Greening Uganda's Urbanization and Industrialization

Development of Green Industrial Masterplans, Infrastructure plans and project concept notes for Entebbe, Pakwach and Soroti

Water and Sanitation (Watsan) Assessment
(Storm water, Water supply, Wastewater and Solid waste management plans)

Final Report for Pakwach Industrial Park

Prepared by Eng. Dr Seith Mugume
29th December 2023

Content

List of Figures

List of Tables

List of Abbreviations and Acronyms

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
GGGI	Global Green Growth Institute
IP	Industrial Park
m	Meters
MDD	Maximum Day Demand
NWSC	National Water and Sewerage Corporation
SW	Solid Waste
SWM	Solid Waste Management
UIA	Uganda Investment Authority
WSP	Waste Stabilization Ponds
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant

1. Introduction

1.1 Background

Based in Seoul, the Global Green Growth Institute (GGGI) is an intergovernmental organization founded to support and promote green growth. It targets key aspects of economic performance such as poverty reduction, job creation, social inclusion, and environmental sustainability. GGGI works with countries around the world, building their capacity and working collaboratively on green growth policies that can impact the lives of millions. The organization partners with countries, multilateral institutions, government bodies and the private sector. This is to help build economies that grow more economically and efficiently. Ultimately, they become more effective and sustainable in the use of natural resources, less carbon intensive, and more resilient to climate change. GGGI is partnered with the European Union (EU) as part of the EU inclusive green economy uptake programme (GreenUP). At present, it delivers a project entitled "greening Uganda's urbanization and industrialization" (2020-2023). The programme is aligned with the government of Uganda's vision 2040, the third National Development Plan (NDP III), and the Uganda green growth development strategy (UGGDS). The project promotes sustainable development and inclusive green growth in Uganda. It focuses on green city development, green industrialization, efficient waste management and green growth integration into planning and budgeting.

1.2 Project objective

The main objective of the project is to develop green masterplans, symbiotic infrastructure plans and infrastructure project concept notes for the 3 locations. The project hopes to support the development of 3 industrial locations at Entebbe, Soroti and Pakwach to support Uganda in becoming mid-income status via industrialization. Therefore, the overall goal is to design the infrastructure to allow the industrial park and its contextual city to thrive, as an economic system. The current status of delivery of the specific objectives of the water and sanitation assessment is presented in **Table 1-1.**

Table 1-1: Assignment objectives and current status of delivery of outputs

#	Specific objective	Current status
1	Preparation of draft inception report	Completed, **29th July 2023**
2	Preparation of final inception report	Completed, **29th July 2023**
3	Site visits, detailed field data collection, and stakeholder engagements	July – August 2023 Additional stakeholder engagements in Entebbe were completed in September 2023
3	Preparation of detailed methodologies for water and sanitation data collection and analysis (or modelling) Preparation of outline designs and master plans for water supply, wastewater collection and treatment, stormwater, and solid waste management for each of the three sites.	Completed, **18th August 2023**
4	Preparation of the proposed water and sanitation infrastructure lay outs/plans	Draft Report for Packwach Industrial Park completed and submitted on **13th October 2023** **Revised Draft submitted on 15th November 2023** **Final Report submitted on 29th December 2023**
5	Preparation of brief environmental impact assessment of the plans	Green infrastructure plans included in final revised water and sanitation assessment report, submitted on **29th December 2023**
6	Development of project concept notes for water and sanitation infrastructure	Draft project concept notes submitted on **15th November 2023** **Final project concept notes submitted on 29th December 2023**

1.3 Pakwach industrial park

This report presents the draft findings of the water and sanitation assessment for the Pakwach Industrial Park. In Uganda, the development of industrial parks is on the rise, offering opportunities for investment attraction, technological learning, innovation, and job creation. Modern industrial parks are evolving into Eco-Industrial Parks (EIPs) by incorporating resource-use efficiency, cleaner production, and industrial symbiosis to promote sustainability. EIPs involve companies collaborating with local communities to reduce waste, share resources, achieve sustainable development, and minimize environmental impact, ultimately aligning with the circular economy model and green growth principles.

The government of Uganda through UIA, identified a private developer, Dero Capital Investment, with an interest, resources, expertise and international connections to develop Pakwach Industrial Park as a private led park. The initiative to develop the Pakwach Industrial Park was driven by the UIA Board's decision in 2017, which approved the establishment of four regional science and technology industrial parks (STIPs), including Pakwach, Rubirizi, Kyankwanzi, and Kamuli.
The Pakwach Industrial Park is located in the Pakwach district, situated in the West Nile region of Uganda. It borders with Nebbi district to the West, Nwoya and Amuru districts to the East, the Democratic Republic

of Congo (DRC) to the South-West, Arua to the Northwest, and Buliisa district to the South. The park is located in Atara, Alwi sub-county approximately 9.1 km west of Pakwach Town along Pakwach -Nebbi road. It covers approximately 500 acres of land and is intended to be a regional Science and Technology Park (STIP) and agricultural value addition industry and logistics industrial park as specified in the July 2021 industrial parks development status report prepared by Uganda Investment Authority (UIA). The current location of the proposed industrial park is does not have any building infrastructure and the local community use this land for agricultural activities such as cultivation of crops and grazing of animals.

The Pakwach Industrial Park boasts several significant competitive advantages. These include its strategic location near the Democratic Republic of Congo. Additionally, the park will benefit from fertile agricultural land (to support agro-processing) and abundant water resources. **Figure 1-1** shows the location of the Pakwach Industrial Park
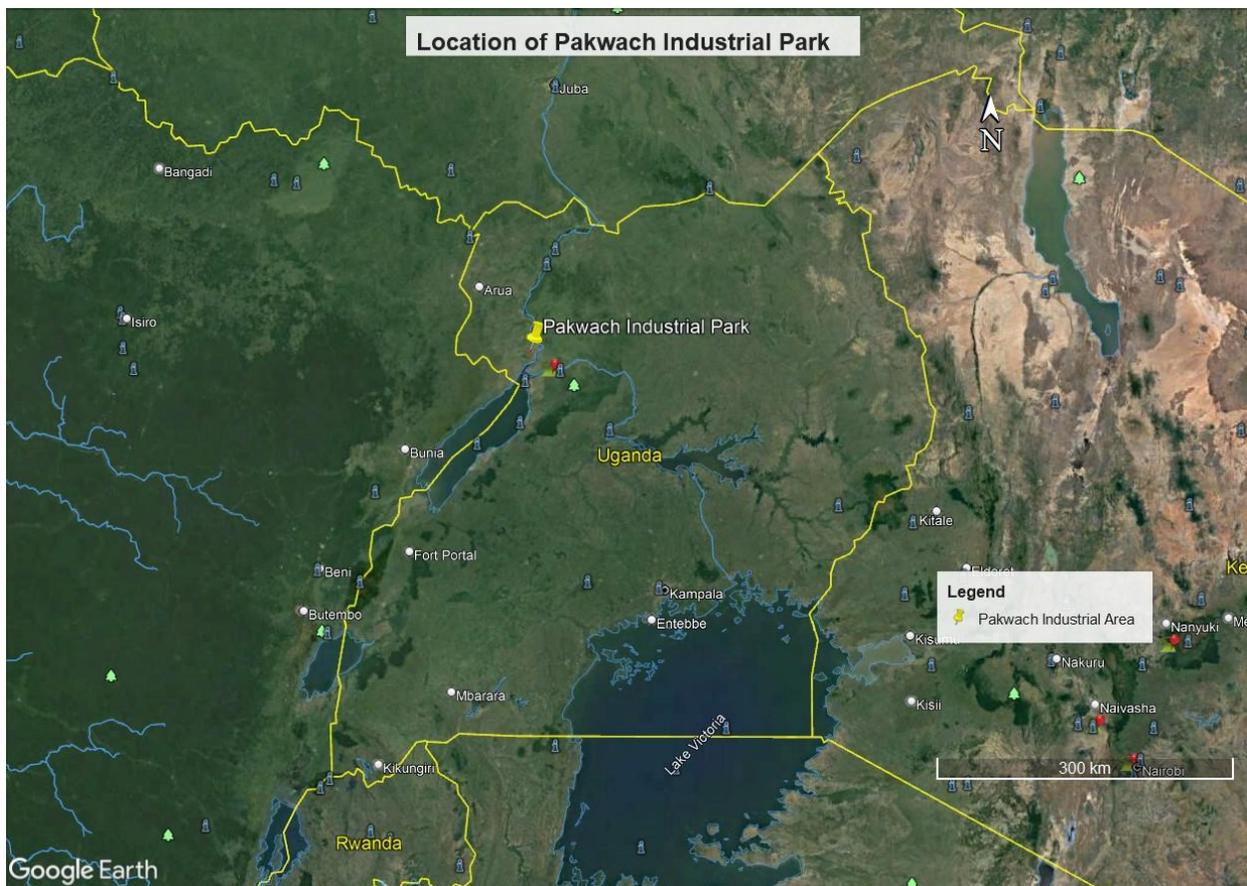
Figure 1-1: Location of the Pakwach Industrial Park

1.4 Stakeholder identification and engagement

A field mission to Pakwach was undertaken in September 2023. The field mission included field visits to various key locations that included Pakwach district offices, the planned Industrial Park area and National Water and Sewerage Corporation - Pakwach district branch. The purpose of the field visits was to engage stakeholders and to undertake a detailed situational analysis I respect to water supply, wastewater, solid waste and storm water management in the industrial park.

1.4.1 Stakeholder engagements with Pakwach district

Key findings from the engagements with Pakwach District officials included insights into solid waste management within Pakwach town. All solid waste from Pakwach town is managed at the Atara Landfill site, located approximately 5.67 km from Pakwach town and 2.41 km from the planned site of the industrial park. Solid waste collected comprises polyethylene, plastics, and organic waste, but there is no separation, sorting, reusing, composting, or recycling at the landfill site. The town faces challenges due to limited transportation means for waste collection, lead to low solid waste collection rates, odour, breeding of vermins and contamination of ground water in the vicinity of the landfill site. Despite proposed plans to relocate the landfill site, no official confirmation has been made. With the anticipation of increased waste generation from the industrial park, managing solid waste cost-effectively remains a significant challenge.

Water supply in Pakwach town primarily relies on surface water from the Nile River, managed by the National Water and Sewerage Corporation (NWSC). The Water Treatment Plant operates between 12 to 15 hours daily, with a primary reservoir capacity of 15,000 m^3 and a secondary reservoir of 130 m^3. The treatment plant operates at 80% capacity. This implies that the existing treatment plant can only cater for additional demand equivalent to 20% of the existing treatment capacity, which is not adequate to meet the projected water demand for Pakwach STIP. While no water shortages were reported, it is worth noting that the NWSC's water supply system does not reach the site of the Industrial park.

Stormwater management within Pakwach Town Council primarily relies on drainage channels along roads. However, these channels occasionally get blocked by solid waste, leading to flooding. Flooding incidents have been reported, particularly in Nyakatita. In 2020, flooding occurred due to rising water levels in Lake Victoria which led to flooding of downstream lakes Kyoga and Albert and the River Nile. The primary stormwater outfall in Pakwach is the River Nile. The impact of the rising river water levels on flooding of the Industrial park and optimal location of the planned raw water abstraction intake should be investigated at feasibility and detailed design stage of the project.

Pakwach Town Council lacks a wastewater treatment plant. Instead, wastewater is managed on-site through septic tanks and soak pits and use of pitlatrines. Faecal sludge collected within Pakwach is transported to a treatment plant in Arua. Further engagements with the Environmental Health Officer at Pakwach revealed that there are gazetted areas at the extreme end of Atara dumping site where the land is excavated and feacal sludge is dumped. This could potentially contaminate the ground water table since this faecal sludge is not treated before it is dumped at Atara.

1.4.2 Stakeholder engagements with the private sector

The private sector engagements involved various stakeholders and local cassava growers and processors. The cassava processing facility specializes in producing cassava flour (farinha) as its sole product and starch as a bi-product. The production process includes cassava harvesting, quality checks, peeling, washing, chipping, grinding, and packaging. For every 500 kg of freshly peeled wet cassava, the facility obtains 200 kg of dry cassava. Water is primarily used for washing cassava, with 100 litres required for every 500 kg batch. Solid waste mainly consists of cassava peelings, with a waste generation ratio of 4:1

(4 kg of wet cassava yields 1 kg of dry cassava). During cassava harvesting, stems are the primary waste, and 8 bags of stems are generated per acre of land. Wastewater management involves direct discharge of water used for cassava washing, resulting in 100 litres of wastewater for every 500 kg of cassava washed. This wastewater is channeled to a soak pit for infiltration into the ground. This leads to cyanide contamination hence necessitating the need to treatment prior to discharge to the environment.

1.4.3   Field visit to the planned site for the Pakwach Industrial Park

The planned site for the Industrial Park spans approximately 500 acres, situated about 8.51 km west of Pakwach Town, adjacent to the Pakwach-Nebbi road. Most of the land is currently used for cultivation and grassland and is privately owned by local individuals. In this respect, GGGI should confirm the ownership of Pakwach STIP land the proposed resettlement action plan prior provision of investment support. In addition, soil erosion has caused gullies in the site due to runoff. Previously, the land used to flood due to Nile River water levels, but a dam construction in a tributary river solved this issue. Locals have constructed a large channel within the site for flood protection and water storage for animals. During the development of the park, arrangements for compensation of the local community water storage infrastructure should be taken into consideration.

2. Potential Sectors

2.1 Introduction

Key sectors for development to be set up in the Pakwach Industrial Park were identified based on extensive discussions, site assessments, socio-economic and environmental analyses. The proposed sectors include; cassava processing to starch, sesame processing to sesame oil, peanut processing, fruits and vegetables, fish, solar power, tourism, logistics, green hydrogen energy and briquettes. The water supply requirements, wastewater generation and treatment, and solid waste management assessment are described in detail in the sections below.

2.2 Fruits and vegetables – Sorting, washing and packaging

The value chain of fruit and vegetable production involves various stages, including sorting, cleaning, grading, packaging, stacking, inspection, storage, and export. At this stage the quantity of fruits and vegetables to be packaged have been based on the sectoral team analysis and quantification for Pakwach Industrial Park. This report has been prepared on the basis of production capacities of 6.67 tons per day for vegetables and fruits.

The sector will rely heavily on adequate water supply for cleaning the fruits and vegetables before packing. Additionally, the sector must tackle solid waste generated during the sorting, cleaning, and packaging processes; therefore, segregation, proper disposal and recycling methods for waste materials should be established to prevent land and water pollution. Similarly, treatment of wastewater generated from washing and processing of fruits and vegetables is vital to minimise discharge of pollutants to the environment. The characteristics of the wastewater generated in storage depend on the specific storage methods and treatments used. Typically, this wastewater contains suspended solids, organic matter, potential chemical residues, and microorganisms, especially if cleaning agents are used.

2.3 Fish sector – Smoked

The fish sector shall involve processing of fresh fish into smoked fish. The processing of fish into smoked fish involves brining, drying, smoking, packaging and storage.

The quantity of fish to be processed has been determined from the team sectoral analysis and quantification basing on the production capacity 4.4 tons per dayThe wastewater characterisation has been determined from previous studies and is detailed in Chapter 4 of this report. The characteristics of the wastewater generated will depend on the specific smoking method, fish quality, and any additives used. Wastewater from brining will be high in salt content, containing dissolved salts and some fish compounds. While that from cleaning and washing fish may contain suspended solids, organic matter, and potential microbial contaminants. The solid waste from smoked fish was also determined from previous studies and is described in detail in Chapter 5.

2.4 Agro-foods sector

The Pakwach Industrial Park is set to become a hub for the processing of a diverse range of agro-foods such as grains, cassava, etc, with each destined for various valuable products. The grains in focus include rice, sorghum and maize.

2.4.1 Cassava

The cassava processing sector will involve the manufacture of cassava flour. In cassava flour production, cassava roots are peeled manually, washed, and crushed to remove cyanide. The resulting pulp is de-watered, dried, and ground to produce high-quality cassava flour. For large-scale production, two methods are employed; one involving extensive screening and the other utilizing starch processing equipment for better purity. The quantity of cassava products to be processed has been determined from the team sectoral analysis and quantification basing on the production capacity of 110 tons per day. The amount of water required in cassava processing will be mainly required for cleaning of the peeled cassava as well as cleaning the equipment, which generates yellowish wastewater. The cassava wastewater is composed of glucose, cyanide, carbohydrates, proteins, lipids, and minerals.

2.4.2 Peanuts

Peanuts shall be processed into peanut butter at the Pakwach Industrial Park. The quantity of peanuts to be processed into butter has been determined from team sectoral analysis and quantification. A value of 2 tons has been considered in this report.

The amount of water required in processing of peanuts will be required for the cleaning of the peanuts as well as cleaning of equipment. Wastewater generated from the processing of peanuts into butter contains a significant amount of organic matter such as fats, solids and proteins. This wastewater needs to be treated adequately so as to prevent pollution of the environment. It may exhibit distinctive brown colour due to the peanuts used and its viscosity will be influenced by the oil and fat content.

2.4.3 Sesame

Sesame shall be processed into oil in the Pakwach Industrial Park.

