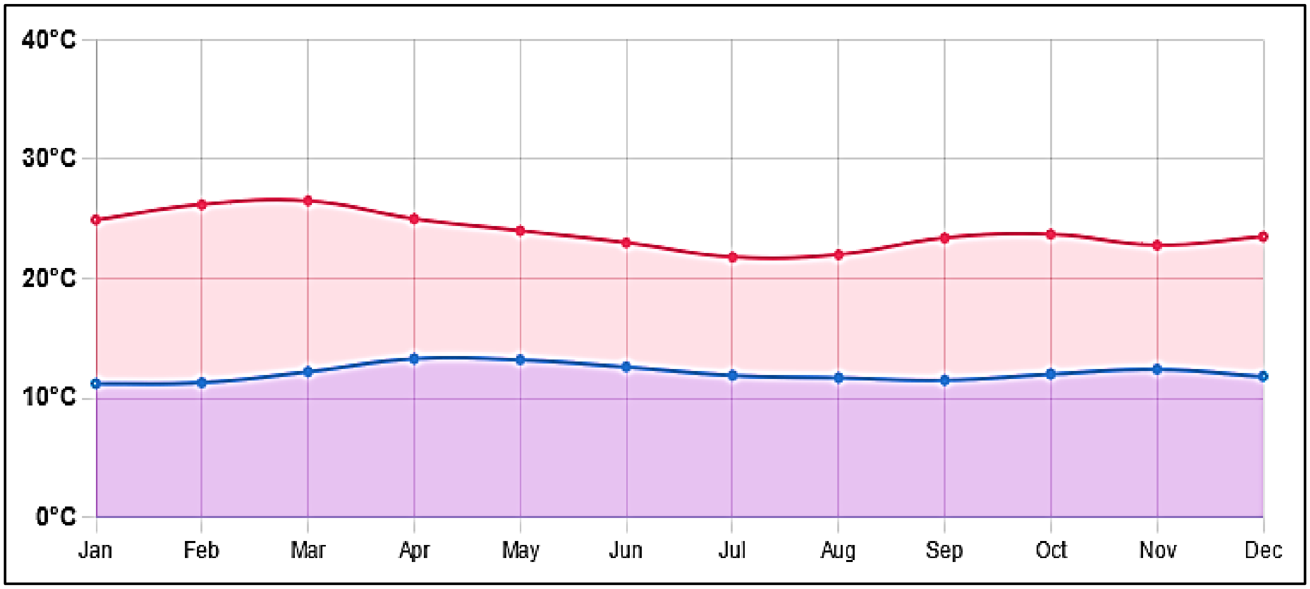

*Figure 2:4 Nyandarua annual Temperature data (Adapted from climate.org) Table 2:1 Weather Average Ndaragwa (*Adapted from climate.org*)*

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature °C (°F)	13.3 °C (56) °F	13.9 °C (57) °F	14 °C (57.3) °F	13.6 °C (56.4) °F	12.9 °C (55.3) °F	12 °C (53.6) °F	11.3 °C (52.3) °F	11.4 °C (52.5) °F	12.1 °C (53.7) °F	12.7 °C (54.8) °F	12.6 °C (54.7) °F	12.8 °C (55.1) °F
Min. Temperature °C (°F)	7.9 °C (46.2) °F	8 °C (46.3) °F	8.9 °C (48.1) °F	10.2 °C (50.3) °F	9.8 °C (49.6) °F	8.5 °C (47.3) °F	7.5 °C (45.5) °F	7.5 °C (45.4) °F	7.4 °C (45.4) °F	8.5 °C (47.3) °F	9.1 °C (48.4) °F	8.5 °C (47.3) °F
Max. Temperature °C (°F)	19.1 °C (66.4) °F	20.1 °C (68.3) °F	19.9 °C (67.8) °F	18.2 °C (64.8) °F	17.1 °C (62.8) °F	16 °C (60.9) °F	15.4 °C (59.6) °F	15.7 °C (60.2) °F	17 °C (62.5) °F	17.5 °C (63.5) °F	17.1 °C (62.8) °F	17.8 °C (64.1) °F
Precipitation / Rainfall mm (in)	78 (3.1)	63 (2.5)	103 (4.1)	189 (7.4)	163 (6.4)	104 (4.1)	74 (2.9)	85 (3.3)	62 (2.4)	121 (4.8)	156 (6.1)	106 (4.2)
Humidity(%)	70%	65%	70%	82%	84%	82%	81%	81%	76%	77%	84%	78%
Rainy days (d)	8	6	11	18	17	13	12	13	10	14	18	13
avg. Sun hours (hours)	9.4	9.8	8.8	6.3	5.0	4.2	3.6	3.8	6.0	6.4	6.2	8.0

2.0.3 Topography

The project area has gentle slopes with an elevation of about 2400m to 2250m above mean sea level. The ground surface is flat lying with a very gentle slope towards the south eastern of Lake Ol Bollossat therefore having a good drainage condition. This area is relatively undisturbed by faults

2.0.4 Soils and Vegetations

The soils in the area are loam soil which are suitable for most horticultural crops. The area being at high altitude, several crops are grown. The type of agriculture practiced here is horticulture farming which is a major income earner. The land is relatively flat making it ideal for drip irrigation systems.

2.0.5 Hydrology

The Kingi Dam site is strategically located at the lower part of a well-defined catchment, making it highly suitable for effective water harvesting and storage. A key feature of the area is a permanent stream fed by the Kingi Spring, located approximately 300 meters upstream of the dam. This spring has a high and consistent yield, ensuring a reliable inflow of water throughout the year, with the dam often overflowing through its spillway even during the harshest dry seasons. Additionally, the surrounding higher grounds generate substantial surface run-off during rains, channeled through naturally formed wide and shallow watercourses that direct water efficiently into the dam. These factors present a significant opportunity for enhanced run-off harvesting, making Kingi Dam a dependable and sustainable source of water for irrigation and domestic use in the area.

2.0.6 Farming System

The proposed project aims to significantly enhance water accessibility and storage for both crop cultivation and livestock use among farmers residing near Kingi Dam. In the target area, the average landholding per household is approximately 3.25 acres, but only a fraction—0.25 acres per farmer—is designated for irrigation under this project. This will collectively bring 50 acres under productive irrigation, directly benefiting 200 households. At present, on-farm income generation remains low due to insufficient and unreliable rainfall, which undermines the sustainability of rain-fed agriculture. To address this challenge, the project will provide a reliable water supply for irrigation, enabling farmers to grow food and fodder crops throughout the year. This will not only bolster household food security but also enhance income generation, reduce poverty, and improve the overall resilience of the farming community.

2.0.7 Management Aspects

The proposed project has an existing Project Management Committee (PMC) in place to operate and maintain the project for sustainability. The level of management is however low and there is need for capacity building to make it more efficient and effective. Once the irrigation project is implemented, farmers will require training on various irrigation technologies and water use efficiency.

2.0.8 Market Outlet

The main potential markets for food crops include nearby urban centers of Mairo-Inya Shopping Centre, Nyahururu Town, Ndaragwa Town, Olkalou Town, Nyeri Town, Nakuru City, and/or Nairobi City. Market outlets for milk are the numerous dairy aggregations, marketing and processing cooperatives in the area such as Umoja Dairy, VIKTAS Dairy and Nyala Dairy.

2.0.9 Land Ownership

Land ownership in the area is freehold with all the members having individual title deeds for their respective pieces of land.

The impact of the project on the environment needs to be assessed to the available water supply, soil erosion due to the prevailing topography, effect of the water on human health.

The farmers in this area are aware of the need to conserve the environment and are doing the following on their farms:

1. Soil and water conservation through planting of Nappier grass strips along contour lines and cover crops
2. Rainwater harvesting, especially roof water harvesting
3. On-farm tree planting where fruit trees and agroforestry trees are grown together with crops.

