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Optimization of Hydropower Generation Potential of Arjo Dedessa Irrigation Dam

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Abstract: Hydropower has been developed to have a positive impact on the quality of life for rural residents in many ways. It offers a wide range of facilities, such as improved lighting, energy for small industries, schools, computer and communication service centers, and clinics. Ethiopia has constructed numerous dams for irrigation and water supply, yet these structures may have untapped potential for other purposes. One example of such a dam is the Arjo Dedessa Irrigation Dam located in western Ethiopia. Advanced optimization models have been developed to maximize the annual energy generation from the Arjo Dedessa Dam, while taking into account restrictions on water release for irrigation and ecological purposes, as well as the need to maintain maximum reservoir yield and storage capacity. The model was analyzed using LINGO software for different probabilities of mean annual inflow exceedance. Two scenarios for hydropower retrofitting were evaluated. The scenario of independent hydropower release with reservoir inflows at 50%, 75%, and 90% probabilities of exceedance results in a total annual hydropower output of 4.8 MW, 4.34 MW, and 0.99 MW, respectively. The matching values for the scenario of complementary hydropower release were 5.27 MW, 4.55 MW, and 1 MW, respectively. The study also measured the potential increase in the reservoir's live storage capacity to 1945.01 Mm^3 by utilizing flood storage, which would allow for a maximum draft increase to 285.74 Mm^3. With an upper limit on storage and draft, and reservoir inflows with probabilities of exceedance at 50%, 75%, and 90%, the hydropower production increased correspondingly to 6.51 MW, 4.54 MW, and 1.935 MW for the scenario of independent hydropower release arrangement. For the scenario of complimentary hydropower release, the hydropower production improved to 6.75 MW, 4.58 MW, and 1.94 MW respectively. The outcomes specify that the Arjo Dedessa Dam is appropriate for the production of hydroelectric power and that its generation potential is between 6.51 and 6.75 MW.

Keywords: Irrigation Dam, Energy, Optimization, Linear Programming, LINGO

1. Introduction

Optimization techniques are utilized in water resources planning and management to model and analyze various types of challenges related to water supply, flood control, reservoir systems, hydropower generation, irrigation, and more. The outcomes of these models are highly beneficial in providing valuable information and data to formulate alternative plans and strategies [13].

The optimal operational rules for large multipurpose reservoirs, which serve various purposes such as irrigation, hydropower, and flood control, are complex due to the size of the problem and conflicting objectives. Optimizing the operational strategies of reservoirs that serve both irrigation and hydropower purposes can be complex, especially if hydropower production is not the primary objective. Hydropower requires a greater head of water in the reservoir to operate efficiently, while crop production requires a higher volume of irrigation release [2].

According to studies [20] enhancing the performance of a vast multipurpose reservoir necessitates a systematic approach. Several optimization methods have been used to derive optimal reservoir operational rules, including linear programming (LP), nonlinear programming (NLP), goal programming (GP), chance constraint linear programming (CCLP), dynamic programming (DP), and more recently, soft computing techniques.

The use of linear programming (LP) in the field of water resources dates back to the early 1960s [23]. Reviews [36] have described LP models as "state of the art." His investigation includes models of stochastic programming that incorporate resource allocation, chance-constrained linear programming, and linear decision rules. Based on the reviews, he concludes that LP is in charge of operations. To be precise, he determined that linearization techniques such as piecewise linearization and Taylor series expansion can be used to effectively model non-linear constraints and objectives using LP. There are several advantages to this method: (I) It is well-defined and easy to understand; (II) It can solve problems of relatively large dimensions compared to other methods; (III) It obtains global optimality; (IV) It does not require an initially feasible provisional policy; and (V) Commercial programs are widely available, so the method does not need to be customized for each application.