The quantity of sesame to be processed has been determined from the team sectoral analysis and quantification as basing on the production capacity of 2 tons per day. Wastewater produced during the processing of sesame contains a high amount of organic matter as well as suspended solids and requires to be treated to the required standards before discharge into the environment.

2.4.4 Coffee

There is coffee growing in the nearby districts such as Zombo. The processing of the coffee will be carried out on the farms and only storage provided at the Pakwach STIP.

The storage is a dry process and insignificant amounts of water is consumed and wastewater generated. However, solid waste is generated from these processes. This waste is known as coffee cherry husks and includes the dried skin, pulp and parchment.

The amount of coffee that will undergo processing has been established at 5 tons each day. Since coffee processing is primarily a dry procedure, there won't be a substantial production of wastewater.

2.5 Logistics

Logistics hubs are large-scale structures within which various logistics service providers collaborate in order to offer value-added services by sharing assets (Vieira & Luna, 2016). These hubs must be well positioned in networks in order to have an increased efficiency on transportation systems since they directly affect the flow of goods (Li et al., 2011).

The water demand in the hub will be majorly domestic demand and water for washing of trucks and other vehicles. The wastewater will include domestic wastewater and water from washing of vehicles. A grease separator is required in order to separate the oil from the wastewater generated from the maintenance of vehicles. Domestic solid waste such as food leftovers, plastics and paper will be generated at the hub.

The development of the logistics hub is viewed as a sector that will develop in the long term, aided by the development of the park.

2.6 Solar Power

Solar panels will be installed in the industrial park to provide renewable energy from the sun. Solar panels convert solar energy into electricity which can be used for lighting, heating, cooking and other processes (Hu et al., 2016).

The water demand expected at the site will include domestic demand from the operators of this facility. Domestic wastewater will be generated by the operators while solid waste will also consist of domestic solid waste such as food wastes, plastics and paper.

2.7 Tourism

A tourism hub for making coffee, crafts and other items is proposed at the industrial park. The hub will be expected to have several people marketing their items. The main water demand for this sector will be domestic demand with domestic wastewater being generated. Solid waste is also expected to be majorly domestic including food wastes, paper and plastics.

2.8 Manufacture of Briquettes

Briquetting involves conversion of agricultural waste into uniformly shaped briquettes that are easy to use, transport and store (Salah & El-Hagger, 2007), the process also increases the net calorific value per unit volume of the products (Bhattacharya et al., 2002). Briquettes act as a substitute for charcoal and wood and also solves the problem of residue disposal.

The water demand includes water for the cleaning processes which in turn is generated as the wastewater. The wastewater that will be generated from this manufacturing process will typically exhibit characteristics that encompass suspended solids and biodegradable organics depending on the specific waste composition, nutrients like nitrogen and phosphorus.

3. Water supply

3.1 Introduction

The sectors that have been allocated land within the Pakwach Industrial Park require varying amounts of water for industrial processes, cleaning, domestic use, and the domestic water demand for the employees expected at the park. This chapter will detail the estimation of the water demand and the water supply options. The opportunities for integrating the existing water supply infrastructure in Pakwach are also explored.

3.2 Existing infrastructure

The water supply system within Pakwach District is managed by National Water and Sewerage Corporation (NWSC). There is an existing conventional water treatment plant managed by NWSC that abstracts water from the Albert Nile. The design capacity of the treatment plant is 1,500 m^3/day. The plant operates between 12 – 15 hours per day with 80% capacity utilisation implying the that the available plant capacity to meet future water needs is 300 m^3/d. The available plant capacity is insufficient to meet the Pakwach Industrial Park water requirements. There is a primary reservoir within the treatment plant of 15,000 m^3 capacity and a secondary reservoir of 130 m^3 capacity. The treated water is pumped to a booster station with a capacity 150 m^3 and an elevation of 10 m at Pajobi along Pakwach – Nebbi road. The existing distribution network pipeline is approximately 5 km from the Industrial Park at the Pine Petrol Station opposite Panyimur road along Pakwach-Nebbi Road. NWSC is currently planning to extend the water distribution mains to Eat Supermarket which is 1.2 km from the industrial park. Figure 3-1 shows the important features of the water supply system in Pakwach.
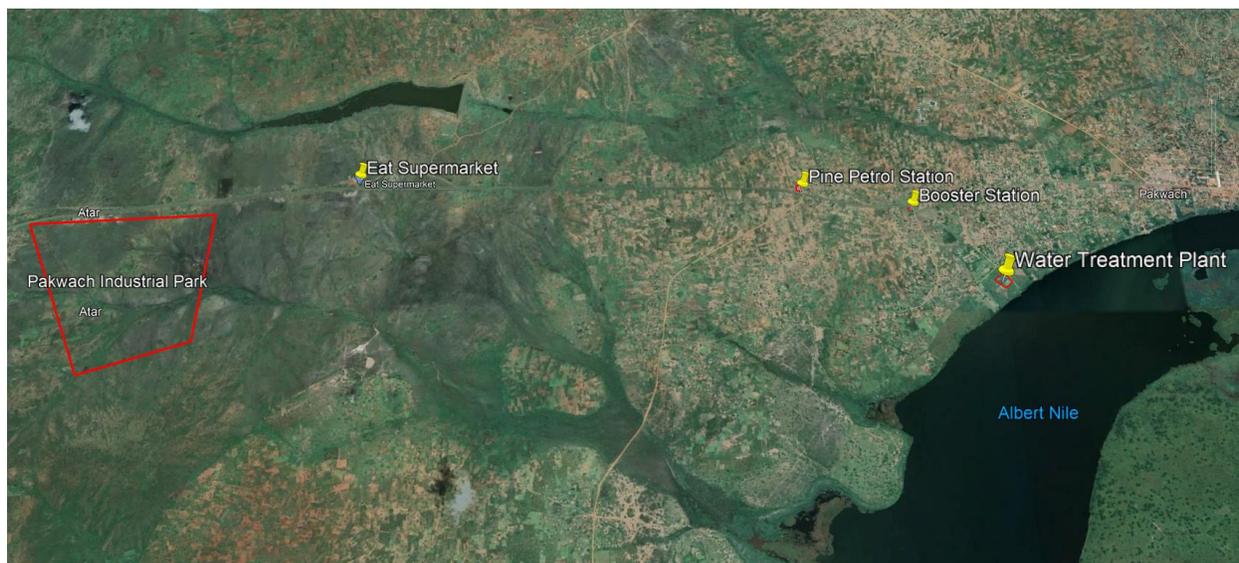
Figure 3-1: Location of the water treatment plant and the Pakwach Industrial Park

3.3 Water demand categories

The different types expected at the Pakwach Industrial Park mainly comprise of;

i. Domestic demand: This is the water consumed by employees and workers at the Pakwach Industrial Park and the surrounding local communities
ii. Industrial demand: Water required to support the sectors and processing plants in the Pakwach Industrial Park. This demand also consists of firefighting and cleaning water requirements.
iii. Community

3.4 Design criteria

3.4.1 Domestic demand

The per capita water consumption has been determined based on the Directorate of Water Development (DWD) Water Supply Design Manual 2nd Edition (Environment, 2013). The domestic water consumption per capita is 50 to 100 litres per capita per day.

3.4.2 Industrial demand

The industrial water demand for different potential sectors at the Pakwach Industrial Park has been assessed considering scalable quantities of raw materials. The water requirements for different sectors expected at the Pakwach Industrial Park have been estimated as presented in the subsequent sub-sections. After estimating the water demand, some of the sectors have been removed, or some of the processes eliminated as explained below.

3.4.2.1 Fruit and vegetable sector - washing and packaging, and processing.

Water requirements have been estimated for different fruit and vegetable types to be processed by the potential industries at the Pakwach Industrial Park. Mangoes, oranges, cabbages, and tomatoes have been considered under this sector. The amount and quality of water required in the process of fruit and vegetable sorting, washing, and packaging depend on several factors, such as the type and condition of the raw material, the processing method and equipment, the hygiene standards and regulations, and the environmental conditions. The unit amount of water consumed in washing and packaging fruits and vegetables was determined based on the study carried out on water consumption in fresh-cut fruit and vegetable production (Lehto *et al.*, 2014). The amount of water demand has been estimated based on 6.67 tonnes per day of fruits and vegetables expected in the range of 16 m^3 to 73 m^3.

3.4.2.1 Cassava Sector

The amount of water required in cassava processing is for cleaning of the peeled cassava as well as cleaning of the equipment. This water demand in a cassava industry largely depends on the required cassava products. The cassava products considered for the Pakwach Industrial Park include; ethanol, cassava flour, and starch, and the water requirement per tonne of raw cassava for each product has been estimated as shown in Table 3-1: Water requirements to process different cassava products. Cassava flour and starch require less amount of water compared to ethanol production. Additionally, considering the large quantities of raw cassava required to produce the flour and ethanol which might affect food security in the area, only processing of cassava flour has been considered for the Pakwach Industrial Park. It is expected that 110 tonnes of cassava will be processed per day at the park and the required water has been estimated in the range of 836 m^3 to 1,045 m^3 per day.

Table 3-1: Water requirements to process different cassava products

Cassava Product	Water requirement (m^3/s)

Cassava flour	7.60 – 9.50
Starch	7.60 – 9.50
Ethanol	4.00 – 24.00

3.4.2.2   Fish sector

Fish filleting and canning processes consume very large quantities of fresh water. Water is used for transporting fish and offal around the plant in flume systems, for cleaning plant and equipment, for washing raw materials and product, and for de-icing and thawing. However, less water is required mainly for cleaning fish and equipment when processing fresh fish to smoked fish. The amount of water required to process fresh fish into fish fillets and smoked fish was estimated as 6.0 - 30.0 m^3 and 1.1 – 2.2 m^3 per tonne of raw fish respectively. This estimation has been based on the study to explore methods of waste minimization, in terms of waste reduction, waste reuse and recycling (McDonald *et al.*, 1999). Processing fish fillets requires large amounts of water compared to smoked fish, this results into corresponding large amounts of wastewater generated. Therefore, only smoked fish shall be considered for the Pakwach Industrial Park. At Pakwach STIP, 4.4 tons of fish shall be processed and the water requirement has been estimated in the range of 4.84 m^3 to 9.68 m^3.

3.4.2.3   Peanut sector – peanut butter

Production of peanut butter from peanuts is not a water intensive process. Water is mainly required in washing and cleaning the peanuts from the garden, grinding to achieve a certain consistency, and mixing and homogenization, and equipment cleaning. However, the amounts of water required in the above processes are still minimal and ranges between 0.06 m^3 to 0.15 m^3 to process one tonne of peanuts into peanut butter. The total water requirement has been estimated for 2.0 tonnes of peanuts per day in the range of 0.10 m^3 to 0.40 m^3.

3.4.2.4   Sesame sector – sesame oil

The volume of water required in the sesame processing to sesame oil is mainly required for cleaning and washing sesame seeds, purification of sesame oil, and maintaining the hygiene of the area. The amount of water required to process one tons of sesame-to-sesame oil has been estimated as 0.1 to 0.5 m^3 based on the study to assess the cultivation technology of sesame seeds and its production in the world and in Egypt (Sharaby & Butovchenko, 2019). The total water requirement has been estimated for 2.0 tons of sesame per day in the range of 0.20 m^3 to 1.00 m^3.

3.4.2.5   Briquettes manufacture

At the Pakwach Industrial Park, briquettes shall be manufactured from organic waste from sesame, peanuts and cassava. Production of briquettes is a dry process, whereby, water is mainly used for cooling machines. The amount of water required to process one tonne of organic waste into briquettes has been estimated as 0.2 m^3. The water requirement for this sector has been estimated for 168 tonnes of organic waste at the park expected to be processed into briquettes as 33.6 m^3.

3.4.2.6   Solar energy

The water consumption considered for the solar energy sector is the domestic water demand for the workers in the sector. An estimate of 50 people has been considered in the determination of domestic water demand for this sector.

3.4.2.7   Hotel and tourism sector.

A hotel is expected to be put up at the park to provide accommodation for the tourists expected at the park. A tourism hub has been considered for the marketing of coffee, crafts, at the Pakwach Industrial Park. The water requirement for this sector has been estimated based on the number of rooms expected for the proposed hotel at the Pakwach. The water demand has been estimated for 50 rooms in the range of 25 m^3 to 100 m^3.

3.4.2.8   Logistics hub.

The water demand for a logistics hub proposed for the park has been estimated as domestic demand for the 100 people expected in the sector.

3.4.2.9   Green hydrogen energy production

Production of green hydrogen energy requires large amounts of water. It requires 9 litres of water to produce 1 kg of hydrogen[1]. However, taking into account the process of water de-mineralization, which is necessary to remove impurities from the water, the ratio can range between 18 to 30 litres of water per kilogram of hydrogen (Adekanbi, Sani, Eshiemogie, Tundealao, & Olofinniyi, 2023). Considering a daily production of hydrogen gas of 100kg, the water required has been estimated in the range of 1.8 m^3 to 3.0 m^3. According to the assessment of the groundwater in the Upper Nile Water Management Zone (UNMWZ), Pakwach sub-catchment has a low potential for groundwater exploitation because of a low groundwater potential (UNWMZ, 2022). The targeted source of water for green hydrogen energy production for the Pakwach STIP is groundwater. Given the low groundwater potential, spatial availability, and prioritization of domestic consumption, this sector is not feasible for the park.

3.4.3   Peak Factors

The average day demand is determined from the summation of the domestic demand and industrial demand. The average day demand is subject to variations in the water demand such as seasonal availability of the quantity of raw materials. The maximum day demand factor of 1.3 is applied to the average day demand. The maximum day demand is used in the design of the storage reservoirs.

There are hourly fluctuations in demand over the duration of the day. The fluctuations are catered for by peak hour factors which are applied to the maximum day demand. The peak hour factor of 2.0 is adopted for the design of the distribution main supplying the Pakwach Industrial Park.

---

[1] Hydrogen production in 2050: how much water will 74EJ need? - Energy Post

3.5 Water demand estimation

3.5.1 Domestic Demand

The per capita water consumption is estimated within the range of 50 to 100 litres per capita per day. Domestic water demand has been calculated based in the estimated 1,100 people at the park when operating at full capacity. Using the upper limit of the per capita water consumption, the computed domestic water demand for the Pakwach Industrial Park is 110.0 m^3/d. Table 3-2 shows the estimated domestic water demand at different development levels of the industrial park.

Table 3-2: Estimated domestic water demand at the Pakwach Industrial Park

Sector	Water requirement (m³/day)	Percentage development of Pakwach Industrial Park		
		35%	75%	100%
Total Domestic Water Demand	Minimum Water Requirement	19.3	41.3	55.0
	Mean Water Requirement	28.9	61.9	82.5
	Maximum Water Requirement	38.5	82.5	110.0

3.5.2 Industrial Demand

The realistic time frames for the gradual development of an industry must be considered when determining the industry's water demand. In this study, progressive development has been considered as a percentage of full capacity for each potential sector. The water demand has been estimated at the 35%, 75% and 100% of full capacity of each sector.
Table 3-3 shows the total water demand; industrial water demand for each sector and at the park.

Table 3-3: Combined Industrial and domestic water demand

Sector	Water Requirement (m3)	Percentage Development of Pakwach STIP		
		35%	75%	100%
Sesame	Minimum Water Requirement	0.07	0.15	0.20
	Mean Water Requirement	0.21	0.45	0.60
	Maximum Water Requirement	0.35	0.75	1.00
Peanuts	Minimum Water Requirement	0.04	0.08	0.10
	Mean Water Requirement	0.09	0.19	0.25
	Maximum Water Requirement	0.14	0.30	0.40
Briquettes	Minimum Water Requirement	11.76	25.20	33.60
	Mean Water Requirement	11.76	25.20	33.60
	Maximum Water Requirement	11.76	25.20	33.60
Cassava (Flour)	Minimum Water Requirement	292.60	627.00	836.00
	Mean Water Requirement	329.18	705.38	940.50
	Maximum Water Requirement	365.75	783.75	1,045.00
Fruits and vegetables	Minimum Water Requirement	5.60	12.01	16.01
	Mean Water Requirement	15.64	33.52	44.69
	Maximum Water Requirement	25.68	55.03	73.37
Smoked Fish	Minimum Water Requirement	1.69	3.63	4.84

Sector	Water Requirement (m3)	Percentage Development of Pakwach STIP		
		35%	75%	100%
	Mean Water Requirement	2.54	5.45	7.26
	Maximum Water Requirement	3.39	7.26	9.68
Total (Domestic)	**Minimum Water Requirement**	**311.8**	**668.1**	**890.7**
	Mean Water Requirement	**359.4**	**770.2**	**1,026.9**
	Maximum Water Requirement	**407.1**	**872.3**	**1,163.1**

The total industrial water demand considering 100% development of the Pakwach Industrial Park ranges from 890.7 m^3/day to 1,163.1 m^3/day.

3.5.3   Average day water demand

The average day water demand at the Pakwach Industrial Park, inclusive of the domestic and industrial water demand is shown in Table 3-4.