2.1.0 General Socio-Economic Factors

Dominated by smallholder, rain-fed agriculture with gradual introduction of irrigation schemes post-dam phase II. Main livelihoods: crop farming (grains, horticulture), livestock rearing, and casual wage labor. Economic vulnerability linked to climatic variability; dam expected to stabilize livelihoods through water availability and agribusiness opportunities

2.1.1 Population

Estimated at 200households, totaling approximately 1000 individuals—this figure to be verified by recent census or county registry. Demographics: likely skewed young (~60% under age 25); household sizes average 5–6 members. Migration patterns: seasonal out-migration during dry seasons; in-migration anticipated once irrigation begins.

2.1.2 Land Tenure

The average land ownership per household in the scheme area is approximately 1 ha (3acres). The land is individually owned and have title deeds. The dam is located in public land. The proposed elevated tank tower site is also public land.

2.1.3 Education

Presence of Kiandege primary and Kiandege secondary schools; however, shortfalls in teacher-to-pupil ratios and infrastructure noted. Literacy estimated at ~80%, matching rural Kenya norms. Potential improvements: dam-phase training programs (e.g., agribusiness/media literacy).

2.1.4 Health

Nearby health facilities likely dispensaries/health centers; shortages of staff and medical equipment common. Prevalent ailments include malaria, diarrhea, waterborne diseases—conditions often exacerbated near water bodies. Dam influx will increase healthcare demands, but social responsibility plans exist to upgrade services

2.1.5 Financial Services & Institutions

Accessibility to microfinance, VIKTAS SACCO, NYALA DAIRY and agent banking (M-Pesa) supports small-scale farmer savings and credit. Dam-driven commercial activity will likely strengthen demand for rural financial services and mobile lending.

2.1.6 Water Supply & Sanitation

Community members rely on boreholes, streams, seasonal wells; water shortages frequent in dry seasons. Roof harvesting is also done the communities in the area. There is Water service provider in place i.e NYANDAWAS that supply potable water to consumers. Sanitation coverage is low (rural sanitation at ~77%); open defecation or pit-latrine usage is common. Post-dam interventions may include piped schemes and improved sanitation infrastructure.

2.1.7 Road Network

Rural dirt roads dominate; many are impassable during rainy seasons. Connectivity to nearest market center (Mairo Inaya is approximately 5km) via tarmac road. Proposed development plans for dam-related roadworks may integrate with national county road improvement programs.

2.1.8 Energy

Rural electrification is patchy. Grid extension within ~10 km of site, but only ~30–40% household coverage. Dominant energy source: firewood/charcoal for cooking; kerosene and small solar units used for lighting.

2.1.9 ICT and Development

High mobile phone penetration; majority access M-Pesa and mobile-based advisory services. Internet connectivity limited to 2G–3G in villages; 4G available only in township centers. The dam project may catalyze installation of ICT infrastructure (e.g., for telemetry, farmer extension services).

2.2.0 General Climatic Conditions

Semi-arid to sub-humid climate, bimodal rainfall (long rains Mar–May, short rains Oct–Dec) Dry season (Jun–Sep) and one-month dry spells during short-rains period; temperature range ~18–30 °C.

2.2.1Agro-Ecological Zones

Union between lower (<800 mm/yr) and upper (800–1200 mm/yr) mid-altitude zones.
Dominant farming zones: AEZs "LM 4–5" semi-humid transitional to "LM 5–6" semi-arid.

Rainfall

Average annual rainfall ~500–900 mm, spatially and temporally variable. Long-term data should be collected from the nearest meteorological station.

Evapo-Transpiration

Potential evapotranspiration (PET) typically exceeds rainfall in dry season; estimated PET of 1,600– 2,000 mm/yr in nearby regions. Requires verification through climate station datasets.

Evapo-Transpiration vs Rainfall

Rainfall deficit: rainy season briefly compensates, but overall PET > precipitation leads to chronic moisture deficits. Dam plays a buffer role, storing excess wet-season water for dry months.

Farmers' Organization & Registration

Exist local SACCOs, irrigation farmer groups, and self-help groups; in the process of registering Irrigation Water User Association (IWUA)

THEIR STRUCTURES: headed by elected project management committees; engaged in credit, bulk-input procurement, or savings.

Kingi dam phase II should register water user associations for licensing and management.

3.0 Design criteria

3.01 Irrigation Water Requirement

Estimation of irrigation water requirements for an irrigation project is always essential for the purpose of planning, design and operation of the irrigation project and the water resources system. Knowledge of the irrigation requirement (quantity) and its variability is crucial for assessing the adequacy of the water resource available and determining the capacity of the irrigation system. Correct estimation of the irrigation requirements results to determination of appropriate capacities of the irrigation network, better system performance and highwater use efficiency leading to decreased development costs.

In the estimation of the irrigation water requirements for the sprinkler irrigation system, the following factors have been established in the preliminary design stage; crop water requirement; net irrigation requirement; net depth of water application; irrigation frequency; irrigation cycle; gross depth of water application and the preliminary scheme water demand. Final system capacities have been determined after selection of the sprinkler to be used and the layout of the irrigation plot to be adopted.

3.0.2 Crop Water Requirement

This is the amount of water that must be applied to the plant root zone to ensure optimum growth from seeding to maturity. It is abbreviated as ET_C and has been calculated using equation below:

$$\mathbf{ET_c = K_c\ ET_0}$$

Where:

ET_c = crop water requirement/evapotranspiration (mm/day)

K_c = crop coefficient/factor (constant)

ET_o = reference crop evapotranspiration (mm/day)

The calculation of crop water requirement has been based on the tomato crop. Since this crop require different amounts of water at the different stages of growth, the highest crop coefficient (K_c) value of 1.03 for the middle season has been used for the design. This value gives the highest amount of water required by the crop during its growth cycle.

Taking the following values for the area and crops to be grown, the ET_C value has been computed as follows;

K_c = 1.03

ET_o = 3.87 mm/day

ET_c = 1.03 x 3.87

= 3.99 mm/day

3.0.3 Net Irrigation Requirement

The net irrigation requirement (NIR) is the crop water requirement less the water contributed to the crop from other sources such as rainfall and ground water, and has been determined using equation 3.2 as follows:

$$\mathbf{NIR = ET_{c\_}P_e} \tag{3.2}$$

Where:

NIR = net irrigation water requirement (mm/day)

ET_c = crop water requirement (mm/day)

P_e = effective rainfall/precipitation (mm/day)

For design purposes we are particularly interested in the peak daily amount of water used by the crop, which is the worst case scenario (Savva and Frenken, 2002). Taking effective rainfall to be equal to zero (worst scenario in the dry days), then;

Net Irrigation Requirement (NIR) = 3.99- 0

= 3.99 mm/day

3.0.4 Net Depth of Application

Readily Available Soil Moisture (RAM)

Soils within the project area are mainly deep clays. For clay, the readily available soil moisture (RAM) ranges between 10 - 15 mm/10 cm depth of soil, with an average of 12.5mm/10cm depth of soil.

Total Readily Available Soil Moisture (TRAM)

The total readily available moisture, TRAM = average rooting depth x RAM

The proposed crops have rooting depths varying between 30 – 120 cm depth, in deep well drained soils.

For the proposed crops, TRAM will therefore lie between 37.5 mm –150mm.

Maximum Irrigation Interval

Maximum irrigation interval (IImax) is given by:

II_{max} = TRAM / ETcrop (max)

For the peak period this will be:

II_{max} = 37.5 / 3.99

= 9.4 days - for shallow rooting crop at peak period Say 9 Days

and

II_{max} = 150 / 3.99

= 37.5 days - for the deeper rooting crops say 37 Days

The adopted irrigation interval is 6 days.

Thus, the Net Depth of Application (dnet) /daily irrigation demand becomes;

6x3.99mm/Day

dnet =23.94mm/day

3.0.5 Gross Depth of Water Application

This is the quantity of water which should be applied during irrigation in order to replenish the water used by the crop during evapotranspiration taking into consideration the efficiency of the irrigation system being used. This quantity which is abbreviated as (d_{gross}) has been calculated using equation 3.5 below:

$$\mathbf{d_{gross}} = \frac{\mathbf{d_{net}}}{\mathbf{IE}} \tag{3.5}$$

Where:

d_{gross} = gross depth of water application (mm)

d_{net} = net depth of water application per irrigation (mm)

IE = irrigation efficiency (%)

IE = E_c x E_d x E_a = 1.0 x 1.0 x 0.7 = 70%

Where for a sprinkler system with pipeline conveyance and distributions;

E_c = conveyance efficiency (100%)

E_d = distribution efficiency (100%)

E_a = application efficiency (70%)

The overall efficiency has been set at 70% for sprinkler irrigation system which is acceptable for moderate climate (Rolland, 1982).