According to the author [2] optimized the operation of the Koyna reservoir in India by maximizing hydropower production while ensuring irrigation demands were met. They used a nonlinear programming model to achieve this goal. The hydropower made from the reservoir was evaluated for three dependable inflow conditions, representing wet, normal, and dry years. Numerous scenarios were examined for each dependable inflow condition, taking into account the limitations of the releases, and the results were compared. The potential for hydropower generation from the dam while meeting irrigation demands was evaluated using linear programming [30]. A study on optimal water management modeling of the Kainji and Jebba hydropower systems on the River Niger in Nigeria has revealed that an optimum energy of 5995.60 GWH can be generated, which is about 41% higher than the average energy generation of 4261.12 GWH based on historical records at the power plants.

Hydropower is a reliable source of energy that accounts for 60% of the renewable energy sector. Hydropower is a significant source of clean energy, accounting for 16.4% of the world's electricity production [17, 27, 32, 21, 14, 3]. The United States has a potential for 12,000 MW of new renewable capacity from non-powered dams, which is equivalent to 15% of the country's existing hydropower production[10].

Developing new hydropower systems to meet energy demands is a significant challenge worldwide, particularly in developing countries. This is due to the need for population relocation, substantial investments, complex processes, high costs, and environmental concerns. Building large hydropower systems is often not environmentally sustainable or socially acceptable [8, 5, 15, 4, 28, 26].

Ethiopia has a massive potential for hydropower, estimated to be between 15,000 and 30,000 MW. So far, only a small percentage (less than 2%) of the enormous potential has been harnessed. To harness the massive potential of power, numerous projects have been initiated to generate additional hydroelectric power. There are approximately 300 potential hydropower plant sites across the eight river basins in the country, with a total power potential of 159,300 GWh/year. Out of the potential sites, 102 are large-scale (over 60 MW) while the remaining sites are small-scale (less than 40 MW) or medium-scale (40-60 MW) hydropower plant sites [11].

Small-scale hydropower development and energy production from existing infrastructure are beneficial because the infrastructure is already in place, which reduces both the investment cost and the time required for development. Moreover, the social and environmental impact of this approach is significantly lower when compared to constructing an innovative hydropower scheme, as supported by various studies [14, 24, 9, 18, 6, 29, 27].

A reservoir system designed for irrigation and hydropower typically consists of a reservoir with canals on the left and right banks, which lead to the irrigated area, and a powerhouse located at the riverbed [37, 1, 12]. The irrigation canals may also have powerhouses along their length. Power is consolidated by diverting irrigation issues into the canals. The riverbed turbine generates power by releasing water downstream from the reservoir [31, 35, 19].

The Arjo Dedessa dam was primarily designed for irrigation purposes, but for this study, a hydropower addition scheme was considered for the dam. The addition of hydropower turbines to the Arjo Dedessa dam has been optimized using linear programming techniques. The mathematical problem has been solved using optimization software, specifically the LINGO 18 version tools. LINGO is capable of solving linear, nonlinear, and integer programming problems. LINGO utilizes the branch and bound algorithm to handle integer variables. The details of LINGO are described in the user's guides for LINGO 17.0 and LINGO 18.0. The primary objective of this study is to optimize the potential for hydropower generation at the Arjo Dedessa dam.

2. Materials and Methods

2.1. Location

The Arjo-Dedessa Dam Project is located in Ethiopia, within the boundaries of Jimma and East Wollega Zones in the Oromia Regional State. The project area is located between 80°30'00" to 80°40'00" N latitude and 36°22'00" to 36°43'00" E longitude. Dedessa river is one the tributaries of Abay River basin. Arjo Dedessa dam is constructed across Dedessa River at specified location of the coordinate point 80 31' 12" N latitude and 36o 40' 1.4" E Longitude.