Table 3-4: Average Day Demand

Sector	Water requirement (m^3/day)	Percentage development of Pakwach Industrial Park		
		35%	75%	100%
Total Water Demand	Minimum Water Requirement	331.0	709.3	945.7
	Mean Water Requirement	388.3	832.0	1109.4
	Maximum Water Requirement	445.6	954.8	1273.1

The maximum day demand at the Pakwach Industrial Park has been obtained as 1,655 m^3/day by increasing the maximum water requirement at 100% development of the Industrial Park by the maximum day demand factor of 1.3. According to the Water Supply Design Manual 2nd Edition by the Ministry of Water and Environment, the industrial water demand is estimated based on the area occupied by the industry. This results into a maximum day demand of 8,003 m^3/day at 100% development capacity based on 380 acres of the park. However, the sectoral approach that was used in this study takes into consideration the intensity of the industries and the varying water requirements for the different industrial processes. This specificity in water demand estimation for the sectoral approach presents a better estimation since the sectors considered for Pakwach are few relative to the acreage of the park.

3.5.4   Firefighting water

Fire hydrants in an industrial park will be placed in close proximity of the industries along the main access roads, where they can easily be accessed by fire trucks. Since firefighting water is regarded as Non-Revenue Water (forms part of the unbilled authorized consumption), the fire hydrants should be secure from commercial water sellers who may misuse the hydrants by getting water free of charge. According to the Water Supply Manual MWE (2013), the firefighting water demand is estimated according to the area on land occupied by the industry. Pakwach Industrial Park occupies 497 acres of land, and its firefighting water demand has been estimated at a rate of 6,480 m^3/d for two hours. Fire hydrants shall be connected to the water distribution mains supplying the industrial park. The distribution mains shall supply water to both the storage tank for use within the Pakwach Industrial Park and the hydrant for use during firefighting operations. The fire hydrants shall be provided to ensure that their clearance around its circumference is

up to 4.7 m for easy connection of the hose pipe. The spacing between the hydrants shall be maintained in the range of 61 m to 91 m[2]..

3.5.5   Water demand ranking.

Industrial water demand per sector and the domestic water demand has been ranked in order of increasing water requirements. Table 3-5 shows the ranking of the different sectoral water requirements. Different water demand combinations that can be met through the existing water supply system and groundwater exploitation have been identified. The values indicated with a superscript G/S indicate the that the water requirement for the sector in that row and sectors above can be met through groundwater exploitation/existing water supply system, G+S can be met by a combination of both groundwater and existing water supply. The highest water demand contribution if from the domestic water demand and water requirement for cassava processing.

Table 3-5: Ranking of water demand per sector and domestic water demand

Sector	Maximum Water Requirement					
	35%		75%		100%	
	Sectoral water requirement	Cumulative water requirement	Sectoral water requirement	Cumulative water requirement	Sectoral water requirement	Cumulative water requirement
Peanut	0.14	0.14	0.30	0.30	0.40	0.40
sesame	0.35	0.49	0.75	1.05	1.00	1.40
Smoked fish	3.39	3.88	7.26	8.31	9.68	11.08
Briquettes	11.76	15.64	25.20	33.51	33.60	44.68
Fruits and vegetables	25.68	41.32	55.03	88.54	73.37	118.05
Domestic demand	38.50	79.82	82.50	171.04	110.00	228.05
Cassava flour	365.75	445.57 [G+S]	783.75	954.79	1,045.00	1,273.05

G – Groundwater (500m^3/d), S – Surface water (300m^3/d)

3.6   Water supply options

3.6.1   Groundwater (borehole production wells)

The industrial park is located in the Albert Nile catchment in the Upper Nile Water Management Zone (UNWMZ). The estimated groundwater recharge in the Albert Nile catchment is 2,257Mm^3/year (UNWMZ, 2022). The estimated groundwater recharge in the industrial park is 582.42m^3/day (based on 2.01 km^2 acreage).

The water demand estimation for the industrial park is a minimum of 1,655 m^3/day. The available groundwater can meet approximately 35 % of the total estimated water demand. A detailed ranking of the water requirements per sector has been presented in **Section 3.5.5.** At 35% development of the park, the total water requirements can be met through the exploitation of groundwater.
At 75% development, groundwater exploitation can meet only 52% of the total water demand requirement . Groundwater can meet 35% of the total water demand at 100% development of the park. However, according to the UNWMZ (2022), the exploitation potential of groundwater in the Pakwach sub-catchment

---

is low, which necessitates a more detailed hydrogeological study before the option can be utilized. In addition, there is no groundwater quality data in the area according to the National Water Resources Assessment Report (NWRA, 2013). Therefore, exploitation of groundwater to meet the needs of Pakwach STIP is not recommended.

3.6.2 Extension of existing water supply system

Currently, the existing water treatment plant is operating at about 80% of its design capacity. There are plans by the NWSC to extend the distribution line from 4.96 km to 1.2 km away from the industrial park.

The reserve capacity of 20% of the plant's design capacity (300 m^3/d) is insufficient to meet the maximum day demand of 1,655 m^3/day of the industrial park at even 100% development. The existing water supply system can meet about 67% of the water demand at 35% development of the park. The deficit of 23% of the water demand could be met through groundwater exploitation as a short-term solution. Depending on the water demand for the park and considering the future growth of water demand, exploiting the existing water supply system would create competition of water demand with the communities and Pakwach Town.

The exploitation of this water supply option would require expansion of the existing water treatment plant capacity from 1,500 m^3/d to approximately 2,900 m^3/d. This can be achieved in phases by expanding the existing water supply system by 700 m^3/d each in the medium term and the long term. The main components of the water treatment plant shall include: raw water intake mains, sump, water treatment plant components (sedimentation tanks, rapid sand filters, clarifiers, clear water tanks and pumping station), transmission mains and a storage reservoir.

3.6.3 Surface water supply

The Consultant explored the possibility of constructing an independent water system for supply to the industrial park. The nearest surface water source is the Albert Nile, located approximately 5.25 km away from the industrial park. The surface water supply option would require the construction of an intake on the Albert Nile, a water treatment plant of at least 1,700 m^3/day capacity, storage reservoir and water transmission pipelines.

This option is capital intensive; however, it presents a reliable long-term source of water for the industrial park to meet the high-water demand requirements. The construction of this water supply system would benefit the Pakwach STIP without causing pressure on the existing water supply system.

According to the National Water Resources Assessment Report (NWRA, 2013), the minimum flow of the Albert Nile is 47Mm^3/day. The water demand for Packach STIP represents less than 0.09% of the minimum flow of the Albert Nile. The river flow considered sufficient to supply the required amount of water (1,700 m^3/day) for the park without causing any ecological stresses on the river and available water for downstream users.

3.6.4 Conclusions on Water Supply Options

The water supply interventions will comprise of short-term and long-term interventions, based on the development of the industrial park.

In the short-term, the consultant proposes the extension of the existing water supply system. This requires utilization of the 20% reserve capacity of the existing water system (300 m^3/d). This supply will meet part of the water requirement during the immediate term of the development of the park. Therefore, the

consultant proposes the expansion of the capacity of the water supply system by 850 m³/day. This will meet the remaining water demand in the immediate term and the medium term of the park development.

Under the long-term interventions, surface water would be abstracted from the Albert Nile, treated and pumped to the industrial park. The water demand in the long-term will be met by constructing a second parallel treatment line of 850 m³/day capacity to meet the 1,700 m³/d water demand at 100% development of the industrial park. The independent water supply system would meet the water demand at the park without causing a water stress on other users in Pakwach municipality.

3.7   Water storage

3.7.1   Design criteria

A storage reservoir is required to provide for fluctuations in water demand during the day (e.g., the hourly peak flow) and minimize disruptions in flow during periods of maintenance. Furthermore, the storage provides for a constant residual pressure and flow for smooth operations at the Pakwach Industrial Park.

The DWD Water Supply Design Manual recommends 30% of the maximum day demand has been adopted for storage.

3.7.2   Calculated storage

The storage requirement has been estimated based on the maximum day demand for 100% production capacity at the Pakwach Industrial Park. The calculated storage is shown in Table 3-6.

Table 3-6: Calculated Water Storage

Water Requirement	Maximum Day Demand (m³/day)	Calculated Storage Capacity (m³/day)	Adopted Storage Capacity (m³/day)
Minimum Water Requirement	1,229	369	370
Mean Water Requirement	1,442	433	435
Maximum Water Requirement	1,655	496	500

The adopted storage reservoirs range in capacity from 370 m³ to 500 m³. The duration of the storage provided by the proposed reservoir tanks over the development of the Pakwach Industrial Park is shown in Table 3-7.

Table 3-7: Duration of Storage

Parameters	Percentage Development of Pakwach STIP			
	35%	75%	100%	110%
Minimum Water Requirement (m³/day)	496.5	1064.0	1418.6	1560.5
Adopted Storage Capacity (m³)	370	370	370	407
Storage Capacity (%)	75%	35%	26%	26%
Hours of Storage (hour)	**18**	**8**	**6**	**6**
Mean Water Requirement (m³/day)	504.8	1081.7	1442.2	1586.4
Adopted Storage Capacity (m³)	435	435	435	478.5
Storage Capacity (%)	86%	40%	30%	30%
Hours of Storage (hour)	**21**	**10**	**7**	**7**
Maximum Water Requirement (m³/day)	579.2	1241.2	1655.0	1820.5
Adopted Storage Capacity (m³)	500	500	500	550

Parameters	Percentage Development of Pakwach STIP			
	35%	75%	100%	110%
Storage Capacity (%)	86%	40%	30%	30%
Hours of Storage (hour)	21	10	7	7

The duration of storage provided at 100% development of the Pakwach Industrial Park is 6 to 7 hours. This is deemed sufficient storage to cater for disruption in supply during maintenance plant shut downs. The storage requirement has also been estimated considering 10% increase in the full capacity of the park as 6 to 7 hours. The increment considered serves to cater for any uncertainties in the water storage and requirements, and it is considered sufficient to cater for any disruptions at 110% of the full capacity of the park.

3.7.3   Storage reservoirs

The storage capacity for the industrial park has been estimated in the preceding sections. The proposed reservoir type is the pressed steel reservoir tanks. The tanks can be erected on reinforced concrete dwarf walls or steel towers. The land within the Pakwach industrial park is fairly flat, and as such the storage reservoirs have to be elevated to provide sufficient residual head.

The proposed minimum storage capacity can be met by providing at least one reservoir tank of 550 m^3 capacity. The reservoir can be erected on a steel tower to a required residual head. This capacity shall be confirmed during the feasibility and detailed design stage of the water and sanitation infrastructure.

During the detailed engineering design, the pressure required at the water consumption ends shall be analysed. Pumps are proposed to boost the water pressure supplied to the park. The consultant proposes that these pumps be operated by hydroelectric power, and a standby source of power from solar energy is proposed as opposed to diesel generators. This is intended to reduce the greenhouse gas emissions from diesel generators. The total quantity of carbon dioxide emission will be determined during the detailed engineering design when the pump specifications and power requirements have been computed. However, it can be noted that for every litre of fuel, 2.62kg of CO_2e emissions are produced[3]. The water pumps will also provide the required water pressure for the fire hydrants.

3.7.4   Operation and Maintenance

The operation and maintenance of the water supply infrastructure at Pakwach industrial park based on the extension of NWSC will comprise of the following:

   i.   Payment of water bills. NWSC will provide water bills based on the water consumed per month. The water bills will be paid on a monthly basis
  ii.   Desilting of the storage reservoirs. The accumulation of silt is dependent on the water quality from the supply main. The desilting can be carried out every two years by the management of the park
 iii.   Routine maintenance works. The routine maintenance works will be determined based on a visual assessment of the infrastructure. This includes works such as replacement of valves, painting of steel tower and repair of leakages of pipes and tanks. These maintenance works should be undertaken by the Park management (for the pipelines within the park) and NWSC for the water treatment plant and transmission mains.

---

[3] How To Calculate Emissions from Diesel Generator? - UtilitySmarts

4. Wastewater management

The various sectors in the Pakwach Science and Technology Industrial Park will require varying amounts of water for industrial processes, cleaning, domestic use, etc. This chapter will detail the estimation of the wastewater flows and pollution load. The opportunities for integrating the existing wastewater supply infrastructure in Pakwach district are also explored.

The design criteria for wastewater management includes determining flow rates and wastewater characteristics, selecting treatment processes, designing layout and infrastructure, managing sludge, ensuring regulatory compliance, and considering energy efficiency and future expansion.

4.1 Existing infrastructure

4.1.1 Existing wastewater management facilities.

The Pakwach Industrial Park is currently not occupied and therefore there are no sewers and treatment plant located within its vicinity. In the development of the industrial park, the consultant shall propose shared infrastructure to manage the wastewater produced from the park.

In addition, Pakwach Town Council does not have a wastewater treatment plant. The faecal sludge collected within the district is dumped at the nearest faecal sludge treatment plant located in Arua. Wastewater treatment within the town council is managed on-site using septic tanks and soak pits.

4.2 Design criteria

4.2.1 Domestic wastewater

The domestic wastewater comprises of wastewater from toilets, bathrooms and kitchens. The domestic wastewater was estimated based on an 80% water consumption return rate. A peak hour factor of 1.5 is applied to the estimated wastewater flow to cater for hourly fluctuations. The domestic wastewater characterisation is shown in Table 4-1.

Table 4-1: Domestic Wastewater Characterization for Pakwach STIP

Parameter	Lower Limit	Upper Limit
BOD (mg/L)	155	286
TSS (mg/L)	155	330
TN (mg/L)	26	75
TP (mg/L)	6	12
NH3 (mg/L)	4	13
Coliform Bacteria	10	100
Faecal Coliforms	10	100

4.2.2 Industrial wastewater

The wastewater generated from the agro-foods sector contains high organic content leading to high BOD and COD levels. Its composition varies according to environmental factors and the knowledge of these physicochemical characteristics is essential to determine its future applications.

According to (de Oliveira Schmidt et al., 2022), the characterization of wastewater differs depending on the final product as shown in Table 4-2 below.

The final selection of the agro-foods to be accommodated within the Industrial Park was done basing on stakeholder analysis and project team analyses.

Table 4-2: Wastewater characterization for the Agro-foods sector for Pakwach STIP

Parameter	Sesame to sesame oil		Peanuts to peanut butter		Cassava Flour	
BOD (mg/L)	500	2000	500	2000	8000	12200
COD (mg/L)	1000	4000	1000	4000	15700	62000
FOG (mg/L)					0	0
TSS	100	1000	100	1000	7	5800
TDS						
TVS						
TN		20		20	360	1730
TP					40	700
Cl						
Zn					1	5
Fe					1	110
NH3						
TIC						
Colour						
Oil and Grease	50	500	50	500		
TS						
CN					12	90
Na					12	90
K					350	5,900

4.2.2.2   Fruits and Vegetables - Sorting, Washing and Packaging

The water used in fruits and vegetables storage serves various purposes, including cooling, washing, and cleaning. It is also used for humidification and atmosphere control in controlled storage environments. The characteristics of the wastewater generated in storage depend on the specific storage methods and treatments used. Typically, this wastewater can contain suspended solids, organic matter, potential chemical residues, and microorganisms, especially if cleaning agents are used. According to Lehto et al., 2014, the characterisation of wastewater from a fruit and vegetable washing, and storage industry is as shown in Table 4-3.

Table 4-3: Wastewater characterisation from washing of Fruits and Vegetables for Pakwach STIP

Parameter	Lower Limit	Upper Limit
BOD (mg/L)	400	1,700
COD (mg/L)	4,400	5,900
TSS (mg/L)	300	6,000
TN (mg/L)	68	92
TP (mg/L)	13	19
TS (mg/L)	4,600	18,900
E. coli	3.1	3.7
Coliform Bacteria	4.6	6.9
Faecal Coliforms	2.3	5.5

4.2.2.3   Fish Sector

The water used in the smoking of fish serves multiple purposes in the smoking process, including brining, steam generation, and fish cleaning. The characteristics of the wastewater generated depend on the specific smoking method, fish quality, and any additives used. Wastewater from brining is typically high in salt content, containing dissolved salts and some fish compounds. In contrast, condensation wastewater is generally cleaner but may contain trace constituents from the smoking process. Wastewater from cleaning and washing fish can contain suspended solids, organic matter, and potential microbial contaminants. Wastewater characteristics of smoked fish were determined from the studies carried out by (Abdulsalam et al., 2016) as shown in Table 4-4.

Table 4-4: Wastewater characterization for processing smoked fish for Pakwach STIP

Parameter	Mean
Turbidity (NTU)	1.38
COD (mg/l)	1,187.5
Fe (ppm)	11
TDS (ppm)	67,206
Ca (ppm)	860
Na (ppm)	22,920
Cl (mg/l)	38,000
K (ppm)	865
Mg (ppm)	2,800
Cu (ppm)	24

4.2.2.4   Solar power

In the solar power generation sector, water usage is minimal for energy production and is primarily reserved for auxiliary purposes like cleaning solar panels and employee domestic activities. The wastewater

generated from these activities is similar to that under the domestic sector wastewater, containing suspended solids, dissolved substances, and nutrients. Notably, the solar industry has made efforts to reduce water consumption and minimize its environmental impact. In contrast to other energy sources like coal or natural gas, which demand substantial water for cooling and steam generation, solar power has a relatively small water footprint and hence its wastewater characterisation is similar to that of the domestic sector as only the employees for this sector are accounted for.