Taking the following values for the climate of the area and the irrigation system to be used:-

d_{net} = 23.94 mm

IE = 70%

d_{gross} = 23.94/0.7

= 34.2 mm

Preliminary Scheme Water Demand

Preliminary scheme water demand has been computed using equation below as follows:

$$\mathbf{SWD} = \frac{\mathbf{10 \times A \times d_{gross}}}{\mathbf{IC \times N_s \times T}}$$

Where:

SWD = preliminary scheme water demand (m^3/hr)

d_{gross} = gross depth of water application (mm)

A = total area to be irrigated (ha)

IC = irrigation cycle (days)

N_s = number of sprinkler shifts per day

T = irrigation hours per shift (hr)

Taking the following values for the project area to be irrigated: -

A = 20,23 ha

d_{gross} = 34.2 mm

T = 5 hours (for better equipment utilization)

N_s = 2 (to make 14 hours per day)

IC = 6 days

SWD = (10 x 20.23 x 34.2)/(6 x 2 x 5)

= 115.311 m^3/hr

OR

SWD = 115.311/3600

= 0.032m^3/sec

Kingi Dam has an estimated reservoir capacity of 35,000 cubic meters.

The reservoir is recharged by a natural spring that has an estimated yield of 30m3/hour.

Total amount of water from the spring in three months = 30m^3/day *24hrs/day*90days = 64,800m3.

3.1 Project Viability

Available water for the scheme = Reservoir Capacity + Spring Discharge in 3Months = 99,800m3.

This shows that the available water (99,800m3) is more that the demanded water of 70.686m3 hence the project has adequate amount of water to serve the intended purpose Taking Dead storage as 30% Available water for Irrigation becomes 69,860m^3. This water can be used for =69,860/ (144.13 x7Hrs) = 69.24 Days

Considering two hundred and (200) farmers who are members of the irrigation water users association (IWUA), individual plot water demand (PWD) has been computed using equation the equation shown below:

$$\mathbf{PWD} = \frac{\mathbf{SWD}}{\mathbf{No.\ of\ Farmers}}$$

PWD = 115.311/200

= 0.577 m^3/hr

OR

PWD = 0.577/3600

= 0.00016m^3/sec

This value of plot water demand gives the criterion for choosing the sprinkler/s to be used within the project area. The Sprinkler selected should have discharge equal or less than the PWD.

3.2 Sprinkler Selection and Spacing

The objective here is to select a sprinkler that will apply the required amount of water to the crop at the best possible uniformity under the prevailing wind conditions and at an application rate that does neither cause run-off nor damage the crop (Savva and Frenken, 2001). To achieve this, careful selection of the best combination of spacing (between sprinklers and laterals), sprinkler operating pressure and nozzle size is desirable. As a rule, the selected sprinkler should have a uniformity coefficient, CU (which is a measure of uniformity of water application) of 85% or more.

3.5 Selection preference

In the selection of the sprinkler and the spacing to be used for plots within the Kingi Irrigation Project, one (1) sprinkler per plot has been adopted. In the selection of this one sprinkler, preference has been given to sprinklers with:-

- Single nozzle in order to minimize the blockage of the nozzle
- Maximum precipitation rate below the basic infiltration rate of 15.0 mm/hr
- Square spacing pattern since this gives better application uniformity
- operating pressures between 20 and 25 m (low capacity, low pressure sprinklers)
- Discharge close to but less than plot water demand of 0**.577** m^3/hr

3.6 Effect of wind speed

In order to find out how the prevailing winds in the project area will affect the spacing between sprinklers or laterals, the average wind speed of the windiest month of the year has been considered. Within the project area, the average wind speed of the windiest month has been established as 18 km/hr. For this wind speed, the maximum sprinkler spacing for the square pattern should be 45% of the wetted diameter (Savva and Frenken, 2001).

3.7 Sprinkler precipitation rate

To avoid runoff of the water applied, the sprinkler precipitation rate should not exceed the basic soil infiltration rate. The infiltration rate for sandy clay loam (silt loam) is in the range of 15 – 25 mm/hr. For this design, the sprinkler precipitation rate has been chosen to be less than 15.0 mm/hr.

3.7.1 Effect of Ground Slope

A reduction of precipitation rate (precipitation rate correction) is recommended in order to avoid runoff in sloping grounds. For the Kingi Irrigation area where the scheme is located, the ground slopes range between 2% and 5%. According to the criteria in Savva and Frenken, 2001, the percentage reduction of precipitation for slopes between 0% - 5% is zero. This means that the ground slope within Kingi Irrigation Project area shall have no effect on the sprinkler precipitation rate. The precipitation rate in this design has therefore not been corrected or reduced.

3.7.2 Sprinkler Operating Pressure

For a sprinkler to function in accordance to the expectations of the designer, the sprinkler has to operate within the operating pressures determined by the designer. This means that the pressure head in the pipeline at the point of sprinkler operation must match that specified for the sprinkler. The hydraulic pressure head (H_p) available within the pipeline at the point where the sprinkler is to be operated forms part of the basis for the selection of the sprinkler nozzle type to be used at that point. Analysis of the hydraulic pressure heads available along the pipelines within the irrigation block shows that hydraulic pressure heads available at the point of operation of the sprinkler nozzle are close to 20m

3.7.3 Sprinkler selection

Based on the criteria discussed above and choosing from the sprinklers available from the NAANDANJAIN irrigation catalogue (NAADANJAIN, 2012), two (2) sprinklers have been selected. For Solar pump system a higher discharge Sprinkler has been selected. The sprinkler has a lower set time close to 7 hours to for average sunshine hours in the project area.

Where the hydraulic pressure head (H_p) is between 20 m – 25 m, a 5022 plastic impact sprinkler, with a 3.2 mm nozzle, operating at 2.0 bars (20 m) has been selected. The sprinkler has a discharge of 0.66 m^3/hr and a precipitation rate of 5.9 mm/hr at a sprinkler-lateral spacing of 12 m x 12 m.

The Gravity selected sprinkler has a lower discharge and a higher set time/irrigation duration. The two sprinklers have coefficients of uniformity of 88 - 92% which are within the recommended range of 85% and above. The sprinkler selection matrix which was used for the assessment of the suitability of the sprinklers which were considered for selection has been shown in Table 13.

Suitability of the sprinklers which were considered for selection has been shown in Table 13.

Table 1: Sprinkler Selection Matrix

Nozzle Type	**Nozzle**	**Press.**	**Disch.**	**Wetted**	**PPtn OK?**	**Spacing (m x m)**		**Wind Requirement?**	
	(mm)	**P (m)**	**Q (m^3/hr)**	**D (m)**	**(mm/hr)**	Sprinkler	Lateral	Sprinkler	Lateral
5022					**Pr < 15**			**Max Spacing = 0.55D**	
	4.0	20	0.76	24.00	5.70	12	12	12.65	12.65

					YES			**OK**	**OK**
	3.2	20	0.57	23	**3.96**	12	12	**OK**	**OK**

3.7.4 Set Time for Pump fed system

This is the time the sprinkler/s should operate at the same position in order to deliver the gross depth of water application. This time, which is abbreviated as (T_s) has been computed using equation 2.8 below:

$$\mathbf{T_s = \frac{d_{gross}}{P_r}} \qquad (2.8)$$

Where: T_s = time of operation at one position (hr)

d_{gross} = gross depth of water application (mm)

P_r = sprinkler precipitation rate (mm/hr)

Pump-fed System

Taking the following values for the block area to be irrigated and the chosen sprinkler:-

d_{gross} = 34.2 mm

P_r = 5.7mm/hr

T_s = 34.2/5.7= 6 hours

Since the set time (T_s) calculated is 6 hours, the value has been adopted.

