Journal of Energy and Natural Resource Management (JENRM), Vol. 9, No. 2, 54-67, 2023
Received: 28 September 2023; Revised: 18 November 2023; Accepted: 22 November 2023

Feasibility Assessment of Integrated Hydropower Generation for Flood Control in the Weija Dam

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Abstract
This paper conducts a feasibility assessment of integrating hydropower generation into Ghana's Weija Dam, a crucial water supply infrastructure. The primary goals are to enhance flood control measures and promote renewable power production. The annual spillage of the Weija Reservoir, managed by the Ghana Water Company Limited for dam safety, has detrimental effects downstream, causing damage to farmlands, homes, schools, and loss of lives. The study explores the potential for hydropower generation from the excess runoff spilled from the reservoir, aiming to generate power while minimizing water supply deficits and reducing downstream flooding. The research assesses hydropower resource availability and potential for power generation, using the Water Evaluation and Planning (WEAP) tool to determine reservoir capacity. Results indicate that despite an expected increase in water demand, the estimated annual runoff into the reservoir can meet total demand without deficit. The Weija Dam possesses a mini-hydropower potential with a dependable capacity of about 320 kW, generating over 2.75 GWh/year using a Kaplan Bulb turbine. A mathematical optimization model is developed for the multi-objective operation of the Weija Reservoir, aiming to maximize hydropower generation while minimizing the risk of water supply deficits. The study provides a decision support framework for optimizing the multi-purpose operation of the dam, offering an optimal operating guideline for releasing water resources for both power generation and water supply.

Keywords
Flood risk; Hydropower Generation; Renewable Power Production; Water supply; Weija Dam

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DOI: 10.26796/jenrm.v9i2.245
Received: 28 September 2023 ; **Received in revised form:** 18 November 2023; **Accepted:** 22 November 2023; **Published:** 30 November 2023

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1. Introduction

Globally, flood risk is projected to increase as a result of the altering of rainfall distribution, patterns, and intensity, occasioned by climate change and population growth (Boulange et al., 2021). The UN's Sustainable Development Goal (SDG) 6, seeks to ensure the availability and sustainable management of water and sanitation for all by the year 2030 (UNEP, 2021). The SDG 6, targets the substantial increase in water-use efficiency across all sectors and to ensure sustainable withdrawals and supply of freshwater to address water scarcity in order to substantially reduce the number of people suffering from water scarcity. The Goal also also aims at implementing integrated water resources management (IWRM) at all levels. Integrated Water Resources Management (IWRM) is a process that promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems(Asumadu-sarkodie et al., 2015; Dorm-Adzobu, 2007; Flood & Tools, 2015; UNEP, 2021)

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This paper examines the potential integration of hydropower generation as a solution for flood control in the Weija Dam, located within the Densu River Basin of Ghana. The increasing demand for electricity globally and the concurrent challenges posed by anthropogenic activities necessitate innovative approaches to water resource management(IHA, 2019; Lumbroso et al, 2014; McCartney, 2007). Reservoirs, such as the Weija Dam, offer multifaceted solutions, serving not only as water supply sources to the Great Accra region but also as potential contributors to clean and sustainable energy. The dam, commissioned for water storage and treatment purposes, has played a pivotal role in meeting the increasing water demand driven by urbanization and population growth(Asamoah et al., 2008; Augusto & Santos, 2008; Dorm-Adzobu, 2007; Owusu-Ansah et al., 2018; Sampson, 2018).

However, the operation of the Weija Dam faces challenges, particularly in managing excess water during periods of heavy rainfall, leading to spillage and downstream flooding(Augusto & Santos, 2008; Ay & Haskoning Nederland, 2004; Dorm-Adzobu, 2007). The consequences of such flooding include environmental degradation, damage to infrastructure, and disruptions to communities located downstream of the dam(Addae, 2018; Augusto & Santos, 2008; Ay & Haskoning Nederland, 2004; Castelletti et al., 2018; Owusu-Ansah et al., 2018; Rain et al., 2015). The challenges faced by the dam underscore the need for innovative and sustainable solutions to optimize its operation and address the dual objective of flood control and energy generation(Afshar et al., 2014; Bosona & Gebresenbet, 2014; Wu & Chen, 2013). The current reliance solely on spillage as a means of managing excess water not only results in adverse environmental and socio-economic impact but also overlooks the potential for harnessing hydropower from the abundant water resources (OECD, 2017).

This study addresses this predicament by exploring the viability of harnessing hydropower from the Weija Dam to simultaneously mitigate flood risks and generate electrical power to offset some of the electricity demand for potable water production. The integration of hydropower in flood control strategies aligns with the growing need for sustainable and multipurpose water infrastructure(Dorm-Adzobu, 2007; Flood & Tools, 2015; Lako & Koyama, 2015; Semonovic & Srinivasan, 1993; Wu & Chen, 2013).

The study aims at conducting a feasibility assessment of integrated hydropower generation into the operation of the Weija dam. The study delves into key aspects such as the water balance of the Weija Dam, the potential for hydropower generation, and the proposition of optimal operational guidelines using mathematical modelling and optimization techniques to simulate the dam operation as a multi-purpose facility, taking into account its operational and climatic constraints. By evaluating the synergies between flood control measures and hydropower generation, the paper seeks to propose a sustainable solution that optimally utilizes the Weija Dam's capabilities while addressing socio-economic and environmental concerns and also promoting resilient water resource management(Castelletti et al., 2018; Zhou et al., 2016)

The paper offers valuable insights for developing policy recommendations for relevant authorities, such as Ghana Water Company Limited (GWCL), offering a nuanced perspective on how hydropower generation can be strategically employed for flood control in the context of the Weija Dam and other dam infrastructure(Castelletti et al., 2018). The findings provide a guide to future decision-making processes, providing a blueprint for the effective and sustainable utilization of water resources(Zhou et al., 2016).