4.2.2.5   Tourism

In a tourism hub, the water usage for actual tourism-related activities is typically minimal. Water is primarily utilized for essential functions such as drinking, sanitation, and domestic needs of the employees and visitors. This minimal water consumption is mainly attributed to the auxiliary and domestic aspects of the tourism industry. The wastewater generated predominantly consists of characteristics similar to domestic wastewater, reflecting the daily activities of employees and tourists. It contains typical components such as suspended solids, dissolved substances from personal care products and cleaning agents, and nutrients resulting from food preparation and personal use and hence its wastewater characterisation is similar to that of the domestic sector.

4.2.2.6   Logistics sector

In a logistics hub, water plays a multifaceted role as it is essential not only for basic domestic purposes catering to the needs of on-site employees but also for industrial activities like cleaning trucks. The wastewater generated in this setting exhibits characteristics of domestic wastewater due to the daily activities of employees, including suspended solids, dissolved substances from personal care products and cleaning agents, and nutrients from food preparation and personal use. Furthermore, the water being used for truck cleaning introduces high levels of solids into the wastewater stream, highlighting the importance of effective wastewater management in the logistics sector. Table 4-5 shows the waste characterisation for the vehicle washing under the logistics sector (Monney et al., 2020). The substantial size and nature of the wastewater produced during vehicle washing led to the decision to eliminate vehicle washing within the logistics sector.

Table 4-5: Wastewater characterization for the logistics sector for Pakwach STIP

Parameter	Lower Limit	Upper Limit
BOD (mg/L)	340	572
COD (mg/L)	990	1413
TSS (mg/L)	1260	3500
TN (mg/L)	2	5
TP (mg/L)	6	10
TDS (mg/L)	142	233

4.2.2.7   Manufacture of briquettes.

In the manufacturing process of briquettes from Agro-food organic waste, water performs multiple roles. It is used for binding and mixing the organic waste materials, aiding in the formation of briquettes, and controlling dust during processing. The wastewater generated from this manufacturing process typically exhibits characteristics that encompass suspended solids, biodegradable organics depending on the specific waste composition, nutrients like nitrogen and phosphorus. The pH, colour, and odour of the wastewater may also vary based on the nature of the organic waste used. Table 4-6 shows the characterisation of wastewater from the manufacture of briquettes (Rajagopal et al., 2013)

Table 4-6: Wastewater characterization for the manufacture of briquettes for Pakwach STIP

Parameter	Lower Limit	Upper Limit
BOD (mg/L)	600	4000

Parameter	Lower Limit	Upper Limit
COD (mg/L)	1000	8000
TN (mg/L)	50	50
TN (mg/L)	3	3

4.3 Wastewater estimation

Wastewater quantities were estimated considering that at the start of the industry, all sectors will not be occupied to full capacity. The occupancy levels considered are 35%, 75% and 100% of the full occupancy for all the sectors. The lower, mean, and upper limit values of characterisation of wastewater from each sector at different percentages of occupancy are shown in the proceeding section. This characterisation has been based on the different sectors in the industrial park.

4.3.1 Agro-food sector

Table 4-7 below shows the wastewater quantification for the various sectors in agro-foods sector.

Table 4-7: Wastewater Quantification for the Agro-foods sector

Sector	Wastewater Volume (m³)	Percentage Development of Pakwach STIP		
		35%	75%	100%
Cassava to flour	Minimum Wastewater Volume	234.1	501.6	668.8
	Mean Wastewater Volume	296.3	634.8	846.5
	Maximum Wastewater Volume	365.8	783.8	1045.0
Sesame to sesame oil	Minimum Wastewater Volume	0.1	0.2	0.2
	Mean Wastewater Volume	0.2	0.5	0.6
	Maximum Wastewater Volume	0.4	0.8	1.0
Peanut to peanut butter	Minimum Wastewater Volume	0.0	0.1	0.1
	Mean Wastewater Volume	0.1	0.2	0.3
	Maximum Wastewater Volume	0.1	0.3	0.4
Total	Minimum Wastewater Volume	234.2	501.8	669.1
	Mean Wastewater Volume	296.6	635.5	847.3
	Maximum Wastewater Volume	366.2	784.8	1046.4
Peak Flow	Minimum Wastewater Volume	351.3	752.7	1003.7
	Mean Wastewater Volume	444.8	953.2	1271.0
	Maximum Wastewater Volume	549.4	1177.2	1569.6

4.3.2 Fruits & Vegetable storage

Table 4-8 below shows the wastewater quantification for fruits & vegetable storage

Table 4-8: Wastewater Quantification for the fruits &vegetable sector

Sector	Wastewater Volume (m³)	Percentage Development of Pakwach STIP		
		35%	75%	100%
Fruits & Vegetables	Minimum Wastewater Volume	3.19	6.84	9.12

	Mean Wastewater Volume	8.92	19.10	25.47
	Maximum Wastewater Volume	14.64	31.37	41.82
Peak Flow	Minimum Wastewater Volume	4.8	10.3	13.7
	Mean Wastewater Volume	13.4	28.7	38.2
	Maximum Wastewater Volume	22.0	47.0	62.7

4.3.3 Fish sector

Table 4-9 below shows the wastewater quantification for the fish sector for smoked fish.

Table 4-9: Wastewater quantification for the fish sector

Sector	Wastewater Volume (m3)	Percentage Development of Pakwach STIP		
		35%	**75%**	**100%**
Fish	Minimum Wastewater Volume	1.69	3.63	4.84
	Mean Wastewater Volume	2.54	5.45	7.26
	Maximum Wastewater Volume	3.39	7.26	9.68
Peak Flow	**Minimum Wastewater Volume**	2.5	5.4	7.3
	Mean Wastewater Volume	3.8	8.2	10.9
	Maximum Wastewater Volume	5.1	10.9	14.5

4.3.4 Employees Sector

The employee sector quantifications included all the employees working within the industrial park, as well as the specific sectors of Solar energy, Coffee and Logistics, where wastewater generation is exclusively associated with employee activities.

Table 4-10 below shows the wastewater quantification for the employees sector.

Table 4-10: for the Employees sector

Sector	Wastewater Volume (m^3)	Percentage Development of Pakwach STIP		
		35%	**75%**	**100%**
Employees	Minimum Wastewater Volume	13.48	28.88	38.50
	Mean Wastewater Volume	21.66	46.41	61.88
	Maximum Wastewater Volume	30.80	66.00	88.00
Peak Flow	**Minimum Wastewater Volume**	20.2	43.3	57.8
	Mean Wastewater Volume	32.5	69.6	92.8
	Maximum Wastewater Volume	46.2	99.0	132.0

4.3.4.1 Tourism sector

Table 4-11 below shows the wastewater quantification for the tourism sector specifically the volumes generated from the hotel that will house the visitors. It should be noted that the wastewater for the employees was accounted for under the employees' sector.

Table 4-11: for the Tourism sector

Sector	Wastewater Volume (m^3)	Percentage Development of Pakwach STIP		
		35%	**75%**	**100%**
Tourism	Minimum Wastewater Volume	3.06	6.56	8.75
	Mean Wastewater Volume	8.20	17.58	23.44

	Maximum Wastewater Volume	14.00	30.00	40.00
Peak Flow	**Minimum Wastewater Volume**	4.6	9.8	13.1
	Mean Wastewater Volume	12.3	26.4	35.2
	Maximum Wastewater Volume	21.0	45.0	60.0

The summary of the wastewater estimation for the Industrial Park is shown in Table **4-12**.

Table 4-12**: Wastewater estimation for sectors within the Park**

Sector	Wastewater Volume (m³)	Percentage Development of Pakwach STIP		
		35%	75%	100%
Cassava to flour	Minimum Wastewater Volume	234.08	501.60	668.80
	Mean Wastewater Volume	296.26	634.84	846.45
	Maximum Wastewater Volume	365.75	783.75	1045.00
Sesame to sesame oil	Minimum Wastewater Volume	0.07	0.15	0.20
	Mean Wastewater Volume	0.21	0.45	0.60
	Maximum Wastewater Volume	0.35	0.75	1.00
Peanut to peanut butter	Minimum Wastewater Volume	0.04	0.08	0.10
	Mean Wastewater Volume	0.09	0.19	0.25
	Maximum Wastewater Volume	0.14	0.30	0.40
Fruits & Vegetables	Minimum Wastewater Volume	3.19	6.84	9.12
	Mean Wastewater Volume	8.92	19.10	25.47
	Maximum Wastewater Volume	14.64	31.37	41.82
Tourism	Minimum Wastewater Volume	3.06	6.56	8.75
	Mean Wastewater Volume	8.20	17.58	23.44
	Maximum Wastewater Volume	14.00	30.00	40.00
Fish	Minimum Wastewater Volume	1.69	3.63	4.84
	Mean Wastewater Volume	2.54	5.45	7.26
	Maximum Wastewater Volume	3.39	7.26	9.68
Briquettes	Minimum Wastewater Volume	2.94	6.30	8.40
	Mean Wastewater Volume	7.35	15.75	21.00
	Maximum Wastewater Volume	11.76	25.20	33.60
Employees	Minimum Wastewater Volume	13.5	28.9	38.5
	Mean Wastewater Volume	21.7	46.4	61.9
	Maximum Wastewater Volume	30.8	66.0	88.0
Total	**Minimum Wastewater Volume**	**258.6**	**554.0**	**738.7**
	Mean Wastewater Volume	**345.2**	**739.8**	**986.3**
	Maximum Wastewater Volume	**440.8**	**944.6**	**1259.5**
Peak Flow	**Minimum Wastewater Volume**	**387.8**	**831.1**	**1,108.1**
	Mean Wastewater Volume	**517.8**	**1,109.6**	**1,479.5**
	Maximum Wastewater Volume	**661.2**	**1,416.9**	**1,889.3**

4.4   Wastewater management options

The volume of wastewater to be treated ranges from 661.2 m³/d to 1,889.3 m³/d.

There is no existing wastewater treatment plant in Pakwach district and the nearest faecal sludge treatment plant is located in Arua which is about 100 km away.

The infrastructure required to deliver wastewater to the facility in Arua comprises a collection sump, lifting station, sewer pumping mains, a collection chamber and sewer gravity mains. The distance from the industrial park to Arua is over 100km, hence this option is not feasible due to the high capital investment costs and environmental hazards.

. The following wastewater management options will be explored:

    i.   Construction of pretreatment wastewater treatment plants at each industry
    ii.   Construction of waste stabilization ponds
    iii.   Construction of a wastewater treatment plant

4.4.1.1 Agro-Foods Sector

The Agro-Foods sector in Pakwach encompasses various subsectors like cassava, sesame, and peanut processing. While these subsectors produce organic-rich wastewater, there are both pros and cons associated with implementing pre-treatment units.

Cassava processing, for instance, results in generation of pollutants such as sodium, potassium and cyanide. The treatment of these pollutants requires ion exchange and monitoring of pH of the wastewater. Consequently, pre-treatment of the wastewater generated from this sector is required.

The sesame sector generates high quantities of oil and grease that require enzymatic digestion. Pre-treatment of the wastewater generated from this sector is required in order to lower the concentration of the oils and fats.

Peanut processing generates high quantities of oil and grease that require enzymatic digestion. Pre-treatment of the wastewater generated from this sector is required in order to lower the concentration of the oils and fats.

The wastewater generated from the sesame and peanut subsectors have similar characteristics of oil and grease; these subsectors can share pre-treatment units where enzymatic digestion can be done to breakdown the fats.

4.4.1.2 Fish Processing Sector (Smoked Fish)

The fish processing sector in Packwach, specifically dealing with smoked fish production, generates organic-rich wastewater. In addition, the wastewater contains a high concentration of inorganic compounds such as potassium and sodium ions. The high likelihood of implementing pre-treatment units, such as small-scale waste stabilization ponds, is attributed to the suitability of these units for removal of the inorganic compounds from the wastewater. However, managing fish waste and controlling associated odors may pose challenges.

4.4.1.3 Fruits and Vegetables Storage Sector

Wastewater generation in the fruits and vegetables storage sector is moderate, offering a straightforward approach to treatment. The wastewater generated from this sector does not necessitate pre-treatment; the wastewater can be screened to remove large particles and directed to a sedimentation tank where primary treatment can commence.

4.4.1.4 Manufacture of Briquettes Sector

The manufacture of briquettes sector presents substantial potential for reusing treated water within the production process, offering higher revenue prospects. The likelihood of pre-treatment unit implementation is low because the wastewater does not contain toxic compounds that have to be treated prior to the primary treatment.

In the employees, and domestic sector, the amount and quality of wastewater generated is low. Consequently, the wastewater should undergo the primary processes of screening and grit removal before being directed to the facilities to undergo primary, secondary and tertiary treatment.

4.4.2   Construction of wastewater management facilities at each of the sectors

This wastewater management option would address challenges associated with treatment of some pollutants and variation in the quantity of wastewater produced by the sectors.

The processing of cassava results in the pollutants such as sodium, potassium and cyanide. The treatment of these pollutants requires ion exchange and monitoring of pH of the wastewater. Hence the treatment of the wastewater containing the aforementioned pollutants within the industries would optimise the use of reagents and provide efficient monitoring of the wastewater influent and effluent.

In addition, the processing of smoked fish results in pollutants such as calcium, magnesium and copper ions, whose treatment would require chemical precipitation. The process of chemical precipitation affects the pH of the wastewater and thus treatment of the wastewater on-site would optimise the use of reagents and provide efficient monitoring of the wastewater influent and effluent.

4.4.3   Construction of waste stabilization ponds

Waste stabilization ponds decrease the organic content and eliminate pathogens from the wastewater. Waste stabilization ponds utilize natural treatment mechanisms that require time due to relatively slow removal rates. As a result, they necessitate larger surface areas.

Waste Stabilization Ponds have low operation and maintenance costs but require large area. The minimum required acreage for the construction of WSP is 7 acres, based on the minimum volume of wastewater. However, the WSP are not effective in the treatment of inorganic pollutants such as Zinc, Chlorides, Sodium, Potassium, Cyanide, etc. The treatment of the wastewater would require additional units for ion exchange, chemical precipitation and pH control.

The establishment of Waste Stabilization Ponds (WSP) within the 500-acre industrial park in Pakwach presents a multifaceted challenge. Although the park's considerable size can accommodate the 7 acres required for WSP construction, addressing the inefficiency of WSPs in treating inorganic pollutants, such as zinc and cyanide, necessitates additional units for ion exchange, chemical precipitation, and pH control. The inorganic pollutants would have to be treated before channelling of the wastewater to the WSPs.
Furthermore, the environmental impact, especially on the adjacent ecosystem and biodiversity, requires rigorous evaluation and calls for an Environmental Impact Assessment (EIA) to prevent adverse consequences. To optimize wastewater management, a comprehensive approach integrating various treatment methods is recommended, with WSPs handling organic pollutants, pre-treatment units addressing inorganic pollutants, and potential inclusion of eco-friendly practices like constructed wetlands. The ultimate objective is to establish a sustainable, cost-effective, and environmentally responsible wastewater treatment solution within the park's confines.

4.4.4   Construction of a wastewater treatment plant

The wastewater treatment plant comprises of the following treatment processes:

i.   Pre-treatment. This comprises of mechanical and biological pretreatment processes such as screening, oil and grease separation, enzymatic digestion and primary sedimentation

ii. Primary treatment: This comprises of processes such as biological and/or chemical treatment processes such as secondary sedimentation, anaerobic digestion, chemical oxidation, chemical precipitation and ion exchange

iii. Secondary treatment: This comprises of biological and/or chemical treatment processes such as filtration, aerobic digestion and pH control

iv. Tertiary treatment: This comprises of polishing treatment such as final treatment in a swamp or constructed wetland. Activated carbon filtration is also considered under tertiary treatment.

The treatment processes result in accumulation of sludge. The sludge is dried and disposed of in a landfill. The sludge containing hazardous materials such as heavy metals must be appropriately handled and disposed of in the landfill.

4.4.5 Selected wastewater management processes

The proposed wastewater management strategy is detailed below:

i. Cassava sector should have pre-treatment processes comprising of screening, primary sedimentation and ion exchange (alkaline chlorination). The wastewater will undergo sedimentation before discharge into the sewer lines. The cassava sector has a maximum wastewater volume of 1,045m^3/day.

ii. Fish smoking sector should have pre-treatment processes comprising of screening, primary sedimentation and chemical precipitation. The wastewater will undergo sedimentation before discharge into the sewer lines. The fish smoking sector has a maximum wastewater volume of 9.68m^3/day.

iii. The wastewater originating from all sectors will be transported via gravity sewer lines to the wastewater treatment facility, with the exception of the wastewater from the employee sector. In the case of the employee sector, on-site treatment, such as septic tanks, is preferred due to the presence of fecal coliforms.