T_s = 6 hours

3.7.5 Plot Layout

Considering the selected sprinkler spacing of 10 m by 10 m and the use of one (1) sprinkler per plot with two (2) setting per day,

Area covered per day = 2 x (10 m x 10 m) = 200 m^2

Area covered in 6 days = (200 m^2 x 6 days) = 1200 m^2

For this area a plot size of 32 m by 32 m with the layout shown in Figure 15 has been adopted.

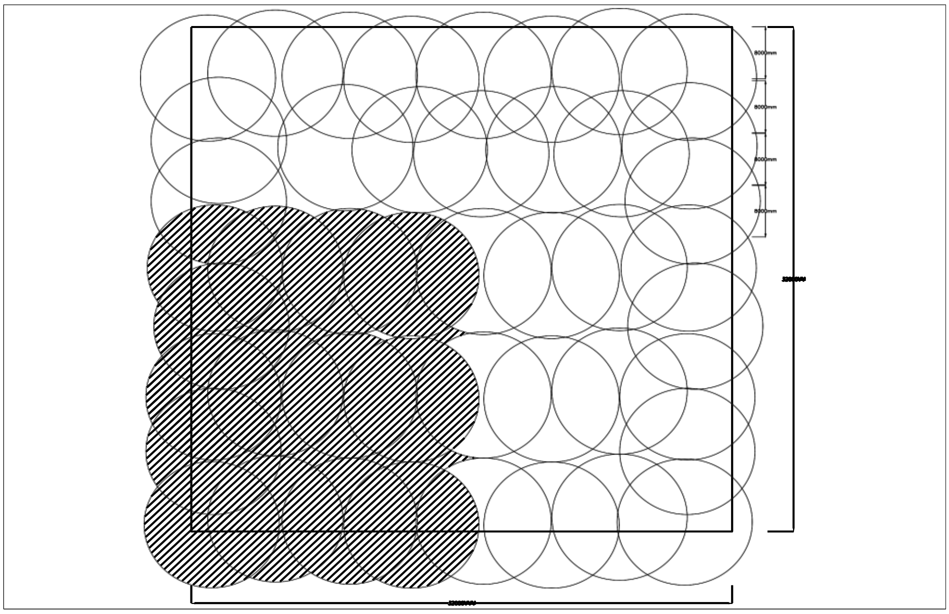

Figure 1: **INFIELD LAYOUT 3200MMX3200MM PLOT**

3.7.6 Final System Capacities

This is the amount of water which is required to be supplied to the individual plots, blocks or entire scheme for irrigation per unit time.

3.7.7 Plot capacity

This is the water requirement for individual plot and has been computed using equation below

$$\mathbf{Q_{plot} = N_l \times N_s \times q_s}$$

Where:

Q_{plot} = plot water requirement (m^3/hr)

N_l = lateral operating per shift

N_s = number of sprinklers per lateral

q_s = sprinkler discharge (m^3/hr)

Taking the following values for the block area to be irrigated and the chosen sprinklers:-

N_l = 1

N_s = 1

q_s = 0.45m^3/hr

Q_{plot} = 1 x 1 x 0.45

= 0.45 m^3/hr

OR

Q_{plot} = 0.45/3600 = 0.00013 m^3/sec

Pump-fed System

This is the water requirement for Pump fed system and has been computed as shown below:

$Q_{pump\text{-}fed}$ = Q_{plot} x (Plots in the blocks)

= 0.45 x 215

= 96.75m^3/hr

OR

$Q_{pump\text{-}fed}$ = 90/3600 = 0.027m^3/sec

This scheme capacity compares well will the preliminary scheme water demand (SWD) computed earlier.

Summarized versions of all the computations which have been carried out in this chapter are shown in the table 14 below -

Table 2: Irrigation demand per abstraction mechanism

Mechanism	Target plots (No.)	Irrigation requirement (m^3/s)
Pumping	215	0.027

It is expected that the irrigation interval will vary in the field for the various crops and even during early growth stages. Summary of water demands

Table 3: Design daily water demand

Abstraction Mechanism	Target plots (No.)	Irrigation demand per setting (m^3/s)	Irrigation Duration (hrs)	No. of settings	Daily irrigation demand (m^3/day)
Pump	215	0.027	6	2	1,440

l

3.7.8 Pump selection and Power Requirements

Due to the hilly terrain upstream of the dam, as well as the immediate surrounding boundary to the right and left, the 139 No. target farms are located at high elevations; to this end, a sprinkler with an operating pressure of 15m has been proposed

In order to supply water from the dam to the most remote farm, a suitable pump has been proposed (see Appendix 1: Pump data & performance curve).

The basic formula for power requirement calculations is provided below:

$$P = \frac{Q \times H}{360 \times E_p}$$

Where:

P = Power requirement in kW

KW = energy transferred from the pump to the water

Q = discharge (m^3/Hr)

H = Total dynamic head (m)

Ep = Pump efficiency (Pump performance curve) =70%

Total dynamic head (H) is composed of the head losses in the supply line in addition to the sum of the following:

- the suction head; (head below water level assumed to be 0m submersible pump)
- the difference in elevation between the level of the water and the most remote area;
- (23901asl - 2278 m a.sl = 112m)
- head losses in Rising main and Mainline =65.1m
- Sprinkler operating pressure = 20m
- Tank Tower + Height of the tank = 12m
- Residual Head = 5

Therefore, Total dynamic head (H) becomes;

H = 112m + 65.1m + 37m = 214.1

$$P = \frac{25 \times 214.1}{360 \times 0.7}$$

= 21.24Kw

Say 22Kw

Pump Power Requirement (Source: FAO: Irrigation Manual, Module 8)

4.0 Detailed Design.

4.0.1 Solar Array Sizing

4.0.1.0 Solar Power Requirements

Considering 30% power losses from the solar panels (German Fraunhofer Institute), the required solar power:

=22kW×1.3

=28.6kW

4.0.1.1 The number of Panels Requirements:

To reduce the space to be occupied by the solar panels, 330 W panels were selected since they give the least number of panels in series due to their high voltages ranges.

No. of panels = [Total solar power requirement] / [size of 1 panel]

$$= \frac{28600}{330}$$

= 86.67 panels

= 87 panels

Figure 6. 1: Solar PV Module Data

PV MODULE DATA

Model	Rated power (w)	Nominal Voltage (v)	Peak Voltage (v)	Open Circuit Voltage (v)	Short Circuit Current (A)	Number of Cells	Dimensions (mm)						Weight (kg)
							A	B	C	D	E	F	
SL20	20	12	18	21.6	1.2	36	496	495	296	350	100	23	1.98
SL40	40	12	18	21.6	2.5	36	665	665	316	516	100	25	3.7
SL50	50	12	18	21.6	2.9	36	667	665	467	588	100	25	4.25
SL60	60	12	18	21.6	3.7	36	689	665	467	667	100	25	5.35
TPS85	85	12	17.6	21.6	4.9	36	759	637	599	664	80	25	6
TPS100	100	12	17.8	21.2	6	72	1006	626	646	664	180	35	7.3
TPS125	125	12	17.5	21.5	7.4	36	1179	626.4	899	664	140	35	9
TPS150	150	24	36	43.2	4.45	72	1486	626.4	1206	664	140	35	11.5
TPS200	200	24	36	44.5	5.7	72	1316	954.4	1036	992	140	35	13.7
YL270	270	24	30.8	37.7	9.28	60	1650	992	990	948	330	35	18.5
YL330	330	24	37.4	46.4	9.29	72	1960	992	1300	948	330	40	22

Source: Market Survey on available PV modules

4.0.1.2 No of strings

To be determined by the choice of the inverter and solar panels.

4.0.1.3 Sizing of Inverter

Here's the formula for Off-grid inverter sizing:

Inverter size (off-grid) = (Total Power rating of all the appliances × 1.25) ÷ 90%

90% here represents the inverter efficiency, but if the brand of inverter you plan on using has a higher or lower efficiency number, feel free to substitute it for that number but for the most part, inverters generally have an efficiency value of around 90%. 1.25 represents a safety factor that allows for some tolerance in our inverter's operation.