1.1 Weija Reservoir and Water Treatment Plant

1.1.1 The Weija Reservoir

The Weija Reservoir was constructed in 1952 by damming the Densu River at Weija, to feed the Weija Water treatment plant which supplies most parts of the Accra Metropolis with potable water. In 1968, the Dam was breached and destroyed by floods and it was reconstructed after four years at the same site(Ankomah-baffoe, 2018; Augusto & Santos, 2008; Dorm-Adzobu, 2007; Owusu-Ansah et al., 2018). Since then, the Ghana Water Company Limited (GWCL) has been supervising an annual spillage of the Weija Reservoir as the dam water level increases, in order not to breach the dam structure(Ay & Haskoning Nederland, 2004; Castelletti et al., 2018; Augusto & Santos, 2008).

The reservoir has a height above river bed of about 15.85 m and the reservoir volume is approximated as 145,000,000 m^3. The dam infrastructure is an earth-fill embankment type with rock fill protection. Its crest level, length and width is 17.07 m-18.29 m, 375 m including spillway and 6.1 m respectively (Ay & Haskoning Nederland, 2004). According to Dorm-Adzobu, (2007) to sustain river flow for environmental maintenance of the Ramsar wetland site at the downstream of Weija dam, an ecological flow has been introduced. The minimum flow requirement is based on a low-flow frequency analysis on the monthly flow data and determined as the 95-percentile flow (i.e. the 20-year minimum flow return period) in each calendar month(Frick-trzebitzky et al., 2017; Kusimi, 2008). Meanwhile site-visit reveal that the ecological flow requirement is not adhered to.

1.1.2 Weija Water Treatment Plant; Coverage and Water demand projections

The Weija Water Treatment plant, situated about 4 km off the Accra – Winneba Road and over 100 m above sea level, has a current design capacity of about 205,000 Cubic meters per day. This location allows for vast distribution of treated water under gravity. The plant has three independent treatment systems, namely Adam Clark, Bamag and Candy. The supply areas of the Weija Water Treatment plant span the Korle-Bu, Dansoman, Accra Central, Darkuman, Sowutuom, Achimota, Mallam, Bortianor, and the Kosoa area. A large percentage of the water demand within the service area is for domestic purposes. There are however a number of low-scale business units, shops, hospitality industries, educational institutions and a few factories within the supply scope (Dorm-Adzobu, 2007; GWCL, 2019).

The Ghana Statistical Service, in its publication of the 2021 Population and Housing Census reports that about 96.4% of the urban populace have access to basic water supply services while, 74.4% of the rural populace have access to basic water supply services. This is an indication of the rapidly increasing demand on water supply(PHC, 2022). According to (Abbey, 2013) , increase in population and its inherent economic growth is the main factor influencing the demand for water in Accra Metro. The research avers that domestic consumption would grow continuously with an average of 4.6% per year, as a result of demographic pressures whereas non-domestic water use will increase at 4.0% per annum averagely. Additionally, the operation of the Weija Water Treatment plant is dependent on grid electricity, as such its operation is susceptible to intermittent power supply. According to the GWCL, the cost of electricity accounts for a significant share in the cost of production of treated water(Abbey, 2013). Hence an intervention to offset some of the electricity demand is worthwhile.

1.1.3 Flooding; Spillage from the Weija Reservoir

Every year, spillage of the dam is carried out mostly in the rainy seasons to release excess water to ensure safety of the dam. It is reported that annually, hundreds of homes downstream of the Weija dam in the Ga South Municipality of the Greater Accra region get flooded during the spillage(Castelletti et al., 2018; Dorm-Adzobu, 2007; Owusu-Ansah et al., 2018; Rain et al., 2015). When the reservoir water level rises close to the maximum allowable level, the spillway is opened to reduce the stress on the dam, as a result, several loss of lives and property are recorded each year (Augusto & Santos, 2008) (JoyNews, 2017). According to the Ghana Red Cross society, communities at high and immediate risk include lower Weija, Oblogo, Tetego, Panbros Industries, Sapema, Bojo beach, Adakope and lower McCarthy with an estimated population of 500,000. It is estimated that about 2 million people could be affected by a spillage covering 8 square kilometres, in the worst-case scenario(Saladin, 2017). The issue of annual flooding of the downstream of the Weija dam was analyzed by Addae, (2018) using hydrodynamic modelling to consider flood impact on the urban settlement, downstream of the Densu catchment for mitigation planning. The study aimed at providing an insight for mitigating against flooding in flood prone areas, utilizing a satellite-based flood extent mapping for calibrating the hydrodynamic flood model of the Densu floodplain (Addae, 2018). By waying of curbing the menace of perennial flooding downstream of the Weija dam, this study explores the feasibility of generating hydropower from the Weija dam, while minimizing the possibility of water supply deficit.