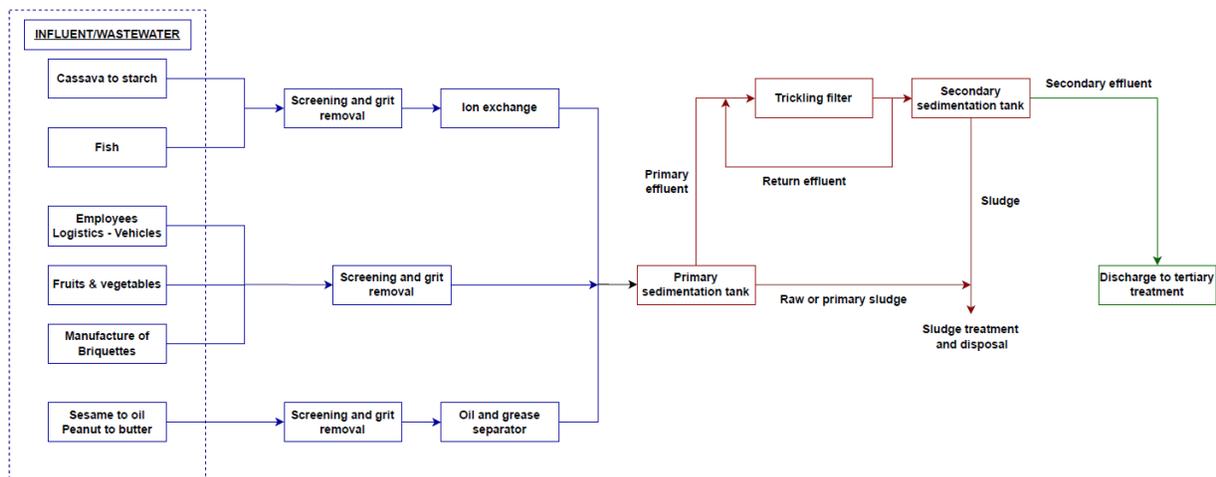The wastewater treatment structures at the treatment plant are listed below:

Figure 4-1: Treatment processes at Pakwach STIP

- Screen and Grit Chamber. The wastewater will flow through a screen and grit trap to remove large solid waste particles.

- Primary Sedimentation Tank. The wastewater will undergo ion exchange in this chamber under chemical oxidation. This will aid in elimination of inorganic pollutants such as Iron and other Total Dissolved Solids. Under routine operation and maintenance, the chamber will be de-sludged, and the sludge dried before disposal in the landfill.
- Trickling Filters: The wastewater will undergo biological treatment where the organic matter in the wastewater will be broken down.
- Secondary Sedimentation Tank. The wastewater will undergo further clarification where suspended solids will settle to form sludge. The pH of the wastewater must be monitored in this chamber and pH correction carried out as required.
- Constructed Wetlands. The constructed wetlands will contain granulated activated carbon. The wastewater will be discharged into the wetlands for polishing treatment. The activated carbon will enable further treatment of residual inorganic pollutants such as Potassium, Chlorides, Zinc and Iron.

There will be minimal power requirements at the wastewater treatment plant for the operation of pumps and associated electrical and mechanical equipment. The treatment plant will be connected to the national grid and standby power provided by a solar power system

4.4.5.1   Agro-Foods Sector

Pretreatment for the Agro-Foods sector will begin at the screen and grit chamber where large solid waste particles are removed from the wastewater. The primary sedimentation tank follows, incorporating ion exchange and chemical oxidation to eliminate inorganic pollutants like iron and total dissolved solids. Routine maintenance will involve de-sludging this chamber, with subsequent drying and disposal of the sludge in a landfill. The treated water proceeds to trickling filters for biological treatment, breaking down organic matter. The secondary sedimentation tank allows for further clarification, settling suspended solids as the pH of the wastewater is monitored and adjusted as needed. The final treatment stage occurs in constructed wetlands containing granulated activated carbon, which polishes the water and removes residual inorganic pollutants.

4.4.5.2   Domestic/Employees Sector

Pretreatment for the Domestic/Employees sector, typically characterized by smaller wastewater volumes, involves screening and grit removal from wastewater. This wastewater is then directed to a collection sump where it is temporarily stored before being transported to the sedimentation tank. The wastewater then undergoes biological treatment in trickling filters after which it is directed to a secondary sedimentation tank and afterwards to tertiary treatment thereafter it is released into the environment.

4.4.5.3   Smoked Fish Processing Sector

For the Smoked Fish Processing sector, wastewater undergoes preliminary treatment in a screen and grit chamber to remove large solids. The primary sedimentation tank performs ion exchange and chemical oxidation to address inorganic pollutants, followed by biological treatment in trickling filters. The secondary sedimentation tank clarifies the water. Finally, the constructed wetlands with granulated activated carbon polish the effluent.

4.4.5.4   Fruits and Vegetables Storage Sector

In the Fruits and Vegetables Storage sector, wastewater treatment commences with screening and grit trapping in order to remove large solid particles from the wastewater. This wastewater is directed to a sedimentation tank where it is allowed to settle and then transported for primary, secondary and tertiary treatment.

Pretreatment in the Manufacture of Briquettes sector involves a screen and grit chamber for initial solids removal. The primary sedimentation tank employs ion exchange and chemical oxidation to reduce inorganic pollutants. Biological treatment in trickling filters addresses organic matter. The secondary sedimentation tank further clarifies the water, with pH adjustments as necessary. The process concludes with the use of constructed wetlands containing granulated activated carbon.

In terms of tertiary treatment providers, their management capacity is an essential aspect to ensure the effectiveness of the entire wastewater management system. Local authorities, environmental agencies, or specialized private companies can take on the role of tertiary treatment providers. These entities should possess expertise in advanced treatment technologies, environmental compliance, and robust management systems. Collaborative agreements with such providers will help in enhancing the quality of the treated wastewater, making it suitable for safe discharge or potential reuse in various sectors. Coordination and partnerships between the industrial park's management and these providers are crucial for a sustainable and environmentally responsible wastewater management solution.

The industrial park is not yet developed but it has been categorized into different levels of development. The estimated capacity of the wastewater treatment plant at 100% development ranges between a minimum flow of 661.2 m^3/d and a maximum flow of 1,889.3 m^3/d. The Consultant proposes that the construction of the wastewater treatment plant is phased to provide for two parallel treatment lines to allow for the growth in the rate of wastewater production.

A wastewater treatment plant of capacity 1,000 m^3/d can be constructed under the first phase. In addition, the wastewater treatment plant should have a provision for the disposal of faecal sludge. This will reduce the transportation costs incurred in the community for the disposal of the faecal sludge and discourage indiscriminate disposal in swamps and wetlands. The design of the wastewater management facilities will be further refined under the feasibility studies and detailed design. The consultant advises to explore potential public-private partnerships for collection and transportation of faecal sludge to the centralized waste water treatment plants. The established PPPs could work for within the industrial park and provide the same services to residents within Pakwach town council.

4.4.6   Operation and maintenance

NWSC is mandated to provide water supply and sewerage services in urban centres. NWSC has the technical capacity and experience to operate the wastewater treatment plant. The Consultant proposes that the operation and maintenance of the plant is undertaken by NWSC.

Based on the proposal to have pre-treatment facilities in some identified sectors, the Consultant recommends that the operation of these facilities is carried out by NWSC. This will enable technical support for the chemical and biological pre-treatment processes and monitoring and control of the wastewater quality received at the treatment plant.

The role of the industries in the operation and maintenance of the wastewater management facilities are:
- Payment of utilities bills that will include a surcharge cost towards payment for sewerage services
- Regular cleaning and maintenance of reservoirs and tanks located within Pakwach STIP.
- Separation of solid waste from wastewater during operations. This will prevent clogging of the manholes and screens.
- Timely communication to NWSC on changes to cleaning agents, chemical additives, etc that affect the quality and quantity of the wastewater

The pump station will be connected to the national grid. A standby power source is required and this can take the form of solar power system. Solar power can be harnessed by mounting solar panels on top of the warehouse roofing sheets Approximately 100 square feet of shade-free rooftop space can provide 4 kWh of solar power per day, on average[4].The power requirements will be determined during detailed engineering design.

4.4.7   Conclusion on Wastewater Management Options

The proposed wastewater management at the Pakwach industrial park is the construction of waste stabilization ponds. The wastewater delivered to the ponds must under-go pre-treatment for the inorganic pollutants identified in the preceding sections.

Treating wastewater to meet effluent will prevent the discharge of harmful pollutants into water bodies. The utilization of waste stabilization ponds for wastewater treatment represents an environmentally friendly approach, leveraging natural processes for the biological decomposition of organic matter without relying on energy-intensive mechanical methods. The production of methane in anaerobic ponds will provide an opportunity for energy generation. Harnessing and using methane as an energy source will decrease dependence on traditional fossil fuels.

The installation of a dome over the anaerobic pond, with an extraction efficiency of approximately 85% (Paredes et al., 2015), will enhance the collection of methane of up to $23.6 \times 10^6 \text{m}^3$, minimizing its release into the atmosphere. By capturing methane from the anaerobic pond, the project will mitigate the emission of this potent greenhouse gas, which has a significantly higher global warming potential than carbon dioxide (EPA). The adoption of methane as an energy source will not only provides an alternative to fossil fuels but also directly contribute to reducing overall greenhouse gas emissions associated with energy production. The extent of the reduction in greenhouse gas emissions depends on factors such as the efficiency of methane capture and utilization.

Treating wastewater to effluent standards will ensure that pollutants harmful to water quality are removed before discharge. This will protect the neighboring ecosystem from contamination. The waste stabilization ponds significantly reduce the biochemical oxygen demand (BOD) and chemical oxygen demand (COD) of the wastewater. This means that when the treated water is discharged, it will have a lower impact on the receiving water bodies in terms of organic pollutants.

The percentage reduction in water pollution is associated with the efficiency of the waste stabilization ponds in removing BOD and COD. The reduction in these parameters indicates a lower level of organic pollutants being discharged, contributing to the protection of the neighboring ecosystem. For temperatures <10°C BOD removal is estimated at 40% with a loading rate of 100g/m^3/d. For temperatures >25°C which are the optimal temperatures, BOD removal is estimated at 70% with a loading rate of 350g/m^3/d(Fernando & Quiroga, 2004).

The precise expected decreases in both greenhouse gas emissions and water pollution cannot currently be determined. This would necessitate a more in-depth study, evaluating factors such as wastewater quality, loading rates, and temperatures.

The local community does not have access to wastewater management facilities. It is proposed that the wastewater treatment plant constructed at the park should have a provision for the disposal of faecal sludge by cesspool emptiers.

The detailed design of the wastewater treatment plant will require review of quantification of wastewater flows for the industrial park and faecal sludge generation rates for the local community, site surveys, Environment and Social Impact Assessment.

---

[4]https://www.solarmango.com/sector/warehouses.

5. Solid waste management

Different sectors in the Pakwach Industrial Park generate various quantities and characteristics of solid waste, these can be treated and handled in quite a number of ways some of which are detailed in the following subsections below.

5.1   Solid waste characterization

Solid waste generated within the Pakwach Science and Technology Park is composed of organic materials, plastics, textiles, metals. This waste emanates from various sectors such as Fish processing, fruits, cassava, manufacture of briquettes, peanut butter making, tourism, Sesame oil, solar power and logistics hub sector.

Table 5-1: Solid waste characteristics and storage/disposal for the different sectors

Sector	Solid waste	Storage/ Disposal
Cassava		
Flour	Peelings, Fibrous residues	Biochar/Animal feeds/composting
Sesame		
Sesame oil	Shells and skins, meal	Animal feeds/Briquetting/Composting
Fish		
Smoked	Viscera, heads, scales	Animal feeds
Logistics hub		
Logistics hub	Domestic waste; organics, paper, plastics	Biogas feedstock, Recycling
Fruits		
Washing & Packaging	Organic chippings	Composting
	Dust and other impurities	Landfill
	Plastics from packaging	Recycling
Solar Power		
Solar Power	Domestic waste; organics, paper, plastics	Biogas feedstock, Recycling
Manufacture of Briquettes		
Briquettes	Domestic waste; organics, paper, plastics	Biogas feedstock, Recycling
Peanut Processing		
Peanut Butter	Shells, skins, meals	Animal feeds/Briquetting/composting
Tourism		
Tourism	Domestic waste; organics, paper, plastics	Biogas feedstock, Recycling
Coffee Processing		
Drying	Coffee cherry husk; dried skin, pulp, parchment	Composting

5.1.1 Volume of solid waste generated

The daily solid waste estimated to be generated without valorization in kilograms (kg) in the STIP is summarized in Table 5-2.

Table 5-2: Daily Solid waste generation (kg) and characterization at the Pakwach Science and Technology Park

Solid Waste Characterization	Level of Development		
	35%	75%	100%
Organic waste	8,717	18,788	25,078
Dust and other impurities	70	150	200
Plastics	79	169	225
Metal	3	6	8
Paper and cardboards	63	135	180
Textile	3	6	8
Others	15	32	42
Totals	**8,949**	**19,285**	**25,740**

5.1.2 Solid waste generated by each sector

The estimated daily solid waste generation without valorization in kg is shown in the Table 5-3 below

Table 5-3: Table showing estimated daily solid waste Solid waste generation in kg in the IBP

Sector	Solid waste Characteristics	Level of Development		
		35%	75%	100%
Cassava				
Flour	Organic waste	7,700	16,500	22,000
	Dust and other impurities	0	0	0
	Plastics	0	0	0
	Metal	0	0	0
	Paper and cardboards	0	0	0
	Textile	0	0	0
	Others	0	0	0
Sesame				
Sesame Oil	Organic waste	280	600	800
	Dust and other impurities	0	0	0
	Plastics	0	0	0
	Metal	0	0	0
	Paper and cardboards	0	0	0
	Textile	0	0	0
	Others	0	0	0
Fruits & Vegetables				

Sector	Solid waste Characteristics	Level of Development		
		35%	75%	100%
Fruit & Vegetable wash	Organic waste	28	60	80
	Dust and other impurities	70	150	200
	Plastics	42	90	120
	Metal	0	0	0
	Paper and cardboards	0	0	0
	Textile	0	0	0
	Others	0	0	0
Fish				
Smoked Fish	Organic waste	334	717	955
	Dust and other impurities	0	0	0
	Plastics	0	0	0
	Metal	0	0	0
	Paper and cardboards	0	0	0
	Textile	0	0	0
	Others	12	26	35
Peanut				
Peanut Butter	Organic waste	80	280	400
	Dust and other impurities	0	0	0
	Plastics	0	0	0
	Metal	0	0	0
	Paper and cardboards	0	0	0
	Textile	0	0	0
	Others	0	0	0
Coffee				
Drying	Organic waste	61	131	175
	Dust and other impurities	0	0	0
	Plastics	0	0	0
	Metal	0	0	0
	Paper and cardboards	0	0	0
	Textile	0	0	0
	Others	0	0	0
Hotel & Tourism				
Hotel &Tourism	Organic waste	32	68	90
	Dust and other impurities	0	0	0
	Plastics	8	17	23
	Metal	3	6	8
	Paper and cardboards	5	11	15
	Textile	3	6	8
	Others	3	6	8

5.1.3 Domestic solid waste generated in the Pakwach STIP

The domestic solid waste in the STIP is majorly generated by the workers, visitors and other people from the different sectors of the STIP. The estimated number of employees in the STIP is about 1100 people. The table below shows the daily estimated quantities of solid waste generation per 1100 people.

Table 5-4: Domestic solid waste generation

Characterization of solid waste	Solid Waste (kg)
Organic waste	577.5
Plastics	82.5
Paper and cardboards	165.0

5.2 Components of solid waste management

5.2.1 Generation

The commencement of the waste management process begins with solid waste generation. This phase involves the production of solid waste materials via diverse activities within the industrial park. These activities encompass the disposal of plastics, the discarding of leaves and stems, agro-grain residues including husks, skins, pulps. The volume and composition of the waste generated are intricately tied to the production methods and patterns in use.

5.2.2 Storage

The storage of solid waste at the STIP will involve the use of storage facilities such as waste bins, containers, cold storage, communal depots, or designated areas for larger waste items preventing littering. Table 5-5 shows the solid waste cold storage requirements for Pakwach Industrial Park.

Table 5-5: Cold storage requirements.

Parameter	Daily	Weekly	Monthly
Waste from Fish sector (kg)	990.0	6,930.0	29,700.0
Density of the waste (kg/m3)	1,000.0	1,000.0	1,000.0
Volume of waste (m3)	1.0	6.9	29.7

5.2.3 Collection

Various collection methods will be employed at the industrial park and these include the following;
- **On-Site Collection:** This will involve collection of waste directly into on-site bins or containers provided around the industrial park. Compactors may also be used to reduce waste volume.
- **Centralized Collection:** Pakwach town has only one garbage collection truck for delivering waste to Atara dumpsite which cannot meet the demand of the STIP and the local community. Private waste collection services will therefore be employed to pick up waste from centralized points within the industrial park. Private waste collection services are assumed to be more cost effective as opposed to a service managed by the park due to costs of hiring trucks, workers and other associated transportation costs.
- **Waste Collection Schedule**: Solid waste will be collected from the STIP at least twice a week.