22000X 1.25/90% = 30.555kW

The type of inverter used in this project was Sunverter 3 with the following specifications.

Table 4.1: Inverter Specifications

Model	**Adapting Pump Motor**		**Max. DC Input Power (kW)**	**Max. DC input voltage (V)**	**Recommended MPPT voltage (V)**	**Rated Output Current(A)**
	Rated Power(kW)	**Rated Voltage (AC) (V)**				
Sunverter 3 (SV3/37T)	30 to 37	3 X 415	37	780	500 to 600	84

Table 4.2: Solar Panel specifications:

Model	**Rated Power(W)**	**Nominal Voltage(V)**	**Peak Voltage (V)**	**Open circuit Voltage(V)**	**Short Circuit Current (A)**
YL335	330	24	37.4	46.4	9.29

The number of panels per string is given by:

The upper limit of the panels' number per string

= Max. Input voltage / Open circuit voltage

$\frac{780}{46.4}$ = 16.81

The lower limit of panels per string

= Recommended MMPT voltage / Peak voltage

$\frac{550}{37.4} = 14.706$

Therefore, **each string will have 16, 15 or 14 panels.**

Since the number of panels required is 87 No. I selected 15 panels.

The system will have 90 panels with each string of 15 panels (6 strings)

Checking voltages per string

Maximum Input Voltage

In a circuit in series, voltages are added while in parallel, it remains the same.

Voltage per string = 15 (46.4) = 696V

Total maximum input voltage for the system when connected in parallel (6 strings)

= 696V (It is within the recommended max. input voltage of 780V)

Recommended MMPT Voltage

Voltage per string = 15 (37.4) = 561V (lies within the recommended value of between 500 to 600V.

Drop cable sizing – 3 phase power

Maximum cable length of a three phase submersible pump is given by:

$L = [U\times\Delta U] / [I \times 1.73\times 100\times (\cos\varphi \times p/q + \sin\varphi \times X_L)]$ m   Eqn. 10

Where

L	= Max. Cable length of a three-phase submersible pump (m)
U	= Rated voltage (V)
ΔU	= Voltage drop % (allowable voltage drop 3%)
I	= Rated current of the motor (A)
Cosφ	= Power factor (0.9)
Sinφ	= $\sqrt{(1-\cos^2\varphi)}$
p	= Specific resistance of copper 0.02(mm^2)
q	= Cross section of submersible drop cable (mm^2)

X_L	= Inductive resistance: 0.078×10^{-3} (ohms/m)

Source: Grundfos SP Engineering Manual

Therefore:

I = Motor power / V (From $P = I\times V$)

= 22,000W / 415V = 53.01A

L = 54m +20m (Dist. to the pump house) = 74m

Hence to determine the size of the cable by substitution, eqn. 10 becomes:

74m = $[415\times3] / [53.01\times1.73\times100\times (0.9 \times 0.02/q + 0.436\times 0.078\times10^{-3})]$

74m = $1245 / [9170.73(0.018/q+ 0.000034)] = 1245 /[56.27/q+0.1063]$

$165.07/q + 0.3119 = 16.824$

$165.07/q$ = 16.72

q = 9.996 mm^2

q = 10 mm^2

Therefore, the drop cable required is 4 core submersible cable 10mm^2 (4×10mm^2), 54m length and 4 core underground cable 10mm^2 of 20m (4×10mm^2)

Engineering cost estimates

	GRAND SUMMARY	
BILL NO.		**AMOUNT (KES)**
1	preliminaries & General Provisions	2,216,000
2	Pump Chamber/Sump	489,092
3	Rising main pipeline	5,153,384
4	Tank Tower with 2No. 10m3 tanks	1,747,500
5	Gravity main pipeline	3,354,730
6	Sub-main pipelines	5,912,110
7	Individual connections fittings	360,000
8	Power house	290,757
9	Pump and accessories	2,362,572
10	Solar Panels and solar structure	4,513,200
11	Spillway repair	355,742
	Grand Total	**26,755,087**

5.0 ECONOMIC AND FINANCIAL ANALYSIS

5.0.1 Introduction

Irrigation plays a pivotal role in modern agriculture by ensuring a stable and reliable water supply to crops, especially in regions where rainfall is insufficient or erratic. It has been instrumental in transforming agricultural productivity, improving food security, and enhancing farmers' livelihoods. However, developing and maintaining an irrigation system requires significant investments in infrastructure, technology, and management.

An economic analysis of an irrigation water project is essential to evaluate whether the benefits of the project justify the costs, considering both the direct and indirect effects on farmers, the local community, and the broader economy. The primary objective of this analysis is to assess the financial feasibility, efficiency, and sustainability of distributing water among farmers, while also evaluating the distributional impacts of the project.

The analysis typically involves evaluating the costs of constructing and maintaining the irrigation system, as well as the expected increase in agricultural productivity and income for farmers. It also examines broader economic impacts, such as employment creation, regional development, and food security, while factoring in environmental concerns, such as water availability and ecosystem sustainability. Furthermore, the project's social and equity implications are crucial, as it is important to ensure that water is distributed fairly, especially among different sizes of farms and communities.

By comprehensively examining the costs, benefits, and risks associated with the irrigation project, this economic analysis aims to provide decision-makers with the necessary information to determine whether the project is economically viable and sustainable, and how it can be optimized to maximize benefits for all stakeholders involved.

5.0.2 Cashflow Analysis

5.0.2.0 Analysis Assumptions

Assumptions before the project installation

1. The water project targets to benefit 215 members who were left out during the implementation of phase 1, each farmer putting an average of 0.25 acres under irrigation
2. The farmers produce horticultural crops e.g. Potatoes, Onions, French beans and other food crops, two seasons in a year.
3. The analysis is based on Potatoes, which is the common crop among the member beneficiaries.
4. The farmers produce 4 tonnes but market an average of 2.8 tonnes (70%) per acre of potato production.

Assumptions after irrigation project installation

1. The farmer can market 80% of the produce due to off-season production with irrigation water.
2. The project will benefit 215 farmers, each producing on 0.25 acre of land.
3. The farmers will produce three seasons per year.
4. The subscription fee of farmers, assumed at Kes 300 per month, will cater for the irrigation infrastructure operation and maintenance costs.
5. The beneficiaries of the irrigation water growth rate assumed is 20% per annum until the optimum number is achieved, i.e. 215 members.

6. The production potential of potato is 14 tonnes per acre, and farmers will get to 13 tonnes by the 10th year as a result of cumulative experience, motivation and reduction in post-production losses.

5.1 Potato Gross Margin

As per the assumptions above, potato is the major crop in the region, which guided the basis of economic analysis for the project. The gross margin below is for one acre of potato in the first year of production with a yield of 4 tonnes per acre, which is expected to increase to 13 tonnes per acre by the 10th year of project implementation.