1.1.4 Integrating Hydropower into the Weija Dam

Hydropower, characterized as a clean, affordable, and dependable source of electricity, harnesses the nature's stored energy in running water. The global surge in demand for renewable energy is driven by concerns over the environmental impact of fossil fuels and their contribution to climate change(Amos & Mensah, 2018; Gyamfi et al., 2018; Kumar et al., 2011; Wu & Chen, 2013).The worldwide installed capacity of hydropower presently stands at 1,360 GW, with an impressive addition of 1.9% increase from 2020.This expansion resulted in an estimated generation of 4,252 TWh of clean electricity through hydropower.(IHA, 2022). The basic principle of hydropower revolves around the conversion of water's potential and kinetic energy into electricity. As water descends under the force of gravity, it propels hydraulic turbines connected to electric generators. This principle underscores the importance of understanding and leveraging the natural elements of water flow, gravity, and terrain for effective hydropower generation(Breeze, 2019). The type and classification of hydropower projects are based on several factors including their hydraulic characteristics, available head, power output, functional basics, nature of the project and the type of fall (Klunne, 2007; Liu et al., 2013; Mortey et al., 2017; Yuksel, 2009). Effective planning and forecasting are crucial in hydropower development. The potential hydropower at any site is determined by factors such as hydraulic head and turbine flow rate. Therefore, successful harnessing of hydropower requires a thorough assessment of water resources, considering both local natural processes and terrain characteristics. Accurate evaluation of water resources is foundational to the planning process(Bosona & Gebresenbet, 2014; Lumbroso et al, 2014).

1.1.5 Multi-objective Reservoir Operation

The integration of a hydropower plant into the design and operation of the reservoir introduces certain complexities into its operations. Thus, it is prudent to employ a robust optimal guideline (decision support) to govern the operation of the reservoir as a multipurpose facility(Castelletti et al., 2018; Konak et al., 2006; OECD, 2017; Wurbs, 2016). Using the water balance method of hydrological analysis and optimization algorithms, an optimal multipurpose operation guideline for the Weija reservoir is defined, taking into account the demand for raw water abstraction for treatment and supply and the flow requirement for hydropower generation, while ensuring that the water demand and supply is not compromised(Asadieh, 2019; Chatterjee et al., 1998; Jager & Smith, 2008; McCartney, 2007; Vadher et al., 2016; Zhou et al., 2016). Water balance, often termed water budget or accounting, involves tracking the inflow and outflows of water in a specific water source, such as a river. Inflows include runoff entering the river system above the point of interest, groundwater discharge, and imported water through inter-basin transfers. Outflows encompass water extractions, losses upstream, transfers out of the basin, and natural losses. This accounting, as explained by Richter & Orr, (2017), provides a comprehensive understanding of the water dynamics. Water-balance models, as highlighted by Vecchia & Vining, (2007) are valuable tools for assessing the sensitivity of water availability and flood risk to historical and potential future climate conditions. These models establish connections between climatic inputs, hydrologic processes, runoff, and reservoir storage within a watershed, offering insights into the complex interactions influencing water resources.

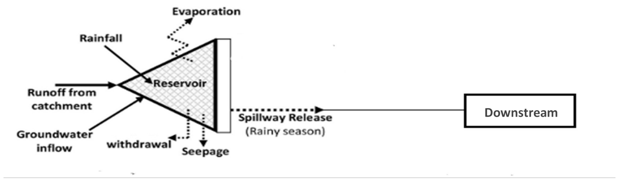

Figure 1. Schematic of Reservoir Water Balance

An optimal operating framework for the dam operation is hypothesized in this study, considering the interests of the reservoir stakeholders, inflows, volume of water impounded, water demand and dam operational and downstream constraints, with the aim of exploring the feasibility of integrating hydropower generation into Weija dam as multipurpose facility (Fang et al., 2014; Wu & Chen, 2013).

2. Materials and Methods

2.1 Research Design

The methodology for evaluating the feasibility of hydropower integration at the Weija Dam followed a systematic and interconnected workflow. The process began with a preliminary assessment, focusing on the Weija Dam as the study area, coupled with an in-depth literature review to comprehend its historical context and challenges. Subsequently, a comprehensive on-site data collection was conducted, which included hydrological data, dam infrastructure design and characteristics, and environmental impact information on the dam's operations. The methodology employed hydraulic modeling to simulate water flow within the dam and downstream to assess the hydropower potential. Simultaneously, hydropower potential modeling estimated electricity generation under two flow(release) scenarios based on the dam's operation. Further, optimization techniques, including multi-objective optimization, were applied to identify optimal operational guidelines while considering ecological benefit to the downstream and ultimately the demand for raw water abstraction. The systematic approach ensured a thorough understanding of the Weija Dam's potential for hydropower integration as a means for flood control, and the formulation of valuable recommendations.