2.2. The Method Used for Analysis

Reservoir Yield

The reservoir storage-yield function determines the minimum active storage capacity needed to maintain a constant release rate for a specific sequence of reservoir inflows [1, 25]. The analysis of reservoir yield capacity is conducted to determine the minimum storage volume needed to meet specified demands with a predetermined level of reliability during the planning stage. Conversely, it can also be used to reevaluate the water demand that an existing reservoir can meet. Mass diagrams, sequent peak analyses, and optimization are three methods that can be used to define these functions [7]. An optimization model based on linear programming (LP) was utilized to establish the yield function for the Arjo Dedessa reservoir's storage capacity. [20, 22] The linear programming (LP) model developed to maximize the reliable yield (Y) of a reservoir with a given active storage capacity is as follows:

Objective function: Maximize Y

Constraint: -

$$S_t + Q_t - Y - R_t = S_{t+1} \ \forall t = 1, 2, \ldots .12 \quad (1)$$

$$S_t \le K \ \forall t = 1, 2, \ldots .12 \quad (2)$$

Where: -

St+1 = the final reservoir storage volume at period t.

St = the initial storage volume at period t.

Qt =Inflow to the reservoir at period t.

Rt = Excess release from the reservoir at period t.

K is the active storage capacity of the reservoir at different level

Y = the yield of the reservoir

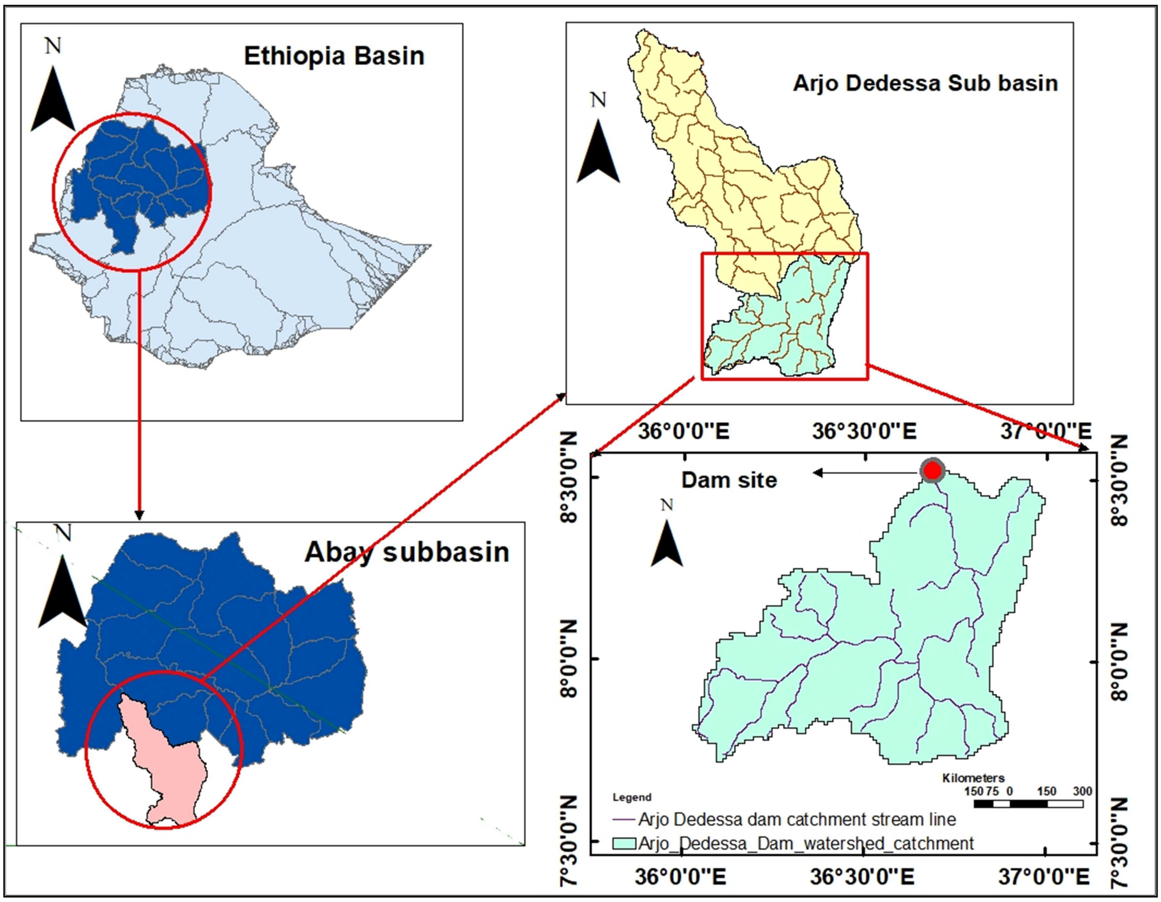

Figure 1. *Map of the Study area.*

2.3. Approximation of the Hydropower Potential Using the Optimization Model

Optimization methods are fundamental tools that are valuable in reservoir management education. The problem of optimum reservoir operation involves finding the optimal release, reservoir storage, and downstream reach-routing flows based on predicted inflows. The period phase in these models can be hourly, daily, weekly, monthly, or yearly. When hydropower processes are combined with flood control or other uses, daily and hourly time steps are advantageous. To model the optimization, the following steps were taken: determination of the reservoir's yield capacity, estimation of the probabilities of reservoir inflow exceedance, establishment of a relationship between the generating head and reservoir storage, development of an optimization model for the binary probable arrangements shown in Figures 2 and 3, and evaluation of the model's output by considering various scenarios.

2.3.1. Estimation of the Reservoir Inflow with Various Probabilities of Exceedance