Table 8:1 Potato gross margin

DESCRIPTION	**Unit**	**Quantity**	**Unit Price (Ksh.)**	**Total (Ksh.)**
Marketable Yield (50kg)	Kg	4,000	45	180,000
A) Total Output	KES			180,000
Variable Costs				-
Soil testing	No	1	2,000	2,000
Land preparation hallowing	Acre	1	6,750	6,750
Seeds certified	50 Kg bag	16	4,200	67,200
Clean seed	50 Kg bag	-	-	-
Fungicides	Kg	1	2,000	2,400
Insecticides	Litres	1	1,600	1,600
Manure	Ton	4	2,500	10,000
Planting Fertilizer	Bags-50Kgs	4	2,500	10,000
Foliar feed	Litres	1	1,000	1,000
Packaging Bags	No	160	25	4,000
Irrigation	Week	12	400	4,800
Ridging	Acre	1	2,250	2,250
B) Sub-total variable cost				112,000
Labour (MDS)				

Manual land preparation	MD			-
Ridging	MD			-
Planting	MD	10	400	4,000
Fertilizer application	MD	6	400	2,400
Irrigation	MD			-
Weeding and earthing up	MD	4	400	1,600
Spraying	Pump	48	50	2,400
Dehulming	MD	6	400	2,400
Harvesting	MD			6,900
Transport from the farm	MD	6	400	2,400
Sorting and grading	MD	6	400	2,400
C) Total labour costs				24,500
D) Contingencies	10%			13,650
E) Total Costs (B+C+D)				150,150
F) Gross Margin / Acre=(A-E)				29,850
Gross Margin Ration (F/A) x100				16.6
Cost of production per Kg	KES			37.6

Projects Ten Years Cashflow

	Year 0	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Inflows	2024/2025	2025/2026	2026/2027	2027/2028	2028/2029	2029/2030	2030/2031	2031/2032	2032/2033	2033/2034	2034/2035
Potato production	20,972,000	67,500,000	84,375,000	101,250,000	118,125,000	135,000,000	151,875,000	168,750,000	185,625,000	202,500,000	219,375,000
Total Inflows	20,972,000	67,500,000	84,375,000	101,250,000	118,125,000	135,000,000	151,875,000	168,750,000	185,625,000	202,500,000	219,375,000
Outflows											
Production input cost	11,042,400	42,000,000	46,200,000	50,820,000	55,902,000	61,492,200	67,641,420	74,405,562	81,846,118	90,030,730	99,033,803
Labour costs	9,779,800	9,187,500	10,106,250	11,116,875	12,228,563	13,451,419	14,796,561	16,276,217	17,903,838	19,694,222	21,663,644
Irrigation infrastructure operations and maintenance cost		1,209,600	1,451,520	2,090,880	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000	1,800,000
Total Outflows	20,822,200	51,187,500	56,306,250	61,936,875	68,130,563	74,943,619	82,437,981	90,681,779	99,749,957	109,724,952	120,697,447
Net Annual cash flow	149,800	16,312,500	28,068,750	39,313,125	49,994,438	60,056,381	69,437,019	78,068,221	85,875,043	92,775,048	98,677,553
Net Annual cashflow per member	281	30,605	52,662	73,758	93,798	112,676	130,276	146,469	161,116	174,062	185,136
Daily per capita Income	0.26	28	48	67	86	103	119	134	147	159	169

The cashflow analysis for the first ten years of the irrigation project implementation indicates a positive growth in the net cashflows. The daily per capita income which is the average income earned by an individual per day is expected increase drastically in the first year of project implementation and gradually thereafter as the enterprise nears optimization.

5.2 Economic Feasibility

The economic feasibility of an irrigation project involves evaluating whether the benefits of the project justify the costs, considering both financial and broader economic factors. A detailed economic analysis helps ensure that the investment in irrigation infrastructure leads to higher productivity, improved livelihoods, and sustainable use of resources.

5.3 Economic Indicators

When evaluating the economic feasibility of the irrigation project infrastructure development, economic indicators like Net Present Value (NPV), Profitability Index (PI), Internal Rate of Return (IRR), and Pay Back Period are essential tools. These indicators help assess the project's ability to generate returns, compare the profitability of different projects, and make informed decisions about whether to proceed with an investment.

Figure 8: 1: Economic Indicators

Investment/Renovation	-21,926,833.0					
Discount rate	1.0	1.12	1.2544	1.404928	1.57351936	1.762341683
Nominal rate	-21,926,833.0					
Real value of cash	-21,926,833.0	18,270,000	35,209,440	55,232,110	70,238,585	105,839,864
NPV	262,863,166.2					
PI	13.0					
IRR	1.36					
Pay Back Period (Years)	2.14 (2 Years 2 Months)	149,800	16,312,500.00	5,464,533.00		

5.3.0 Net Present Value (NPV)

The economic feasibility of an irrigation project involves evaluating whether the benefits of the project justify the costs, considering both financial and broader economic factors. A detailed economic analysis helps ensure that the investment in irrigation infrastructure leads to higher productivity, improved livelihoods, and sustainable use of resources.

$$NPV = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$$

The project has a positive Net present Value of KES 262,863,166. The fact that the NPV is positive indicates that the project's expected cash inflows (benefits) are greater than its cash outflows (costs). In other words, the project will create value and generate more income than it costs to run.

5.3.1 Profitability Index

The Profitability Index (PI) is a financial metric used to evaluate the relative profitability of an investment or project. It is the ratio of the present value of future cash inflows to the present value of cash outflows. In other words, it helps determine how much value is generated per unit of investment.

$$PI = \frac{\text{Present Value of Benefits (Cash Inflows)}}{\text{Present Value of Costs (Cash Outflows)}}$$

The project has a positive profitability index of 13. A Profitability Index of 13 means the project is expected to generate a very high return on investment, far exceeding its costs. This indicates the project is exceptionally profitable and, therefore worth investing in.

5.3.2 Internal Rate of Return

The Internal Rate of Return (IRR) is a key financial metric used to evaluate the profitability of an investment or project. It is the discount rate at which the Net Present Value (NPV) of a project becomes zero. In other words, the IRR is the rate of return at which the project's total expected cash inflows equal its total expected cash outflows (including initial investment), making the NPV zero.

The project has an Internal Rate of Return (IRR) of 1.36, meaning that the project or investment is expected to generate a 136% return per year over its lifetime. This means that for every shilling invested, the investment is expected to generate 1.36 shillings in return and therefore forecasted to grow at a rate of 36% annually, based on its cash inflows and outflows.

5.3.4 Pay Back Period

The Payback Period is the time it takes for an investment to recover its initial cost from the cash inflows generated by the project. A Payback Period of 2 years and 2 months means that the irrigation project will take 2 years and 2 months to recover the initial investment from the cash flows it generates, thus a profitable and worthy investment.

In conclusion, all the key financial indicators suggest that the irrigation project is highly viable. The positive NPV, the attractive IRR, the favourable PI, and the quick payback period collectively demonstrate that the project is not only financially sound but also represents a profitable and low-risk investment opportunity. These metrics strongly indicate that the irrigation project will generate a substantial return on investment, recover its costs rapidly, and deliver significant economic benefits over its lifetime.

6.0 POTENTIAL ENVIRONMENTAL AND SOCIAL IMPACTS AND MITIGATION MEASURES

6.1 Introduction

This chapter identifies both positive and negative environmental and social impacts associated with the proposed project development. The mitigation measures to the negative environmental and social impacts have been proposed. The impacts and mitigation measures are categorized into four project phases namely: planning, construction, operation and decommissioning phases.

6.2 Construction Phase

6.2.0 Anticipated Positive Environmental and Social Impacts

- Employment opportunities
- Improved aesthetic value of the project area
- Improved economic growth through the utilization of local labor and locally available construction materials.
- Increased business opportunity for vendors
- Improved livelihoods through enhanced incomes

6.2.1 Anticipated Negative Impacts and Mitigation Measures

Environmental Impacts and Mitigation Measures

Air pollution through the exhaust fumes of construction machinery and dust from construction sites

Mitigation measures:

- Construction vehicles to maintain low speed at construction sites
- Carry out servicing of vehicles and stationary engines as necessary to reduce heavy smoky emissions.
- Provide and strictly enforce use of PPEs
- Carry out excavation of pipeline trenches in the early mornings or later in the evenings to minimize dust emissions.
- Apply water on un-vegetated ground surface at the water tower construction site to reduce dust emission.

- Provide construction workers with nose/mouth masks and goggles

Impacts on Existing Infrastructure

Trenching activities for purposes of water reticulation to different farmlands can cause significant environmental impacts on existing infrastructure like roads, existing water lines, buildings, etc. These impacts can include: damage to roads and buildings due to excavations and vibration, water damage from potential leaks leading to cracks and even structural instability.

Mitigation measures:

- Careful planning of the trenching routes through maps and survey techniques to avoid damaging existing infrastructure
- Employ vibration-damping techniques to minimize damage to surrounding structures
- Implement robust water management strategies to prevent leaks, flooding, and water logging

Noise pollution and vibrations

Movement of vehicles, operating construction machinery, and workers may temporarily cause noise and vibration that are nuisances, though temporary.