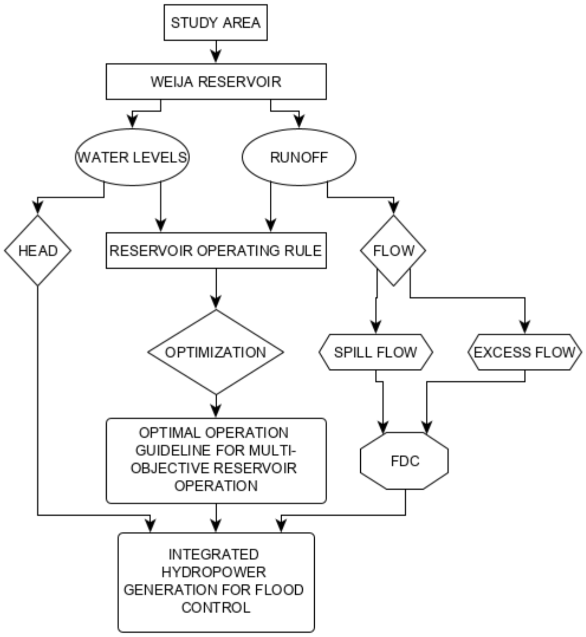

Figure 2. Schematic of Research Methodology

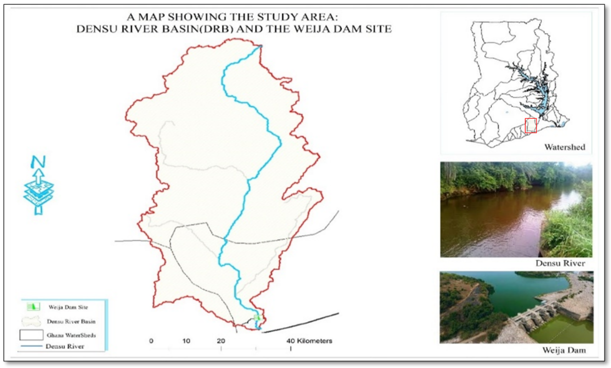

Figure 3. A Map showing the Study Area; Densu River Basin and the Weija Dam site

2.2 Description of Study Area

The Weija Dam is sited on the Densu River, georeferenced as latitude 5°34'10.80"N and longitude 0° 20' 38.96"W.

The river takes its source from the Atewa-Atwiredu mountain range in the Eastern Region of Ghana. The Weija reservoir is created as a result of the dam infrastructure across the Densu River. The Densu River Basin (DRB) shares boundaries with Odaw and Volta Basin to the east and the north respectively and shares the northwest to Birim and to the west with Ayensu and Okrudu Basins (Dorm-Adzobu, 2007) The Densu River Basin (DRB) covers a highly densely populated part of Ghana; within the latitude 5°30'N - 6°17'N and longitude 0°10'W - 0°37'W. The DRB has a diversified topography which is characterized by steeply dissected landscapes with hilly and rolling lands to the north and flat coastal plains to the south with slopes and erosion surfaces. The topography of the DRB is closely related to its geology and it consists of three divisions; including Western lowland, Akwapim Range and Eastern Plains(Asante, 2009; Augusto & Santos, 2008; Castelletti et al., 2018; Dorm-Adzobu, 2007; Kusimi, 2008)

2.3 Characteristics of the Weija Dam (reservoir)

The design characteristics of the Weija Reservoir including the runoff, dam infrastructure and spillage is provided in Table 1.

Table 1. Design Characteristics of the Weija Reservoir (Ay & Haskoning Nederland, 2004;Dorm-Adzobu, 2007; GWCL, 2019)

Item	Description	Quantity (Unit)
Run off into Reservoir	Average annual runoff into the Weija reservoir	$248 Mm^3/year$
Reservoir Surface Area	At maximum water level	$30km^2$
Dam infrastructure		
- length	Earth-fill embankment type with rock fill protection.	- 375m
- width		- 6.1m
- crest level		-17.07 - 18.29m
Volume at MWL (15.85m)		$143.115 Mm^3$
Volume at NWL (14.33m)		$113.5 Mm^3$
Minimum Water Level		13.72m
	Level	17.08m-18.29m
Dam Crest	Length (incl. spillways)	375m
	width	6.1m
No. of Spill gates	9.14 m wide, 6.1m high ($55.75m^2$)	5 gates
Flow at 1inch per gate opening		$2.23m^3/s$

2.4 Energy demand of the Water Treatment Plant

The average energy consumption of the water treatment plant computed as 2,821.15 MWh/month and 33.85 GWh/yr., which is served by the national grid. The monthly energy consumption trends of the treatment facility are shown in the Figure 4 and Table 2.

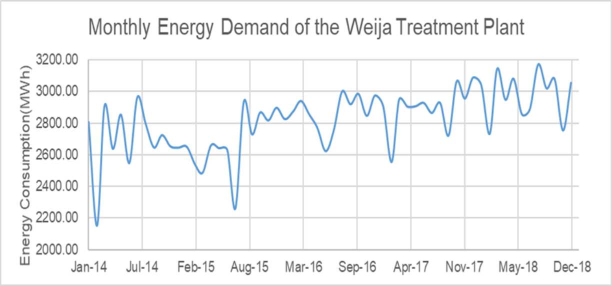

Figure 4. Monthly energy demand of the Weija treatment plant

2.5 Hydropower Potential of the Weija reservoir

The methodology employed is to assess the hydropower potential of the Weija dam based on the available head and the allowable release (flow rate). The development of the hydropower scheme at the Weija reservoir is geared toward offsetting the power demand at the water treatment facility, by way of exploring the potential of excess runoff into and/or the spillage from the reservoir and its corresponding water level (head). The theoretical hydropower potential of the Weija dam is computed from the equation;

$$P_{th} = \ell *\ g *\ Q *\ H_{gross}$$

Where P_{th} is the water power potential (theoretical power), ρ is the density of water as $1000 kg/m^3$ g is acceleration due to gravity as 9.81m/s and Q is the turbine flow and H_{gross}, is the gross head.

2.6 Determination of the Turbine flow

The turbine flow of the reservoir spillage regime occurs only during the rainy seasons, and thus could support power generation for only about 4 months in the year, whereas a regulated continuous release of surplus (excess) runoff as turbine flow would allow for an all-year-round hydropower generation.