5.2.4   Transportation

Once waste materials have been gathered, they must be conveyed to their ultimate destinations, which may encompass recycling facilities, landfill sites, or dedicated treatment centers. The solid waste in Pakwach is currently conveyed to the Atara dumpsite, occupying a 6-acre tract of land situated approximately 2.4km away from the STIP. It is proposed that all the solid waste that is not going to be valorized be transported to Atara landfill where it will undergo sorting, composting or landfilling. Figure 5-1 below shows the location of Pakwach STIPSTIP and Atara landfill site.
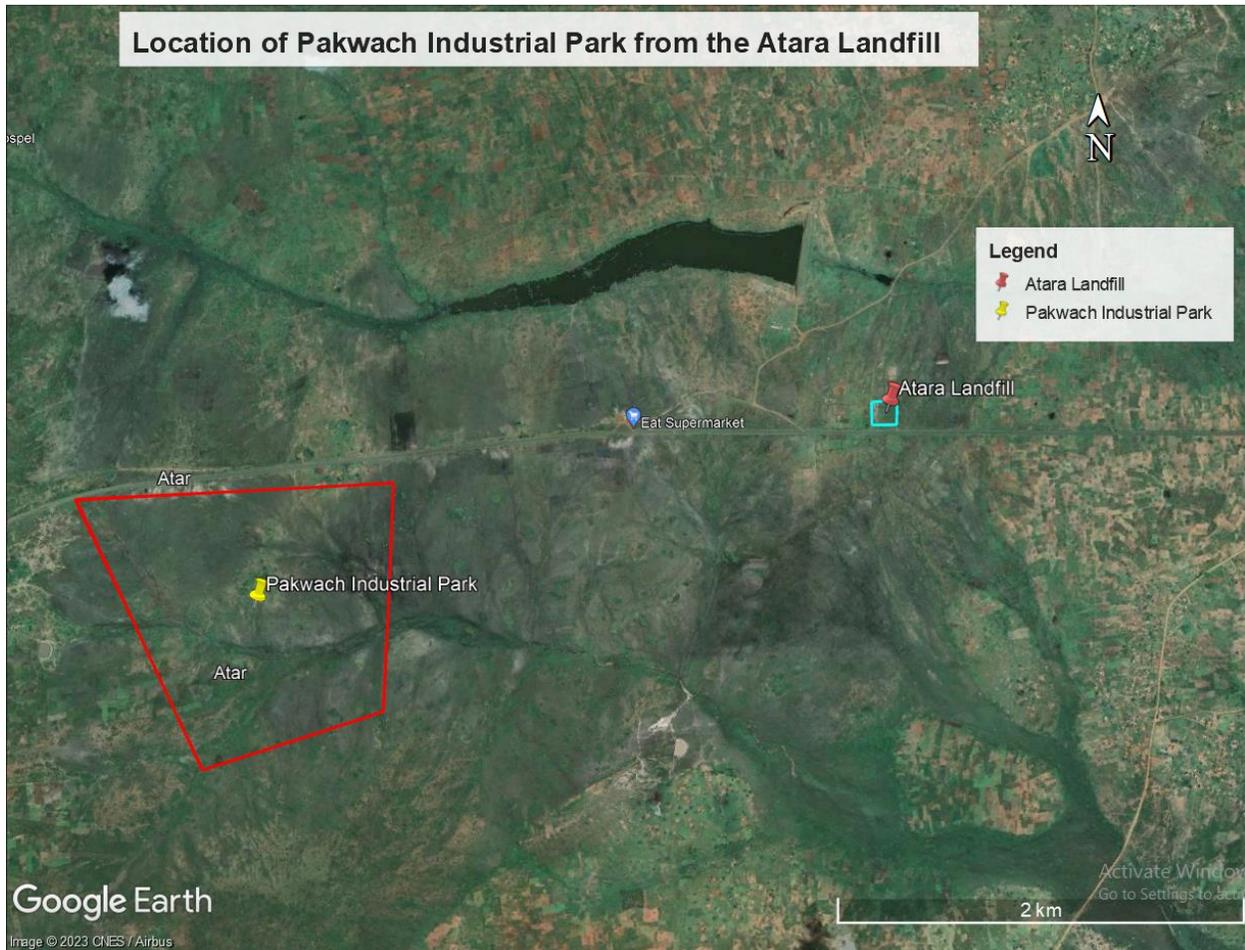

Figure 5-1: Location of Pakwach Science and Technology Park from Atara landfill

5.2.5   Disposal

The concluding phase of solid waste management entails the careful and secure handling of waste to reduce potential environmental and health hazards.

5.3   Waste Valorization

Waste valorization is the process of converting waste materials into more useful products including chemicals, materials, and fuels (Arancon *et al.*, 2013). Valorization will utilize about 12.5 tons per day of the solid waste generated at the STIP. Some of the waste valorization techniques proposed at the Pakwach STIPSTIP include the following;

- Manufacture of briquettes utilizing the organic waste from the different sectors in the STIP especially the agricultural sector. Briquettes could be used as a substitute for wood and charcoal during cooking. The process is estimated to produce about 16,800kg of briquettes per day.
- Recycling of plastics and paper generated within the STIP. These papers and plastics will be collected by trained collection agents from Atara landfill to be taken to the various recycling companies. New products will be generated from these types of waste.
- Manufacture of animal feeds. Solid waste from sectors like smoked fish or agro-based industries can be utilized for the manufacture of animal feeds. The fish viscera, fish heads, cassava fiber will be fed into a feed mill where they will be processed into pellets to be used as animal feeds.
- Manufacture of biochar: cassava peels from the processing of cassava to starch will be valorized by pyrolysis to produce biochar which is a great product to improve on the soil fertility and to limit the use of chemical fertilizers.

5.4   Solid Waste Management Techniques

Currently, all the solid waste from Pakwach town is transported and managed from the Atara landfill site which is managed by the Pakwach town council. The landfill site is about 6 acres wide and located approximately 2.4km from the planned site of the industrial park. The solid waste collected from Pakwach town is majorly characterized of plastics and organic waste. No sorting, separation, composting, recycling or reusing of the solid waste is practiced at the dumpsite. There are discussions to move this dumpsite to a new location and these are awaiting confirmation. Figure 5-2 shows the current state of Atara landfill site.

A Public Private Partnership (PPP) for the upgrade of the Atara landfill site has been proposed and the layout of this is shown in Figure 5-2. The landfill will now include an office, sorting area to allow for removal of recyclable and reusable materials, a composting area for generation of manure, leachate collection systems to reduce the impact of the landfill on the environment. Also, a weigh bridge will be put in place next to the gate to determine the amount of solid waste entering the landfill for invoicing and other management purposes.

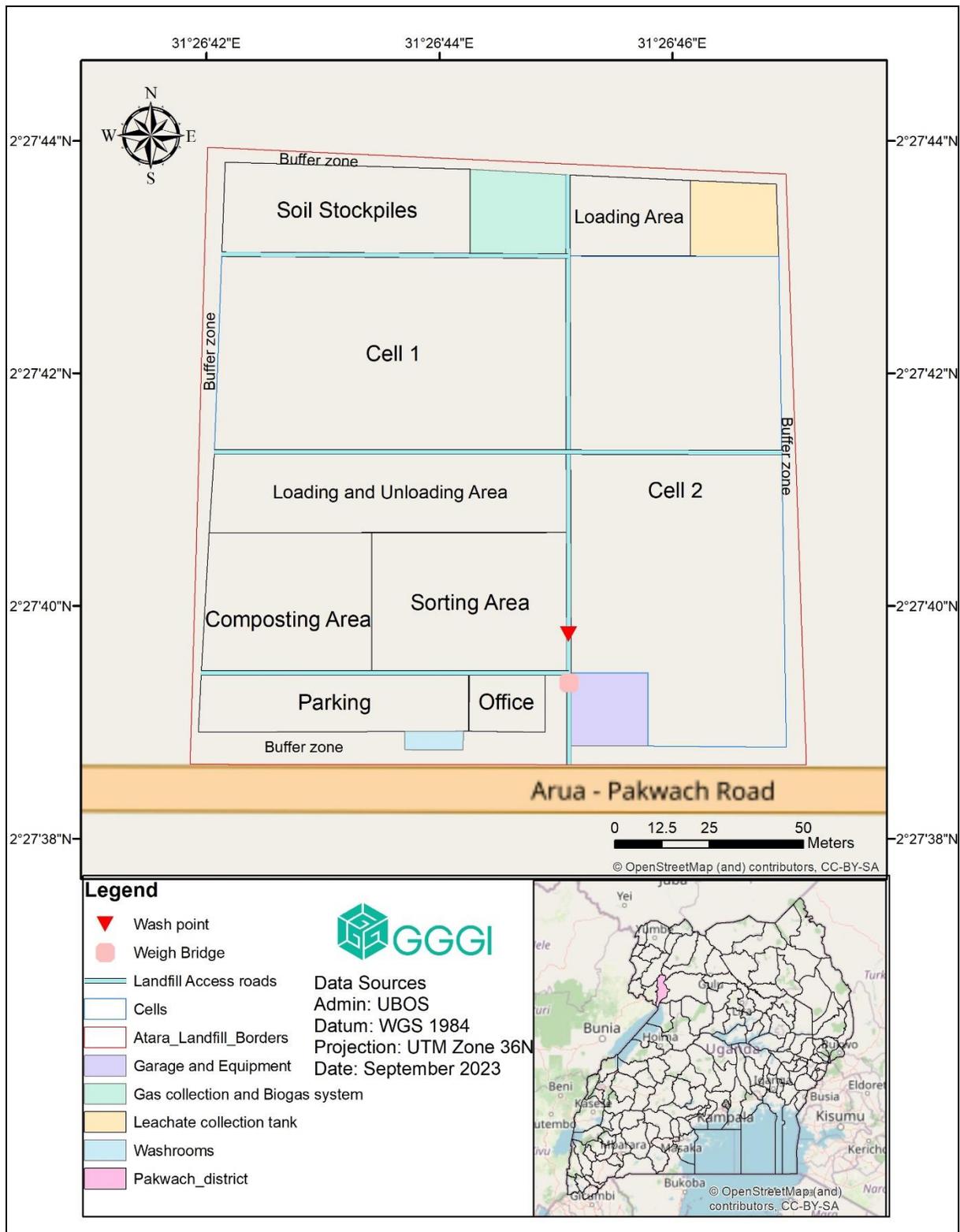**Figure 5-2: Current state of Atara landfill site**

Figure 5-3: Proposed site layout of the Atara landfill

The detailed description and analysis of the different solid waste management options at the STIP has been discussed below and these options include composting, landfilling, incineration and anaerobic digestion. The criteria shown in Table 5-6 was followed for choosing the best option for management of solid waste at the Pakwach Science and Technology Park. The feasibility of each option is discussed below;

- **Landfilling:** The Atara landfill located about 2.4km from the proposed site is deemed to be a more feasible option as it is easily accessible due to its close proximity to the park, the area available (6 acres) is sufficient to take in all the solid waste from the STIP for about nineteen (19) years (Figure 5-3) with valorisation. However, the site is yet to be fully developed and there are future plans for changing its location but are yet to be confirmed.
- **Incineration:** There is no existing plant for incineration around the proposed site for the STIP. Purchase of a new plant will be required if this option is to be taken on. However, most of the solid waste generated at the STIP will be majorly organic waste (97%), incineration of this waste would lead to high fuel consumptions and high gas emissions during this process. This option has therefore been considered unfeasible based on the above arguments.
- **Composting:** the composting process to produce manure has been proposed to take place at the Atara landfill when it has been fully developed (Figure 5-3). Currently no composting is done at this site. The windrow system has been proposed to be used and this will be done under a shed. The volumes required for this process will be met as other organic waste coming in from the city will be utilized for this process.
- **Anaerobic digestion:** Anaerobic digesters are an energy recovery mechanism for making biogas. These will be fed with the organic waste that will not be valorised (majorly domestic food wastes). However, biogas has a low energy density and therefore it will require large volume of space to transport it to areas where it is required. In addition, biogas production requires organic substrates with high water contents, low structure and low lignin (Körner et al., 2006). Wastes like cassava peels, shells from agro-foods have high lignin and would not be suitable for the anaerobic digester as they would require prior treatment before feeding. Domestic food wastes may also be in scattered locations around the STIP.

Table 5-6: Multi-Criteria analysis for identification of suitable solid waste management option

Criteria	Composting	Landfilling	Incineration	Anaerobic digestion
Capital cost	+	+	x	x
O & M costs	+	+	x	++
Material and energy recovery	x	+	×	++
Environmental impact	+	×	×	+
Acceptance	x	×	+	++
Local Labour Experience	+	++	+	+
Feasibility	++	++	×	+

Key: ++ Good +Fair x Bad

Based on the data presented in Table 5-6 and the feasibility check for each option, the most appropriate solid waste management methods for the Pakwach Industrial Park are landfilling and composting.

5.4.1.1 Composting

Currently, there are no composting activities taking place at the Atara landfill. It is proposed that a Public Private Partnership (PPP) to upgrade the landfill site to include composting processes be undertaken. The organic waste that will not be valorized and from the general public will be subjected to composting using the windrow method and this will be done within the Atara landfill site area. The composting pad of about

964.7m^2 (Table 5-7) will be made of up of concrete flooring and roofed at the top, this will prevent rain from penetrating into the waste. The windrows will be designed with a gentle slope to allow for leachate gravity flow. Drains of about 0.5m wide and 0.5m deep and approximately 340m of length will be constructed around the composting pad to convey away the leachate to the lagoon where it will be treated. The organic waste in the active stage where decomposition initially takes place will be moisturized with recycled leachate and water in order to increase the moisture content of the waste. After the active stage which will be about 3-4 weeks, the compost will be shifted to the next windrow using a wheel loader for the curing stage which takes 6-8 weeks. When maturation is attained, the compost will be sieved to separate the larger particles from the fine compost. The larger particles will be taken back for re-composting or could be landfilled while the fine compost will be sold to the farmers with a kilogram of compost estimated at USD 0.04. Approximately 357 tons of compost is expected to be generated from the solid waste coming in from the STIP. The composting processes is suggested to take place at the Atara dumpsite and the processes to be followed are shown in Figure 5-4 below.
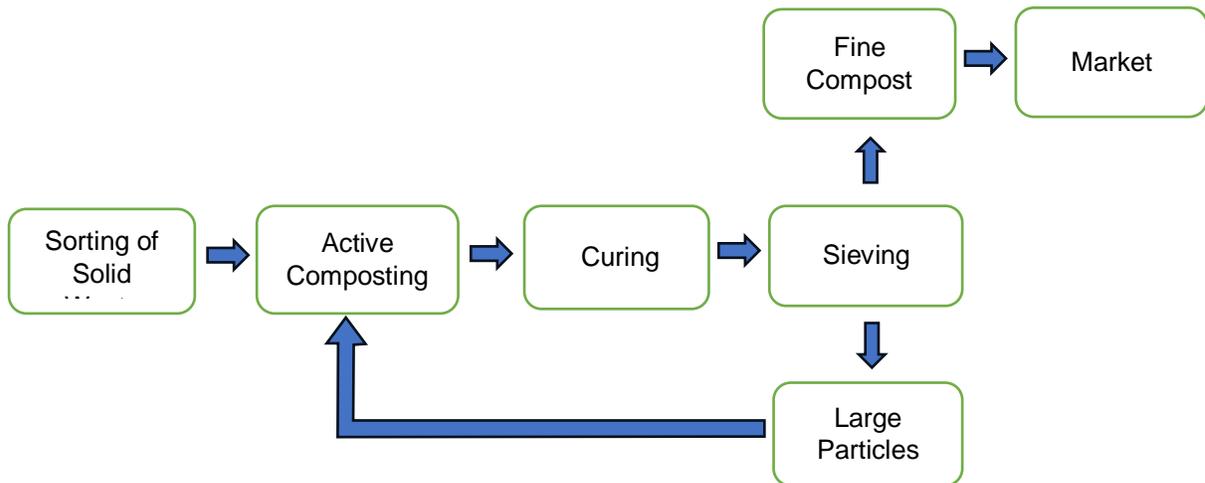

Figure 5-4: A flow chart showing the composting process

An estimate of the area required, dimensions of windrows and dimensions of the footprint area required for composting the monthly organic matter generated in the industrial park is shown in Table 5-7 below.

Table 5-7: Calculation of estimated footprint area required for composting

Parameter	Units	Level of Development		
		35%	75%	100%
Height of Windrow	m	1.5	1.5	1.5
Length of Windrow	m	30.0	30.0	30.0
Width of windrow	m	3.0	3.0	3.0
Width of aisle	m	1.0	1.0	1.0
Volume of each windrow	m³	89.1	89.1	89.1
Feedstock generated in 4 weeks	Kg	130,758.9	281,826.3	376,168.4
Volume of feedstock generated in 4 weeks	Kg/m³	217.9	469.7	626.9
Number of windrows required	No	2.4	5.3	7.0
width of all windrows	m	7.3	15.8	21.1
Width of all aisles	m	2.4	5.3	7.0
Combined width of aisles, buffer area and windrows	m	11.8	23.1	30.1
Combined length buffer area and windrows	m	32.0	32.0	32.0
Required Pad footprint Area	m²	377.1	738.8	964.7
Length of Pad	m	35.0	35.0	35.0
Width of Pad	m	10.8	21.1	27.6

The capital cost for the setting up the composting process was also estimated based on the estimated cost for the Mbale composting plant (Niwagaba et al., 2015) as shown below.