Mitigation measures:

- Provide and enforce the use of appropriate PPEs
- Limit construction works to daytime only (0800- 1700 hours)
- Locate noisy equipment at a secluded place and fit it with a silencer
- Service and maintain machinery regularly
- Where possible, machinery should be interchangeably used with human labour
- Switch off engines when idle

Waste generation

The proposed construction works are bound to produce large quantities of both solid and liquid waste. The solid waste will compose of packaging materials like bags of cement, gravel packs, empty cartons, rejected materials, metal cuttings, broken pipes and pieces of lighting fixtures. Other solid waste will be generated from the food remains/wrappers and packages of the construction crew and in some cases from broken machinery and replaced vehicle/machinery spare parts if any. Liquid waste may involve vehicle/machinery oil refilling and servicing remains like waste oils, used grease and general dirty water from the site. If not properly maintained, accumulation of such waste may make the working environment non-conducive, reducing its visual quality.

Mitigation measures:

- Provide waste bins and a temporary disposal area.
- Segregate waste into decomposable or non-decomposable materials.
- Use construction materials that have minimal packaging requirements
- Recycle/reuse broken pieces of construction materials where applicable
- Use durable, long lasting construction materials that do not need frequent replacement
- Sensitize workers and members on proper waste management strategies
- Designate a specific area for carrying out servicing of machinery and disposal of waste grease and oils appropriately.
- Engage a NEMA licensed waste handler to remove waste from construction site and dispose it as required by law.

Removal of vegetation and loss of habitat

During site clearing, there will be removal of vegetation to pave way for excavation and construction activities hence loss of habitat in the affected areas. The proposed removal of vegetation will occur: - at the site where the water tower will be constructed; at dam site where the pump chamber, power house and the steel structure for solar panels will be constructed; along the pipelines during trenching: and at the spring where blue gum (eucalyptus) trees will be removed. Some vegetation loss would also occur within the farms as farmers cut down trees, shrubs and remove grass as they open up new land portions to create room crop production under irrigation.

Mitigation measures:

- Limit excavation activities to specific development areas only.
- Compensate for lost vegetation through landscaping with site-friendly/ecologically suitable indigenous/fruit tree species
- Plant cover crops in the farms
- Introduce fruit tree and bamboo shrub nurseries within the project area to support revegetation in the farms and around the spring area.

Social Impacts and Mitigation Measures

Occupational Health and Safety

During construction works, workers are likely to have accidental injuries and hazards from the intensive construction-related activities. The health of all people involved in the project, especially the construction crew should be taken into consideration. The contractor should adhere to the rules set by different authorities to protect workers.

Mitigation measures:

- Provide, enforce and supervise use of PPEs.
- Provide a well-stocked first aid kit at the site and train workers on basic administration of first aid
- Prevent spillage of petroleum products on site
- Provide serviced firefighting equipment and train workers on firefighting skills
- Constitute and operationalize Environment, Health and Safety committee at site
- Provide clean and potable water for workers
- Ensure proper site planning and management to prevent accident
- Train works on proper use of tools
- Restrict operation of machinery and equipment to skilled machine operators only
- Report any accidents and injuries as soon as it occurs and ensure medical attention is sort immediately.

Children protection

Children in or around a construction site may be vulnerable to child labour, sexual abuse, Teenage pregnancies and exposure to diseases.

Mitigation measures:

- Cordon off the site to keep off unauthorized persons especially children
- Ensure workers have valid identification documents to ascertain age
- Contractor to develop and implement a Children Protection Strategy.
- All personnel must sign & adhere to Child Protection Policy.

Sexual Exploitation and Abuse (SEA)

Implementation of the project will offer opportunities that may trigger sexual exploitation or sexual abuse among the workers or the local community.

Mitigation measures:

- Develop and implement a SEA action plan with an Accountability and Response Framework as part of the ESMP.
- Contractor to sensitize workers on SEA and put in place adequate mechanisms to prohibit/deter it.
- Contractor to have a displayed code of ethics chart on site with prohibited/unwanted behaviors and potential sanctions clearly spelled out.
- Create a Grievance Redress mechanism desk for community engagement.
- Regular community sensitization on social risks.
- Institutionalize disciplinary procedures against SEA offenders.

Labour Influx Effects

This impact is likely to be triggered by demand for labourers for the proposed construction works from within and outside the local community. The result of labour influx is the concentration of people in the area drawn from diverse social and cultural backgrounds. This would lead to a number of issues such as creating strain on various resources, grievances from local community over job opportunities, sexual exploitation & abuse and unwanted pregnancies.

Mitigation measures:

- Develop and implement a labour Management Plan (LMP) in consultation with PMC
- Give the local community members the available job opportunities unless the required skills are unavailable
- Ensure effective community engagement and strong grievance redress mechanisms
- Adhere to effective contractual obligations and mitigate labour related risks
- Keep and monitor records of labour force on site
- Comply with provisions of Workplace Injuries and Benefits Act (WIBA) 2007
- Develop and implement Children Protection Strategy.

Gender Based violence and Sexual Harassment

Violence/conflicts and harassments may occur amongst workers during the course of implementation of the project.

Mitigations measures:

- Sensitize community members and workers on GBV and Sexual harassment
- Develop and enforce human resources policy on sexual harassment
- Integrate provisions of sexual harassment in the employees' COC
- Provide equal opportunities for both males and females.
- Operationalize a referral mechanism for GBV at the community level

6.3 Operation Phase

6.3.0 Anticipated Positive Environmental and Social Impacts during Operation

Easy accessibility of water

The target community will have reliable and sufficient water for the intended agricultural purpose, especially irrigation. This will ease the burden of food insecurity and build resilience to climate change risks.

Improved food security

The project is meant to provide water for small-scale irrigation to the target beneficiaries. The beneficiaries will grow food and fodder crops under irrigation throughout the year, upon water reticulation to their farms. This will enhance access to food and livestock fodder for households and reduce food insecurity in the area.

Increased income

Irrigated agriculture will result to production of enough food for household consumption and surplus for sale. The sold produce will generate income to the members of the beneficiary community.

Employment opportunities

Employment opportunities will be available directly and indirectly throughout the project cycle. The employment opportunities that the project will create includes, among others :- plumbers, transporters, caretakers of the installed infrastructures, on-farm workers, and traders.

Improved livelihoods

The proposed small-scale irrigation project will enable farmers to produce diverse agricultural commodities such as vegetables, onions, and carrots among others as well as fodder for livestock. Sale of these produce will increase income and savings for the beneficiaries. Excess income will be channeled towards addressing urgent needs in the households. In addition, availability of water at the homestead of each household will save time for fetching water and the saved time would be invested in carrying out constructive activities.

Improved health

Provision of adequate water for irrigation will enable farmers to produce a variety of food crops that are fresh and nutritious for their bodies, hence improved health.

Increased security within the project area

Idleness and unemployment are potential causes of crime, especially among youths. The project will provide employment opportunities to the youths, keeping them active and productive and saving them from engaging in criminal activities.

Improved sanitation

Access to and use of adequate water for cleaning and washing will improve sanitation in the area.

Improved tree cover

Establishment of indigenous and fruit tree nursery beds is part of the project. This will help the beneficiaries to grow a variety of trees on their farms, hence improving the vegetation and tree cover in the project area.

Area growth and development

Implementation of the project will contribute to the growth of the area as more economic activities will be undertaken.

6.3.1 Anticipated Negative Impacts and Mitigation Measures during the Operation Phase

Social Impacts and Mitigation Measures

Health and safety concerns

The proposed dam might have some negative implications on the health and safety of the local community.

These may include: -

1) The dam may serve as a breeding ground for disease vectors such as mosquitoes and bilharzia snails. If measures are not taken, there could be an increase in the incidence of malaria and bilharzia in the area.
2) Consumption of untreated water from the dam could result in increased incidence of water-borne diseases such as typhoid, cholera and diarrhoea.
3) Risk of drowning in the dam

Mitigation measures

- Sensitize the community on the potential health and safety risks
- Sensitize residents on the need to treat drinking water
- Sensitize household members neighbouring the dam on use of mosquito nets
- Fencing of the reservoir area
- Sensitize community on hygiene and sanitation around the dam and the area in general.