2.6.1 Turbine Flow; Using Spillage (spill flow)

Daily spillage data of the reservoir into the downstream was collected from the Weija Dam. The Dam has 5 spillway gates of 9.14m width and 6.1m height each (55.754 m^2). The estimated runoff of the spilled water of all 5 gates at 15 inches opening is 167 m^3/s. Hence, it implies that, 1 inch opening of a gate allows for $2.23 m^3/s$ of spill water into the downstream of the reservoir. The total annual spillage from the reservoir is estimated as 5,988.56 m^3/s

Table 2. Monthly Energy Consumption

Monthly Energy Consumption (2014-2018)	MWh/month
Maximum	3169.55
Min	2151.16
Average	2821.15

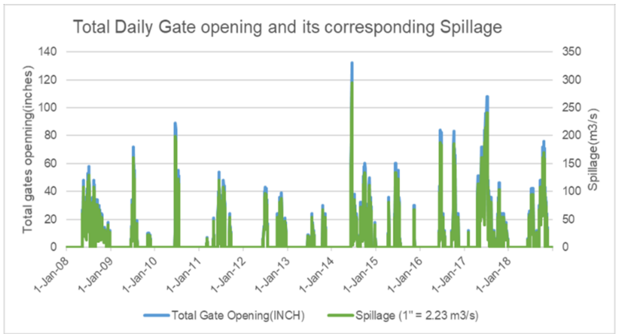

Figure 5. Total gate opening and its Corresponding spillage

From Figure 5, it is deduced that spillage occurs only about one-third (1/3) period of the year (i.e. 4 months), and hence using the spill flow would not support the release of hydropower generation all-year-round.

2.6.2 Turbine Flow; Using Surplus (excess) Runoff into the Weija Reservoir

The Surplus (excess) runoff is defined as the remainder of the mean runoff into the Weija reservoir after the demand for raw water abstraction for water treatment is met. The accumulation of the excess runoff in the reservoir accounts for the increase in the reservoir water levels and the subsequent spillage. The Figure 6, shows the inflow, and outflows of the reservoirs. This study considers utilizing the resource potential of the surplus (excess) runoff into reservoirs for hydropower, thus ensuring a continuous release for power generation.

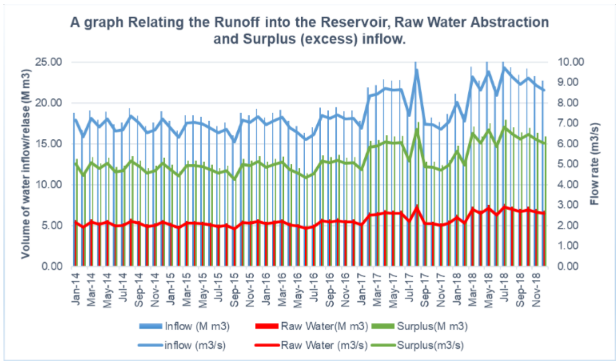

Figure 6. Runoff into the reservoir, raw water abstraction and surplus (excess) inflow

2.6.3 Flow duration Curve computation

A flow-duration curve is a graph of the historical flow at a water body ordered from maximum to minimum flow (Figure 7). The flow-duration curve is used to assess the anticipated availability of flow over time, and consequently its power potential. The firm flow that will be available for electricity production is determined from the flow-duration curve data, the percentage of time the firm flow should be available and the residual flow(S. Hydro & Analysis, 2004). The spill flow and monthly surplus (excess) runoff is computed using the HydroOffice FDC software to determine the flow duration curves. The HydroOffice FDC software is a tool for calculating and rendering flow duration curves for hydrological analysis (Gregor, 2010). The two scenarios of harnessing either the spillage (spill flow) or the surplus (excess) runoff as turbine flow were used to calculate the hydropower out and its corresponding energy out. From the graph (Figure 7), it appears that the maximum percentage of occurrence is about 28% of time, at which, a flow of $4.46 m^3/s$ is achieved. Figure 8 also indicates that at a 90% reliability, the firm (dependable) flow is $4.57 m^3/s$ from the flow duration curve.

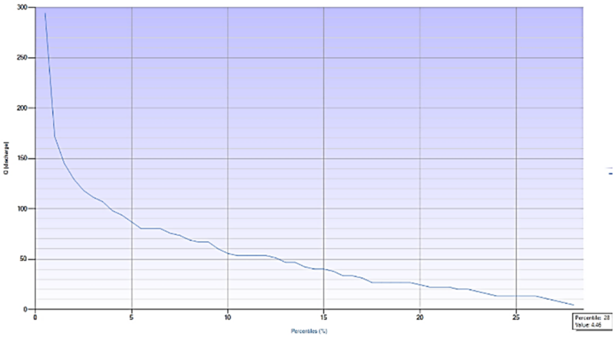

Figure 7. Flow duration curve of Weija reservoir spillage

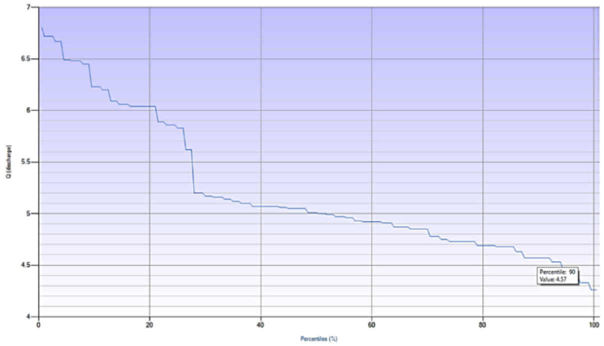

Figure 8. Flow duration curve of surplus (Excess) runoff Into Weija reservoir

Table 3. Turbine flow characteristics at different release scenarios

Release Scenario	Flow Rate (m^3/s)	Percentage of Time (Dependability)	Occurrence in the year
Spillage (spill flow)	4.46	28%	About 1/3 of period
Surplus (excess) Runoff	4.57	90%	Almost throughout the year

Table 4. Selected Turbine Design Parameters

Name	Value	Unit
Nominal speed	500	1/min
Number of pole pairs	6	-
Specific speed	212.6289	-
Runner diameter	0.944625	m
Setting depth	-0.2842	m

2.6.4 Daily Water Level

Daily readings of the water levels of the reservoir are collected by the Ghana Water Company Limited (GWCL). A measure of 45 ft (13.716m) and 47 ft (14.33m) are the standard operating water levels representing the minimum and normal operating water levels respectively. The Weija Dam usually spills above the normal operating level. Figure 9 shows the normal operating water level and the minimum operating water level.