Table 5-8: Estimated capital cost for setting up the composting process

Parameter	Level of Development		
	35%	75%	100%
Land Occupied (m2)	377.08	738.78	964.66
Land Occupied (acres)	0.09	0.18	0.24
Amount (USD)	11647.25	22819.58	29796.74

5.4.1.2   Landfilling

Currently, the waste from Pakwach town is dumped at the Atara landfill without taking the necessary safety precautions and management practices. Some of the failures at the landfill include no sorting of waste, no collection of plastics for recycling, no leachate and gas management systems and also the waste is exposed producing odors from decomposition and posing a fire hazard at the site.

Some necessary steps that could be taken to improve the landfill site are described below. A waste sorting bay will be provided for to separate recyclable items and organic waste from other types of waste. The waste footprint area will be divided into two (2) individual cells (about 2 acres each), each lined at the base with liner materials to prevent soil and groundwater contamination and to facilitate leachate collection and removal. The leachate will be collected through perforated pipes and conveyed to a sump where it will be pumped to the lagoon for treatment. The monthly generated leachate was calculated based on Equation 1 (Choden et al., 2022) where V is the monthly volume of leachate generated, R is the maximum monthly average rainfall sum obtained from literature as 234mm for Pakwach and A is the area of cell.

$$V = R \times A \times 0.15 \qquad\qquad (1)$$

The monthly amount of leachate was obtained as 284.09m^3 (9.5m^3/day) and from a technical analysis, the proposed size of the lagoon is suggested to be about 300m^3 (10×10×3m). One cell will be constructed and filled at a time which will help to reduce initial investment costs, minimize soil stockpile expenses, reduce leachate generation, limit exposed waste areas, and controls litter, birds, and pests. Leachate management systems be installed in the landfill to convey the leachate away from the active cell to a leachate holding tank. Mechanical compaction should also be performed, followed by the daily covering of the waste surface and side slopes with a soil layer of at least twelve (12) centimeters. Compaction will help to increase on the lifespan of the landfill while covering of the solid waste could help to prevent fire breakouts, reduce on odor and prevent scavengers from accessing the landfilled solid waste. The existing access roads will also be improved and expanded to about 550m to enable easy access and movement in the landfill. Trucks exiting the landfill will also be washed or their tyres be sprayed to prevent waste mud and contaminants from being transported onto public roads. Figure 5-5 illustrates the process involved during landfilling.
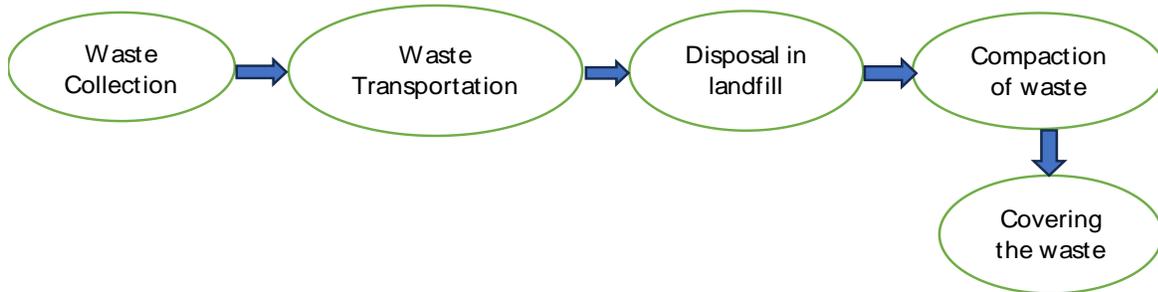

Figure 5-5: Flow chart showing the process of landfilling

An estimate of the total area required for the disposal of the annual waste generated in the Pakwach Science and Technology Park after valorisation is shown in Table 5-9 below.

Table 5-9: Estimation of area required for landfilling the annual generated solid waste in the STIP

Parameters	Level of Development		
	35%	75%	100%
Projected Annual Waste Generation (tons)	1,633.2	3,519.5	4,697.6
Volume of the waste (m^3)	1,921.4	4,140.6	5,526.6
Total Volume of annual Daily Cover (m^3)	192.1	414.1	552.7
Total volume for liner system and caps (m^3)	480.4	1,035.2	1,381.6
Volume due to settlement in (m^3)	192.1	414.1	552.7
Capacity of landfill (m^3)	2,401.8	5,175.8	6,908.2
Average landfill height (m)	5.0	5.0	5.0
Area for landfilling (m^2)	480.4	1,035.2	1,381.6
Area of Atara landfill (m^2)	26,113.0	26,113.0	26,113.0

A Public Private Partnership (PPP) is proposed to fully develop the Atara landfill for sorting, composting and landfilling processes. The consultant also further proposes composting and landfilling as the suitable solid waste management options for the Pakwach STIP to be carried out at the Atara landfill.

5.5 Solid Waste Management Strategy

The solid waste management strategy that will be adopted incorporates the valorization of solid waste into new products as the priority option. This will be followed by composting of the organic waste not subjected to valorization and finally landfilling of the inorganic waste.

The strategy aims at creating a greening process through reduction of the greenhouse gases generated. The global warming of landfills potential is especially high for methane gas which has 21% more potential than carbon dioxide to cause global warming (Ramprasad et al., 2022). Projections of methane emissions for the business-as-usual scenario and the proposed strategy were done using the IPCC Waste Model and Guidelines (IPCC, 2007). The projections indica ffffffffrcted that the methane emissions will be reduced by about 23Gg of methane over a period of 30 years if the proposed strategy is taken up. The manufacture of briquettes to be used for cooking will act as a remedy for fossil fuels which will also indirectly contribute to the greening strategy.

6. Stormwater management

6.1 Hydrological studies

Comprehensive hydrological studies were carried out to identify and determine the catchment area and estimate the design flows for the appropriate return periods for the catchment of the Industrial Park.

6.1.1 Design return period

The choice of the re-occurrence of the flood magnitude was guided by the following factors:
  i)   Amount of traffic and expected level of service
  ii)   Potential flood hazard to property
  iii) Magnitude and risk associated with damages from larger flood events
  iv)   Conditions for practical detour during probable failure

In addition, other factors like; potential upstream land use for the anticipated life of the possible drainage structures and construction cost were also considered in selection of the design return periods.
The design return periods shown in Table 6-1, based on geometric design criteria, were used for planning, design and analysis (MoWT, 2010).

Table 6-1: Design return period for structure types by Geometric Design Criteria

Structure Type	Geometric Design Standard			
	PIa, PIb	PIII Gravel A	PIII, Gravel B	Gravel C
Gutters and Inlets*	10/5	2	2	-
Side Ditches	10	10	5	5
Ford/Low-Water Bridge	-	-	-	5
Culvert, pipe (See Note) Span < 2m	25	10	5	5
Culvert, 2m < span < 6m	50	25	10	10
Short Span Bridges 6m < span < 15m	50	25	25	25
Medium Span Bridges 15m < span < 50m	100	50	50	50
Long Span Bridges spans > 50m	100	100	100	100
Check/Review Flood	200	200	100	100
PIa = Paved Ia PIb = Paved Ib PII = Paved II PIII = Paved III				

Note: The span in the above table is the total clear opening length of the structure. For example, the span of a double 1.2 m diameter pipe is 2.4 m.

6.1.2   Estimation of rainfall intensities

6.1.2.1   Analysis of recorded rainfall time series

Daily rainfall data obtained from the nearest rain gauge station to the project area which has adequate years of rainfall time series is detailed in Table 6-2 **.**

Table 6-2: Rain gauge Station in close proximity to the site

Rain gauge Station	No. of rainfall recorded years	Start year	End year
Gulu Met. Station	30	1991	2020

Gulu Meteorological station data was used for the analysis due to its close proximity to the Pakwach Industrial Park as well as having a long (39 years) rainfall time series of adequate data. The maximum 24-hour rainfall recorded during the period of record is 114.4 mm and was recorded on 4th September 2012.

6.1.3   Rainfall Intensity Duration Frequency (IDF) relationships

Using the Annual Maximum Series (AMS) method (Butler and Davis, 2011), the annual maximum daily rainfall depths were abstracted from the observed daily rainfall time series. The annual maximum values were then ranked from 1 to x in order of decreasing magnitude.

Weibull plotting position formula was applied to estimate the rainfall return periods.

$$T = \frac{(x+1)}{n}$$ Equation 1

Where;
T is the return period and,
n is the rank.

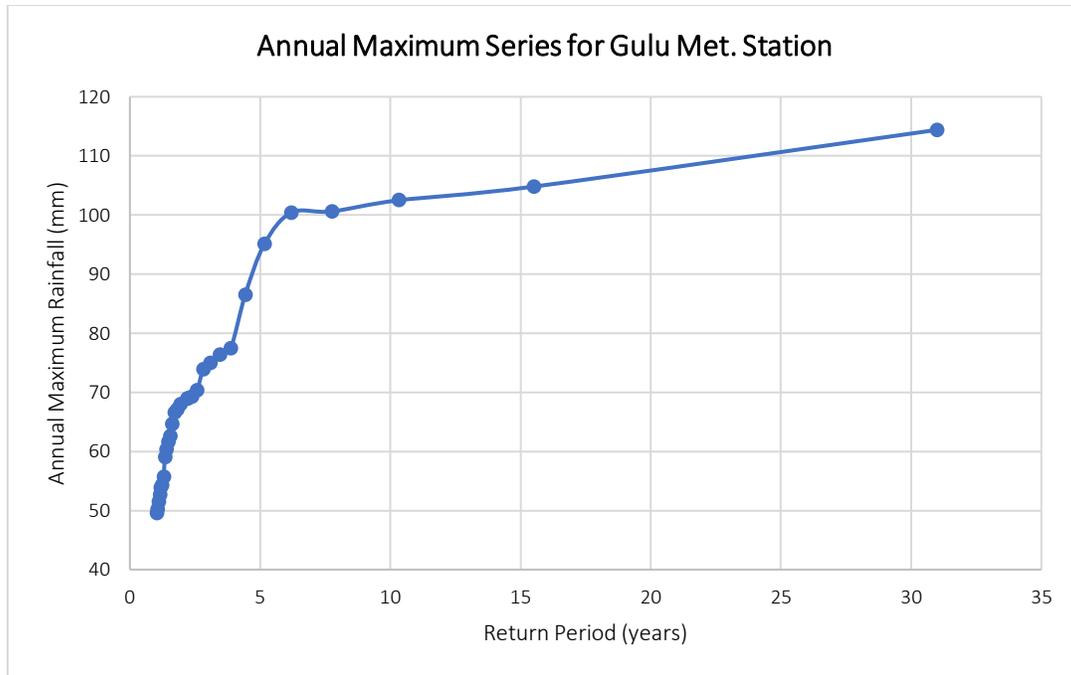The above method was applied to estimate the rainfall with low returns as shown in Figure 6-1.

Figure 6-1: Derived nnual Maximum Rainfall time series for Gulu Meteorological station

In this study, the 2-yr 24-hour rainfall value for Gulu Met. Station was determined from the graph above as **68.5 mm** and considered for further analysis.

6.1.3.1   Impact of climate change on daily maximum rainfall

According to the 4th Intergovernmental Panel on Climate Change Assessment Report, the global climate change models project an increase in average temperatures in Uganda by up to 1.5°C in the next 20 years and by up to 4.3°C by the 2080's. In addition, the report predicts an increase in rainfall and corresponding run-off volumes of 10 – 20% over most of the country (UN-Habitat, 2009).

In this study, all hydrological studies and hydraulics designs for the project took into consideration a climate change factor of 1.2 (Mugume et al., 2013). This climate change factor was applied to the 2 yr 24-hour rainfall to account for the effect of climate change on rainfall extremes. The 24-hour rainfall depths estimated for higher return periods are shown in Table 6-3.

Table 6-3: 24-hour Rainfall Depths at Pakwach Industrial Park

Rainfall Return Period, T	10	25	50	100	200
Flood Factor	1.52	1.81	1.90	2.09	2.47
Index 'n'	0.96	0.96	0.96	0.96	0.96
24 hr Rainfall Depth (mm)	124.94	148.78	156.20	171.80	203.03

6.1.4   Catchment delineation

Catchment delineation refers to the process of creating a boundary that represents the contributing area for a particular control point or outlet. The process of catchment delineation is used to define boundaries of the study area and/or to divide the study area into sub-areas. In this work, the Digital Elevation Model (DEM) based automatic catchment delineation was undertaken in ArcGIS software, using the ArcHYDRO Extension. The input data into ArcGIS was a SRTM DEM. The DEM has a horizontal resolution of 30 m

and was downloaded from United States Geological Survey (USGS) data. The delineated catchment for Pakwach Industrial Park covers an area of 5.0 km² with an average slope of 4.6% and an outfall at location 2°27'7.20"N and 31°25'30.00"E. Figure 6-2 below shows the delineated catchment for Pakwach Industrial Park.
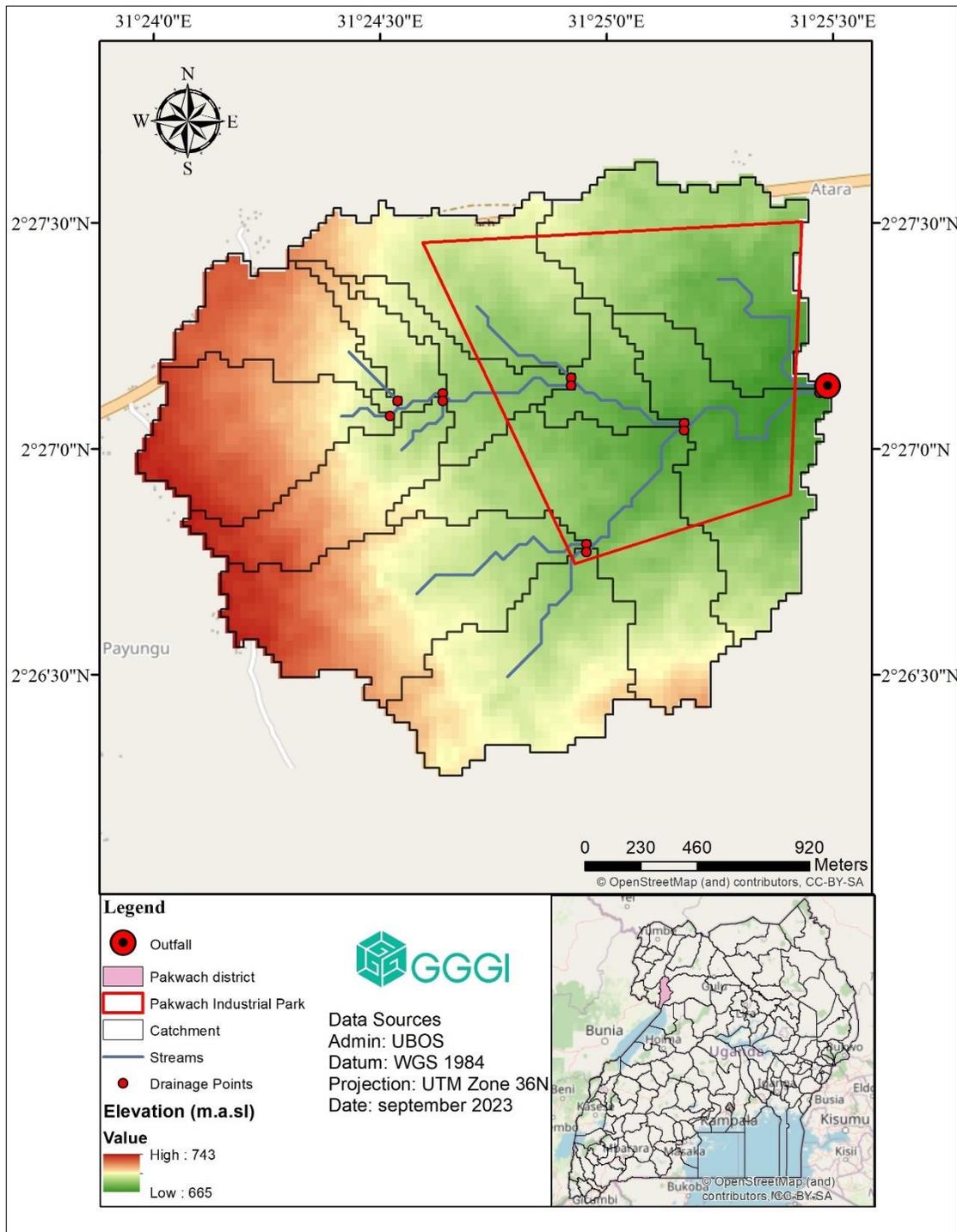

Figure 6-2: Delineated catchment for Pakwach Industrial Park showing sub catchments and streams overlain a Digital Elevation Model

6.1.5 Estimation of design peak flows

6.1.5.1 Choice of flood flow estimation methods

Having chosen the design return periods, peak design flows were estimated using hydrologic parameters of the catchment area using the most appropriate methods for flood flow estimation for an ungauged catchment. Various methods for flood flow estimation were evaluated in detail and the most context appropriate ones chosen. Table 6-4 shows the comparison of the various methods for flow estimation.