The reservoir inflow was fit with probability distribution method based on the monthly mean of the historical data and the extent of data. The reservoir inflow at the dam site, the best probability distribution method was evaluated using Easy fit software. The reliability of 50%, 75%, and 90% of the probability of inflow to the reservoir is determined using the equation below.

$$Q = \bar{Q} + \delta K \quad (3)$$

Where:
Q = flow of a particular month (Mm^3),
$\bar{Q}$ = Mean flow (Mm^3)
σ = Standard deviation (Mm^3) and
K is a constant, depending on the probability, reservoir inflow volume of 50%, 70%, and 90%, and the probability of exceedance.

2.3.2. Generating the Head as a Function of the Reservoir's Storage Equation

The elevation and storage data from the topographical map of an Arjo Dedessa reservoir's impounding area and the assumed tail race elevation will use to obtain the relationship between the head and reservoir storage. The tailrace elevation will be deducted from the reservoir elevation to obtain a generating head.

2.3.3. Formulation of the Problem of Reservoir Operations

System and description of the problem

The main features of the reservoir system can be briefly summarized as follows:

An Arjo Dedessa reservoir has a catchment area of 5632.64km^2 and a live storage capacity of 1515.8 Mm^3.The purposes of this reservoir system are irrigation, water supply, and ecological releases The hydropower was proposed as an additional scheme. (i e., integration of a hydropower turbine for energy generation). Energy production requires water to drive the turbine and can be released to serve the purposes the reservoir will be designed.

Expansion of a long-range operational guide for the Arjo Dedessa Dam. The linear programming technique is one of the further most extensively used mathematical programming methods in water resources planning and management due to its suitability, particularly in the optimal allocation of scarce resources for various purposes. The objective function will be the expansion of energy, while the reservoir characteristics, irrigation requirements, ecological needs, and the non – negative of the hydropower releases are included in the constraints.

2.3.4. System and Problem Description for the Scenario of Independent Hydropower Release

In this scenario, the Arjo Dedessa reservoir; the irrigation, hydropower system and ecological release are positioned in the plan below. The release assigned for the hydropower in this scenario is independent of releases for other uses. This plan is portrayed in in figure below, However, in this case, the hydropower is to be integrated so that a dispersed release of water is assigned for the hydropower scheme.