Water Use Conflict

The targeted project area and its surrounding suffers water scarcity and conflicts may arise over access and use of the water resource especially during dry periods.

Mitigation measures

- PMC in collaboration with Water Users' Association (WUA) to guide on water usage and conflicts resolution.
- PMC to enforce by-laws regarding water use
- PMC to strictly follow the agreed water distribution schedule to minimize grievances
- Establish and operationalize a grievance redress mechanism for the project.
- Apply for water abstraction permit from water resources authority and ensure adherence to the conditions in the permit
- Metering at the water source to determine the volumes of water used and regulate water wastage

Environmental Impacts and Mitigation Measures

Soil erosion

Cutting down of trees and removal of vegetation to create more space for cropland as well as soil erosion resulting from poor irrigation practices on the target farms are some of the negative environmental impacts that the project can bring about.

Mitigation

- Sensitize beneficiary community on environmental protection and conservation, water use efficiency and soil conservation measures.
- Plant and nature environment friendly and ecologically suitable indigenous & fruit tree species within the farms and bamboo shrubs around the spring.
- Plant Napier grass strips along contour lines of sloppy lands
- Encourage farmers to cultivate along the contours

Water reduction/ depletion

Increased abstraction of water from the dam for irrigation in the proposed project area will result to reduced volume of water in the dam.

Mitigation

- Protect the spring and its catchment area to ensure continued supply of sufficient water to the dam.
- Fence the spring area
- Remove all exotic species around the spring and its catchment area and replace them with bamboo shrubs
- Sensitize the beneficiaries on efficient water use to reduce water wastage.

7.0 Conclusions & Recommendations

The following conclusions can be drawn from the design report carried out: The following can be concluded at this stage of the study

The financial and economic evaluation results indicate that the project is viable with a BCR of 2.3 and a payback period of 3 years. Net Irrigation Area

The target irrigation area consists of 215 farmers, each irrigating a 0.101 ha plot. The proposed Kingi phase 2 project will thus comprise 20.23 ha of irrigated area.

7.1 Suitability of the area for irrigation

From the fieldwork studies, the land slopes and soils are suitable for irrigation purposes. Soils in the scheme were found to be suitable for the proposed crops.

7.2 Project costs

The preliminary design cost estimate has been determined as KES, **26,755,087.00** and the cost per hectare is KES **1,244,422.65,** which is lower than the IWMI estimated cost of **KES 1,569,305** for similar works.

7.3 Farmers participation and commitment

The farmers' interest and participation in the design activities was exemplary. From our findings, this high interest could be attributed to:

- Past studies that have recommended the development of an irrigation scheme in the area;
- The high benefits that have been witnessed by farmers irrigating by pumping water from nearby streams and rivers.

7.4 Support of Stakeholders

The proposed development of Kingi dam phase II Irrigation Project's success depends on collaborative efforts from multiple stakeholders, including government agencies, community organizations, private sector partners, and local leadership. This sub-section details the roles and contributions of the relevant stakeholders such as National Irrigation Authority (NIA), County Irrigation Development Unit (CIDU), County Project Coordinating Unit (CPCU), Irrigation Water Users' Association (IWUA), Kenya Forest Service (Forestry), Cooperatives Department, and local leadership among others during the implementation phase and after the project is handed over to the community. These roles align with the NAVCDP's objectives of enhancing market participation and value addition.

7.4.0 County Project Coordinating Unit (CPCU):

The CPCU has been and will remain integral in overseeing local implementation and stakeholder coordination at all nodes of the project implementation and utilization. In the next phase of project implementation, the CPCU will Conduct site inspections to ensure quality of infrastructure is attained. The unit will also provide the ongoing support through extension services and NAVCDP's M&E framework. The Unit will also manage funds per the Bill of Quantities (KES **26,755,087**) and track the work plan for successful project implementation. In collaboration with CIDU, the CPCU will also organize workshops to train the IWUA on how to manage the project sustainably.

7.4.1 Irrigation Water Users' Association (IWUA):

The IWUA will play an active role implementation of the project by holding monthly progress meetings with the CPCU and contractors as well as providing feedback on issues like material delays, monitoring construction quality for all the project construction works.

7.4.2 County Irrigation Development Unit (CIDU):

CIDU has Collaborated with the CPCU & the IWUA to facilitate participatory survey works, technical design & reviews which has ensured that the final design meets community needs. In the next phase of project implementation, CIDU will train IWUA members to monitor construction of the irrigation system & O&M practices as the project gets handed over to them. The IWUA will also receive support from CIDU in establishing a grievance redress mechanism, reinforcing community ownership post-handover. Lastly, CIDU together with the CPCU will train the IWUA members on water allocation, maintenance, and dispute resolution to ensure equitable distribution among 215 farmers.

7.4.3 Kenya Forest Service (Forestry):

The Kenya Forest Service will be integral in ensuring the sustainability of this project. The department will be responsible for protecting Kingi dam catchment, which is well-forested. Further, the department will advise farmers on catchment conservation to maintain water quality and base flow ($Q80 = 0.13\ m^3/s$). It will also ensure construction activities, like weir building, avoid upstream vegetation loss. Implementation of the SLM activities aimed at conserving the catchment will also be done in consultation with the KFS Supports to reduce siltation risks at intakes.

7.4.4 Cooperatives Department:

The cooperatives department has and will continue strengthening farmer organizations for market access, aligning with NAVCDP's Market Access & Infrastructure Development (MA&ID) component. The department will also spearhead training of the IWUA members on cooperative governance and financial management to handle water user fees during implementation.

7.4.5 Local Leadership:

Local leadership such as Chiefs and Sub-chiefs and village elders will continue playing a major role in community mobilization and conflict resolution in Leshau Pondo Ward, Ndaragwa Sub-

County hence effective project implementation and management. They will also support the CPCU and IWUA in sensitizing farmers about project benefits, ensuring high participation. Local leaders will also mediate potential disputes over land or water allocation. In addition, the local leadership will help in advocating for infrastructure improvements, such as feeder roads and collaborate with the National Government Constituency Development Fund (NGCDF) to secure funding.

7.4.6 National Irrigation Authority (NIA):

NIA is likely to support the IWUA in maintaining and potentially expanding the scheme. It also has the potential of linking the IWUA to national programs for funding or equipment, such as sprinkler replacements in years 10 and 20. It will also provide technical assistance for sprinkler, pipeline and head works maintenance to sustain 70% irrigation efficiency. Scaling up beyond 100 Ha in future will also need NIA's advisory.

7.4.7Sustainability- O&M by the IWUA

The dam management committee will be responsible for routine operations and maintenance, system repairs, and financial management.

Ownership of the project will be farmer-led, fostering accountability, and sustainability through active involvement, decision-making, and long-term commitment from the beneficiaries and continued local stewardship. Upon completion and handover of the scheme, the community will take full responsibility for its management.

7.5 Conclusion and Recommendations

The following can be concluded at this stage of the study

- The net irrigation area proposed for the project 21.5Ha by direct abstraction from Kingi Dam with a storage capacity of 35,000m^3.
- The financial and economic evaluation results indicate that the project is viable with BCR of 2.3 and payback period of 3 years.
- There is support for the project by local community as well as by various stakeholders and the members of IWUA.

- The project if implemented will address to a great extent the set objectives including food security, income generation, employment creation, supply of raw materials to industry and foreign exchange generation.
- Implementation of the project will significantly increase total agricultural production and corresponding revenue in the County/ Project areas and so contribute to increase in the national production output of various crops, notably horticulture.
- The expected environmental and social impacts are manageable.
- The total estimated project cost is **KES 26,755,087 equating** to **KES 1,244,422.65** per hectare which is significantly lower than the *International Water Management Institute's* benchmark of KES 1,569,305 for similar projects. Farmers' contribution is estimated at **KES.8,000** for infield hose pipe and sprinkler.