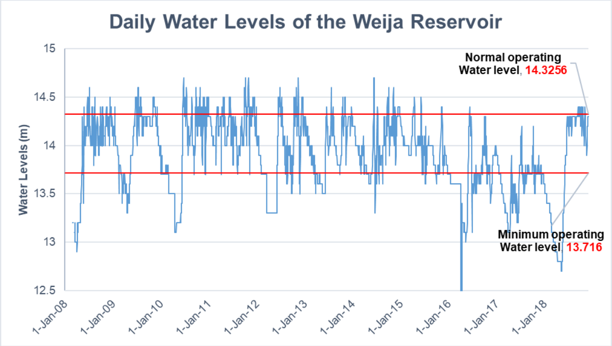

Figure 9. Graph of the Daily Water Level of the Weija Reservoir

2.6.5 Gross Head determination

The Gross head (H_{gross}) of the Weija dam is the elevation between the water levels at the headrace and the tailrace of the reservoir. Head race water level (HWL) is assumed as the normal operating water level, which is 14.33m (47ft). The tailrace water level (TWL) is found to be 4.57 m (15ft). Gross head H_{gross} of the reservoir is given as

$$= HWL - TWL = 14.33m - 4.57m H_{gross} = 9.76m$$

2.6.6 Actual Hydropower Output and Turbine Design

The actual hydropower computation is given by the

$$P_{actual} = \rho * g * Q_f * H_{net} * \eta$$

Where, P_{actual} is the actual hydropower, H_{net} is the net Head (considering hydraulic head loss(H_{loss})(C. Hydro, 2019)), Q_f is the firm inflow and ŋ is the efficiency of the turbine selected

2.6.7 The Net Head calculation

The net head is given as

$$H_{net} = H_{gross} - H_{loss}$$

Considering a hydraulic head loss of 10%,

$$H_{net} = 9.4 - (9.4 * 0.1) \qquad = 8.46m$$

2.7 Actual Hydropower Computation and Turbine Selection in HydroPower Software

Using the UNESCO-IHE Institute of Water Education's HydroPower software, the actual power that Weija Dam can generate and its appropriate turbine design was modelled. The actual hydropower output that could be generated from the Weija reservoir is considered using both the spillage and the surplus runoff scenarios.

2.7.1 Actual Hydropower computation: Spillage (spill flow) Scenario

With a Net head of 8.46 m, firm flow of 4.46 m^3/s at 28% dependability, and an assumed turbine efficiency of 85%, the hydropower out is calculated as 326.674 kW; generating 940.822 MWh/year for 1/3 period of year.

2.7.2 Actual Hydropower computation: Surplus (excess) Runoff Scenario

With a Net head of 8.46 m, firm flow of $4.57m^3/s$ at 90% dependability, and an assumed turbine efficiency of 85%, the hydropower output is calculated as 334.731 kW; generating 2.932 GWh/year. Power generation occurs almost throughout the year.

2.7.3 Turbine Selection and Design

Based on the turbine flow of the two scenarios and the net head, the appropriate turbine selected for the hydropower development is the pit-type Kaplan Bulb turbine. The following design parameters as shown in Table 3;

2.8 Multi-Objectives Reservoir Operating Rule for Weija Reservoir

A mathematical model for multi-objective operation of the Weija Reservoir is developed based on its water balance. The objective of the model is to provide an optimal operation guideline for operating the Weija dam as a multi-purpose facility by way of maximizing hydropower output after the demand for raw water abstraction is met. Thus, ensuring that maximum power out is achieved constantly, as far as the dam's operational constraints including demand for raw water and operating water levels are not tempered with; and making use of excess(surplus) runoff in the reservoir to limit spillage into the downstream. Figure 10 shows the inflows and outflows of the reservoir, that is, the reservoir water balance

2.8.1 Key assumptions

1. Precipitation, groundwater recharge and losses, evapotranspiration and environmental flow from the reservoir are assumed to be negligible and hence zero(Devisree & Nowshaja, 2014; Fang et al., 2014; Giuliani et al., 2016; McCartney, 2007; Rheinheimer, 2004; Wurbs, 2016)
2. Runoff into the reservoir is assigned a reliability factor of 90%. This is to account for the vagarious nature OR vagaries and susceptibility of streamflow to climatic conditions (Burn, 2011; Konak et al., 2006; Mounir et al., 2011; Wurbs, 2016)

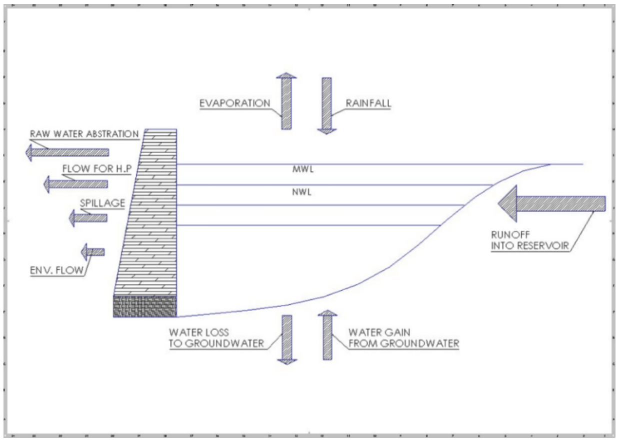

Figure 10. Schematic of the multi-objective reservoir operation

2.8.2 Mathematical Modelling in MATLAB

An optimal operation guideline is proposed for operating the Weija Reservoir as a multipurpose facility using mathematical optimization algorithms in the MATLAB environment.