Table 6-4: Comparison of various design flood flow estimation methods

Pros	Cons
TRRL East African Flood Model	
• Provides a simple and straightforward method for predicting design storms for flood estimation in East Africa. • Based on extensive field and desktop analytical studies in East Africa	• Suitable for catchments < 200 km^2
Modified Rational Method	
• Simple and straight forward rainfall intensity-based run-off estimation method • Suitable for catchments with limited data • Provides an estimation of the maximum flows from a catchment • Accounts for the effect of storage on flood wave attenuation for large catchments	• Uses a constant rainfall intensity which is not appropriate for long duration time series • Inaccuracies in estimation of the composite run-off coefficient which is dependent on various factors e.g., soil moisture content, rainfall intensity and duration, degree of soil compaction, vegetation etc.
Soil Conservation Service (SCS) Method	
• Widely used dimensionless Unit Hydrograph method • Simple and straight forward method	• Key parameter such as the ratio of time to peak to the base time not satisfactorily applicable to East African Catchments • Applicable to small ungauged urban catchments

In this study, the TRRL Method was chosen and applied for the flood estimation.

6.1.5.2 Estimation of design peak flows using the TRRL Method

The Transport and Road Research Laboratory (TRRL) method that was developed for Uganda, Kenya and Tanzania made use of limited data for flood estimation for highway bridges and culverts. The model is used for estimating flows for catchments less than 200 km^2.

The TRRL method combines catchment parameters such as catchment area and slope, length of the main stream, land cover and channel slope together with other parameters such as Standard Contributing area coefficient, Catchment wetness factor, catchment lag time and contributing area coefficient to predict the peak flow and base time of design hydrographs for catchments.

The TRRL Method (Fiddes et al., 1974) involves the following main steps
  i) Determination of time of concentration
  ii) Design rainfall estimation

iii) Estimation of rainfall excess
iv) Estimation of run-off

The detailed description of the TRRL method is found in section 5.3 of the Ministry of Works and Transport (MoWT) Drainage Design Manual (2010), Volume 2 and Chapter 4 of the TRRL Laboratory report 706 (Fiddes et al, 1976). The results in Table 6-5 below indicates the design peak flow for the Pakwach IP catchment for the estimated return periods.

Table 6-5: Design flood estimates obtained using the TRRL Method

Parameter	T = 50 yrs	T = 100 yrs	T = 200 yrs	Remarks
Catchment Area, A (km^2)	5.0	5.0	5.0	
Land Slope, S_L (-)	0.0460	0.0460	0.0460	
Length of main stream (km)	2.4820	2.4820	2.4820	
Channel Slope (-)	0.0157	0.0157	0.0157	
Initial retention, Y (mm)	5.0	5.0	5.0	Semi-Arid Zone with initial retention of 5 mm
Standard Contributing Area Coefficient, C_s	0.45	0.45	0.45	Rolling (Catchment slope 4-10%), Slightly Impeded Drainage: Calcareous clays and Red Sands and Loamy Sands (0.45)
Catchment Wetness Factor, C_W	1.0	1.0	1.0	Semi-Arid Zone: Ephemera Streams
Land Use Factor, C_L	0.3	0.3	0.3	Wetland; Subsistence farmland
Contributing Area Coefficient, C_A (km^2)	0.149	0.149	0.149	
Catchment Lag Time, K (hrs)	11.500	11.500	11.500	Cultivated land, Papyrus swamp in valley bottom
Rainfall Time, T_P (hrs)	0.750	0.750	0.750	
Initial Flood Wave Attenuation Time, T_A (hrs)	0.000	0.000	0.000	
Base Time, T_B (hrs)	27.200	27.200	27.200	
T yr 24 hr rainfall for Pakwach (mm)	156.2	171.8	203.0	Climate Change factor of 1.2 applied to the 2 yr rainfall
Rainfall during base time, R_{TB}	157.2	172.9	204.4	
Areal Reduction Factor	0.932	0.932	0.932	
Average Rainfall, P (mm)	146.4	161.1	190.4	
Total Volume of Runoff, RO (m^3)	104,806.7	115,657.9	137,360.3	
Average flow, Q_{avg} (m^3/s)	**1.0**	**1.1**	**1.3**	
2nd Iteration				
Flood Wave Attenuation Time, T_{A1} (hrs)	0.00872	0.00851	0.00815	
Base Time, T_B (hrs)	27.209	27.209	27.208	
Rainfall during base time, R_{TB}	157.207	172.928	204.369	
Average Rainfall, P (mm)	146.4	161.1	190.4	
Total Volume of Runoff, RO (m^3)	104,809	115,660	137,362	
Average flow, Q_{avg} (m^3/s)	**1.0**	**1.1**	**1.3**	
3rd Iteration				
Flood Wave Attenuation Time, T_{A1} (hrs)	0.00872	0.00851	0.00815	
Base Time, T_B (hrs)	27.209	27.209	27.208	
Rainfall during base time, R_{TB}	157.207	172.928	204.369	
Average Rainfall, P (mm)	146.4	161.1	190.4	
Total Volume of Runoff, RO (m^3)	104,809	115,660	137,362	
Average flow, Q_{avg} (m^3/s)	**1.0**	**1.1**	**1.3**	
Peak flow, Q_T	**2.3**	**2.5**	**3.0**	**For K > 1 hr, F = 2.3**

Therefore, the chosen 50-year, 100-year and 200-year design peak flows are **2.3 m³/s, 2.5 m³/s** and **3.0 m³/s** respectively. These design storms shall be reviewed and utilised during feasibility and detailed design of the drainage system for the industrial park.

6.1.6   Blue Green Infrastructure for stormwater management

6.1.6.1   Rain water harvesting systems

Rainwater harvesting involves the gathering and retention of stormwater for on-site reuse, typically through the capture of runoff from building rooftops. Rainwater harvesting systems can serve as highly effective tools for controlling runoff and water storage systems within the proposed Pakwach Industrial Park. Given that a significant portion of the Pakwach Industrial Park remains unpaved, these systems can be strategically placed both above or below ground in designated zones, such as parking lots and open green spaces or adjacent to industrial buildings.

The existing permeable landscape at the IP facilitates natural drainage. Nevertheless, the need for water storage, whether for industrial or residential purposes, is crucial, both in the current situation and in anticipation of future industrialization. Rainwater harvesting systems can assist in meeting this demand while also serving as a means to control peak runoff flows. The ideal locations for these systems may vary depending on specific goals. Placing them upstream captures rainwater closer to its source, reducing the risk of downstream flooding.

In the context of urban water management and water-sensitive urban design, these systems align with the overarching goal of decentralizing water supply solutions (Sharma, 2015). They will promote resilience in the face of climate change impacts and minimize the environmental footprint of urban development (Sharma, 2015). Therefore, incorporating rainwater harvesting systems into the Pakwach Industrial Park will not only address water supply needs but also enhance the sustainability and adaptability of the region's infrastructure, especially as the area undergoes industrial growth.

6.1.6.1.1   Estimation of rainwater harvesting tanks

The computation of the approximate volume of rainwater tanks was done using BS 8515:2009 – the British Standard for designing rainwater harvesting tanks. The intermediate approach was followed in the design and this method takes the lower of 5% of the annual rainwater yield or 5% of the annual non-potable water demand.
The annual average rainfall for Pakwach was determined as 1332 mm from literature and input into the equation shown below.

$$Y_R = A \times e \times AAR \times \text{ŋ} \times 0.05$$

Where
Y_R is 5% of the annual rainwater yield
A is the collecting area (m²)
e is the yield coefficient (%)
AAR is the depth of the annual average rainfall for the location (mm)
ŋ is the hydraulic filter efficiency

Table 6-6: Computation of the rainwater harvesting volume

Description	Value
Average Annual Rainfall (mm)	1332
Roof Plan Area (m²)	153780.5
Yield Coefficient (%)	90

Hydraulic Filter efficiency (%)	90
Rainwater yield (l)	8295844.4
Rainwater yield (m³)	**8295.8**

The annual non-domestic demand was estimated from Chapter 3 of the report as 1,163 m³/d.

Table 6-7: Annual Industrial Demand

Description	Value
Industrial Demand at 100% development (m³/d)	1163
Annual Water Demand (m³)	424495
5% of annual demand (l)	21224750

The required volume of rainwater tanks was estimated to be 8,296 m³. This volume is less than 5% of the annual non-domestic demand and was therefore adopted as the final volume of the rainwater tanks.

A minimum volume of one rain water tank of 8,296 m³ is required or 12 tanks of 724.5 m³ each are adequate and proposed for the Pakwach Industrial Park

The required volume of rainwater tanks will lead to a reduction in annual water bills of 35% which corresponds to approximately UGX 414,792,218 savings annually. This consequently lowers the energy demand for pumping by 35% since this demand is met by the rainwater tanks.
Additionally, rainwater tanks will reduce peak runoff generated from the catchment by 3% while reducing the peak runoff generated from the industrial park by approximately 10%.

6.1.6.2   Detention Ponds

Detention ponds are engineered or naturally created depressions which serve the crucial function of temporarily storing and gradually releasing stormwater runoff. Their benefits encompass peak flow reduction, which significantly mitigates the risk of downstream flooding and erosion and also safeguard both infrastructure and the local environment. They also act as efficient sediment traps, allowing particulate pollutants to settle out of the runoff before discharge, thereby enhancing water quality.

In comparison to traditional drainage systems, detention ponds tend to require less maintenance and provide multiple benefits beyond runoff control. To ensure their effectiveness, it is imperative to determine the appropriate size of the pond based on site-specific factors and the desired reduction in peak runoff.

The size of the detention pond was estimated basing on the water quality volume method shown in the equations below.

$$R_v = 0.05 + 0.009(l)$$

$$WQ_v = \frac{1.5 R_v A}{12}$$

Where
I is the percentage of impervious cover
WQ_v is the water quality protection volume (acre-feet)
R_v is the volumetric runoff coefficient
A is the total drainage area (m)

Table 6-8: Preliminary design of the detention pond

Description	Value
I (%)	90
Rv	0.0581
A (acres)	3,202.49
WQv (m³)	10,722.9

The required volume of the detention pond was determined as approximately 11,000 m^3.

6.1.6.3   Bioswales

Bioswales are gently sloping, vegetated landscape depressions designed to capture, treat, and allow the infiltration of stormwater runoff. These are essentially vegetated channels that channel and convey runoff; during periods of heavy rainfall, these channels temporarily store water before its gradual discharge.

At Pakwach STIP, the consultant recommends use of bioswales (green vegetated drainage channels) instead to concrete or stone pitched drainage channels to convey site run-off. Construction of bioswales will provide safe conveyance of the generated storm water from the site and contribute to infiltration of storm water into the soil and reduction of surface run-off velocities.

7. Conclusions

7.1 Water and Sanitation Infrastructure at the Pakwach Science and Technology Industrial Park (STIP)

The proposed water and sanitation infrastructure at the Pakwach STIP is presented below.

7.1.1 Water Supply

Construction of three water storage tanks of approximately 200 m^3 capacity using pressed steel panels erected on steel towers to increase the residual head for the end-point users. The storage reservoir tanks will be supplied by the existing NWSC piped water system. In addition, a total of approximately 2.13 km of distribution trunk mains are required to distribute the water from the reservoir to the different units at the industrial park. Furthermore, approximately 60 No. 4''x4'' double fire hydrants are will be installed along the main access roads at 100 m spacing to manage the risk of fire outbreak at the park. The fire hydrants will be supplied from an independent reservoir of capacity 150m^3. A medium-term and long-term option for meeting the demand at the park requires the construction of two parallel water treatment units of 850 m^3/day with 1.2km transmission mains to the booster station at Pajobi.

7.1.2 Wastewater

An approximate 25km long sewer line will be laid on site to convey wastewater to a 1,900 m^3/d capacity waste stabilization pond. Wastewater from cassava processes will be pre-treated to remove inorganic pollutants from a packaged wastewater treatment plant of a capacity of approximately 1,100 m^3/day before it is conveyed to the waste stabilization pond.

7.1.3 Solid Waste

The proposed solid waste management infrastructure includes a valorisation of approximately 49%. The rest of the solid waste will be dumped at the Atara dumpsite where 357 tons of compost will be produced per month, inorganics recycled and the rest dumped. Two landfill cells of about 2 acres each will be constructed at the Atara dumpsite with synthetic material at the bottom.

7.1.4 Stormwater

The proposed stormwater infrastructure includes the construction of approximately 25km m of on-site grass-lined or stone-pitched drainage channels; and the construction of approximately 16,600 m^3 rainwater harvesting tanks to capture 10-year runoff from roofs. A detention pond of approximately 11,000 m^3 will be constructed to temporarily store runoff from peak flow events. It is also recommended to construct bioswales instead of concrete or stone pitched drainage channels for stormwater drainage.z

7.2 Proposed greening options for water and sanitation infrastructure

The proposed greening options have been considered in the detailed water and sanitation assessment for the Pakwach STIP. Specifically, the following greening options have been considered:
  i.   Water Supply: Rainwater harvesting by different industries from their respective roofs at the park.
  ii.   Wastewater: Use of anaerobic ponds with a dome constructed over to capture methane at 85% efficiency and pretreatment of wastewater from cassava processes to remove inorganic pollutants.

iii.   Solid waste: Composting of organic waste generated at the park, manufacture of briquettes (fuel), and recycling of inorganic waste.

iv.   Stormwater: Rainwater harvesting for non-potable uses and construction of a detention pond to temporarily store runoff and reduce peak flows.

References

Agency, J. I. (2011). *The Development Study on Water Resources Development and Management for Lake Kyoga Basin.*

Ajero, I., & Campbell, D. (2017). Bechmarking Water Use in the UK Food and Drink Sector: Case Study of Three Water-Intensive Dairy Products. *Water Conserv*, 1-17.

Costa, C. F., Amorim, C. L., Duque, A. F., Reis, M. A., & Castro, P. M. (2022). Valorization of wastewater from food industry: moving to a circular bioeconomy. *Rev Environ Sci Biotechnol*, 269–295.

Ekka, S. A., Rujner, H., Leonhardt, G., Blecken, G.-T., Viklander, M., & Hunt, W. F. (2021). Next generation swale design for stormwater runoff treatment: A comprehensive approach. Journal of Environmental Management, 279, 111756. https://doi.org/10.1016/j.jenvman.2020.111756

Environment, M. o. (2013). *Water Supply Design Manual.*

Latiffi, N. A., Mohamed, R. R., Shanmugan, V. A., Apandi, N. M., Tajuddin, R. M., & Kassim, A. M. (2019). Characteristics of Water Quality from Meat Processing Wastewater. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, 78-84.

Krishnamoorthy, S., Manickam, P., & Muthukaruppan, V. (2020). Bioprocessing of Cane Molasses to Produce Ethanol and Its Derived Products from South Indian Distillery (pp. 129–145). https://doi.org/10.1007/978-981-15-1390-9_6

Liu, J., Sample, D., Bell, C., & Guan, Y. (2014). Review and Research Needs of Bioretention Used for the Treatment of Urban Stormwater. Water, 6(4), 1069–1099. https://doi.org/10.3390/w6041069

Madhania, S., Muharam, Y., Winardi, S., & Purwanto, W. W. (2019). Mechanism of molasses–water mixing behavior in bioethanol fermenter. Experiments and CFD modeling. Energy Reports, 5, 454–461. https://doi.org/10.1016/j.egyr.2019.04.008

Mangmeechai, A., & Pavasant, P. (2013). Water Footprints of Cassava- and Molasses-Based Ethanol Production in Thailand. *Natural Resources Research*. doi:10.1007/s11053-013-921

Mugume, S. N., Gomez, D. and Butler, D. (2013) 'Statistical methods for climate change impact assessment on urban rainfall extremes for cities in tropical developing countries – A review', in Butler, D. et al. (eds) *International Conference on Flood Resilience: Experiences in Asia and Europe*. Exeter, United Kingdom: University of Exeter.

Ohio Department of Transportation (2014) 'ODOT Roadway Drainage Manual', *Chapter 7 Hydrology*, (November).

Sharma, A. K. (2015). Rainwater Tank Systems for Urban Water Supply: Design, Yield, Energy, Health Risks, Economics and Social Perceptions. Water Intelligence Online, 14. https://doi.org/10.2166/9781780405360

Spraakman, S., Rodgers, T. F. M., Monri-Fung, H., Nowicki, A., Diamond, M. L., Passeport, E., Thuna, M., & Drake, J. (2020). A Need for Standardized Reporting: A Scoping Review of Bioretention Research 2000–2019. Water, 12(11), 3122. https://doi.org/10.3390/w12113122

UN-Habitat (2009) *Climate Change Assessment for Kampala, Uganda: A Summary*. Nairobi: United Nations Human Settlements Programme (UN-HABITAT).

UNWMZ. (2022). *Albert Nile catchment management plan.* Lira: Ministry of Water and Environment