The Mathematical programming (algorithm) for the optimization problem, thus generating an optimal release sequence and operating rule is based on the following objective function and constraints. (Burn, 2011; Giuliani et al., 2016)

Objective Function:

- To maximize the hydropower production, E

$$\sum_{t=1}^{12} (p(R_t H_t))$$

- To minimize water supply deficit

$$min \sum_{t=1}^{12} (Demand - allocation)$$

Constraints:

1. Flow for Hydropower: $Q_{min} \leq Q_t \leq Q_{max}$ According to the reservoir water budget equation (ignoring

ground water recharge, evapotranspiration, rainfall) and thus considering only the inflow from the Densu River in to the reservoir; the problem is also optimized so that spillage is avoided

$$Q_{net} = Q_{in} - Q_{hy} - Q_{rw} \tag{1}$$

where Q_{net} is net change in volume over time, Q_{in} is the total inflow from the Densu River into the Weija reservoir, Q_{hy} is the total allowable release of water for hydropower production over the and $Q_r w$ is total amount of water released to satisfy raw water abstraction requirements of the reservoir, at given time period.

Assuming steady flow conditions,

$$Q_{net} = 0 \tag{2}$$

The equation therefore reduces to:

$$Q_{in} = Q_{hy} + Q_{rw} \tag{3}$$

Assuming a runoff reliability factor into the reservoir as of 90

$$0.9Q_{in} = Q_{hy} + Q_{rw} \tag{4}$$

From which,

$$Q_{hy,max} = 0.9Q_{in} - Q_{rw} \tag{5}$$

2. Operating Hydraulic heads Water level:

$$H_{min} \leq \ H_{op} \leq \ H_{max} \tag{6}$$

3. Optimal Hydropower Generation Hydropower, P, produced by a hydraulic turbine with overall efficiency, η when water of head, H, flows through it at a rate, Q is given by:

$$P = \pi * \rho * \ g * \ Q * \ H \tag{7}$$

Where ρ is the density of water and g is the acceleration due to gravity.

Assuming an overall turbine efficiency of 0.85, and as $\rho = 1000kg/m^3, g = 9.81m/s^2$; equations (6) and (7) are combined as, the maximum hydropower that can be harnessed from the reservoir is given by;

$$P_{max} = \ 8338.5 * \left(0.9Q_{in\ (t)} - Q_{rw(t)}\right) * \ H_{op(t)} \ kW;$$

$$GrossHead_{NWL} \ \leq \ H_{op} \leq GrossHead_{MWL}$$

4. Storage Volume: $NWL \leq S_t \leq MWL$ The maximum reservoir design height of the Weija Dam is 15.85 m

5. Spillage (overflow) constraint Spillage ($Sp_{(t)}$) only if $S_t > MWL$, The reservoir is however intended to operate such that all the surplus runoff into the reservoir is used for hydropower, eliminating the chances of spillage.

Table 5. Energy Consumption of the Weija Water Treatment Plant

Consumption	**Energy Consumption**	
	Monthly Demand (kWh)	**Daily Demand (kWh)**
Minimum	215,116.2	71,705.4
Maximum	316,954.5	10,5651.5
Average	282,114.6	94,038.2

3. Results And Discussion

3.1 Integrating Hydropower generation for flood management at the Weija Dam

By way of integrating hydropower generation for flood management at the Weija Dam, the study computed the power demand of the Weija Water Treatment Facility based on monthly energy consumption data. The results, as summarized in Table 5, provide insights into the energy consumption patterns of the water treatment plant, indicating minimum, maximum, and average monthly and daily demands.

3.1.1 Firm Hydropower generation

The results of the dependable hydropower output from that Weija dam are for the two release scenarios (spill flow and surplus runoff) is shown in table 6;

Harnessing the potential of the surplus (excess) runoff is favourable, since it presents a greater operational dependability and that the hydropower generation could be operated almost throughout the year. In the Spill flow scenario, the turbine flow for power generation is available only during the rainy seasons, where the dam spillage occurs. Therefore, the surplus (excess) runoff scenario is postulated for the hydropower integration since it also affords the opportunity for continuous release of water from the dam by way of flood control and ecological flow to recharge the Densu Delta.

Based on the hydropower potential of the Weija reservoir, it is classified as a mini-hydropower project(International Renewable Energy Agency, 2012; Kumar et al., 2011; Lako & Koyama, 2015; Breeze, 2019).

However, the average annual energy consumption of the Weija water treatment plant is 33.85 GWh/year. This suggests that the integrating hydropower generation into the Weija Dam provides an incentive of serving about 8.5% of the facility's energy demand for water treatment annually.

Table 6. Firm power output for the release scenarios

Release Scenario	Flow Dependability	Flow Rate	Power Output	Annual Energy/year
Spill flow	28%	4.46m3/s	314.625 kW	906.12 MWh/year
Excess (Surplus) runoff	90%	4.57m3/s	322.385 kW	2.824 GWh/year

3.2 Results of the Multi-reservoir Optimization of the Weija Dam

The result for the optimization problem of maximizing hydropower generation while minimizing the possibility of water supply deficit was categorized into flow (release) sequence and optimal operating guideline for the Weija reservoir as a multi-purpose facility.

The release sequence relates how much inflow enters the reservoir, how much is abstracted as raw water for treatment and how much could be released for power generation. On the other hand, the optimum operating guideline (curve) provides a deterministic model to generate constant hydropower output while head (water level) and allowable release may vary stochastically.

The maximum power capacity of the Weija dam is computed as 383 kW at the optimum operating head and its corresponding optimal release (flow).

3.2.1 Flow (Release) Sequence

The flow sequence graph indicates that the flow requirements for raw water abstraction (RWA) and hydropower generation (HP) could be met at all times, with some excesses. This suggests a robust capability of the Weija Dam to balance the demands for raw water and hydropower generation throughout the year as shown in Figure 11.

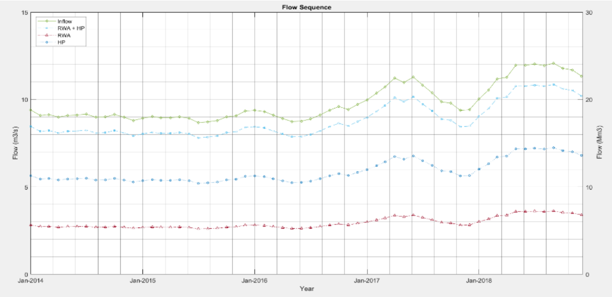

Figure 11. Flow Sequence of Weija reservoir as a multi-purpose facility

3.2.2 Optimal Operating Guideline

Figure 12 generated from the mathematical programming provides an optimum operating curve for integrating hydropower generation.

The optimal operating curve provides a deterministic model for constant hydropower output while accounting for variations in head (water level) and allowable release; the maximum power capacity achieved is 383 kW.. The graph illustrates the relationship between the optimum head and its corresponding flow rate for power generation, considering all reservoir constraints.

These results not only offer a technical understanding of the hydropower generation potential of the Weija Dam but also provide valuable insights for managing water resources efficiently, meeting power demands, and ensuring ecological sustainability. The optimization outcomes contribute to the development of a comprehensive strategy for the integrated and sustainable use of the Weija Dam for both water treatment and hydropower generation purposes and consequently allowing for flood management.

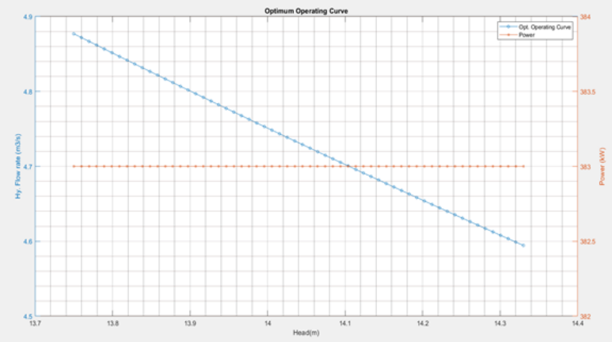

Figure 12. Optimum operating curve (head versus flow rate) for power generation

4. Conclusion and Recommendation

4.1 Conclusion

In conclusion, this study has explored the potential integration of hydropower generation as a multifaceted solution for flood control in the Weija Dam, located within the Densu River Basin of Ghana. The Weija Dam, a critical water resource, currently faces challenges related to dam spillage and downstream flooding, which adversely impact the surrounding environment. The research has demonstrated that by harnessing hydropower from the excess runoff of the Densu River into the Weija Reservoir, it is possible to simultaneously mitigate flood risks and generate electrical power.

The study considered both spillage scenarios and the utilization of surplus (excess) runoff, recommending the latter for continuous hydropower generation throughout the year. The findings indicate that integrating hydropower generation into the dam's design is technically feasible, offering a solution that optimizes the use of the reservoir's capabilities.

The Weija Reservoir as a multipurpose facility has the capacity to generate electricity to offset of 8.5% its demand for water treatment at 90% dependability; making use of the excess runoff, which hitherto would accumulate and spilled off into the downstream.

The investigation employed mathematical modelling and optimization techniques to simulate the operation of the Weija Dam as a multipurpose facility. The maximum hydropower power capacity of the Weija dam is computed as 383 kW at the optimum operating head and its corresponding optimal release (flow) and a firm power generation capacity of 320 kW.

The integration of hydropower into the Weija dam would ensure a regulated release of water to the downstream, thus curbing the issues of perennial flooding and also resuscitating the ecology of the Densu Delta.

4.2 Recommendations

The recommendations proposed in this study advocate for the implementation of hydropower generation at the Weija Dam by the Ghana Water Company Limited (GWCL) and relevant authorities, emphasizing its technical feasibility and potential contributions to the country's energy needs and flood control.

Continuous Monitoring and Evaluation of Densu River's hydrology and the impact of anthropogenic activities are emphasized. Also, regular assessments to gauge the hydropower potential and its performance, in the wake of climate change and water insecurity is recommended.

It is crucial to conduct a comprehensive Environmental and Social Impact Assessment (ESIA) before project implementation to assess potential ecological and social consequences and guide the development of sustainable practices.

Additionally, the study recommends cost-benefit analysis and carbon footprint accounting, integration into broader water resource management plans for the Densu River Basin to align with regional development goals and contribute to Sustainable Development Goals (SDGs) related to water.

Lastly, the importance of ongoing investment in Research and Development is highlighted to explore the potential integrated water resource management for sustainable development.

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