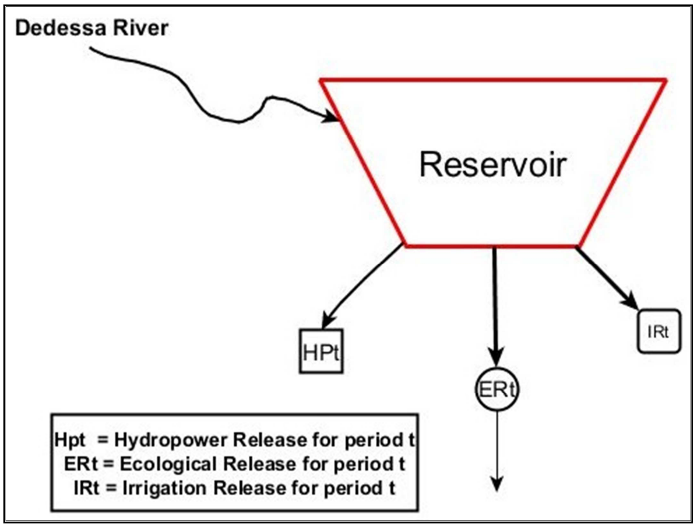

Figure 2. *System Diagram of the study basin for Scenario of independent hydropower release.*

Objective Function

$$TE = Max\ \sum_t^T (E_t) \quad (4)$$

$$E_t = 2.73 HP_t H_t e\ (MWH) \quad (5)$$

Model Constraints: -

$$TR_t = IR_t + ER_t + HP_t \leq Upper\ limit. \quad (6)$$

$$TR_t = IR_t + ER_t + HP_t \geq Lower\ limit \quad (7)$$

$$ER_t \geq EC_t. \quad (8)$$

$$IR_t \geq I_t. \quad (9)$$

$$HR_t \geq 0 \quad (10)$$

$$D_{sc} \leq S_t \leq L_{sc} \quad (11)$$

$$S_{t+1} = S_t + Q_t + P_t - TR_t - E_t - SP_t. \quad (12)$$

Where: -
HPt = Release for hydropower generation (Mm^3)
Ht = Generating head (m)
T =Monthly period t = 1, 2, T = 12
e = overall efficiency of the plant.
S_{t+1}: Final reservoir storage at the next of the previous month (Mm^3)
S_t: Initial reservoir storage at the starting of the month

(Mm^3)

Q_t: Monthly stream inflow into the reservoir (Mm^3)

P_t: Monthly direct rainfall over the reservoir (Mm^3)

TR_t: Total monthly releases (Mm^3)

Et: Monthly evaporation losses (Mm^3)

SP_t: Monthly overflow (Mm^3)

ERt: Monthly ecological releases (Mm^3)

IRt: Monthly irrigation Releases (Mm^3)

EC_t: Monthly ecological demand (Mm^3)

Lsc: Life storage capacity of the reservoir (Mm^3)

Dsc: Deadly storage capacity of the reservoir (Mm^3)

Technically available power is obtained by including losses due to conveyance, plant losses such as entrance loss, rack loss, generator, and turbine loss, etc. For SHP, the overall efficiency, e, of 50% is multiplied with the theoretical power to obtain the technically available power. The low overall efficiency is as a result of the following losses [8, 5, 16, 27, 38].

Penstock losses = 10%

Turbine losses =20%

Generator losses = 15.4%

Step-up and down transformer losses = 4%

Transmission losses = 10%

Other losses = 5%

Power output is obtained after all these losses are considered.

Power output = 0.5* power input

Therefore, overall efficiency, e for SHP=0.5. Due to the above reason, the overall efficiency of the power plant is 50% used for this study.

2.3.5. System and Problem Description for Scenarios of Complimentary Hydropower Release

In this scenario, hydropower is to be integrated as designated, so that the whole of the available flow is used to turn the turbine, after which diversion for various other uses can be achieved. This is the optimum plan since the turbine only needs water for turning purposes and can be fully released for other users. This plan must be combined into the main design at the beginning of the project for real operation.

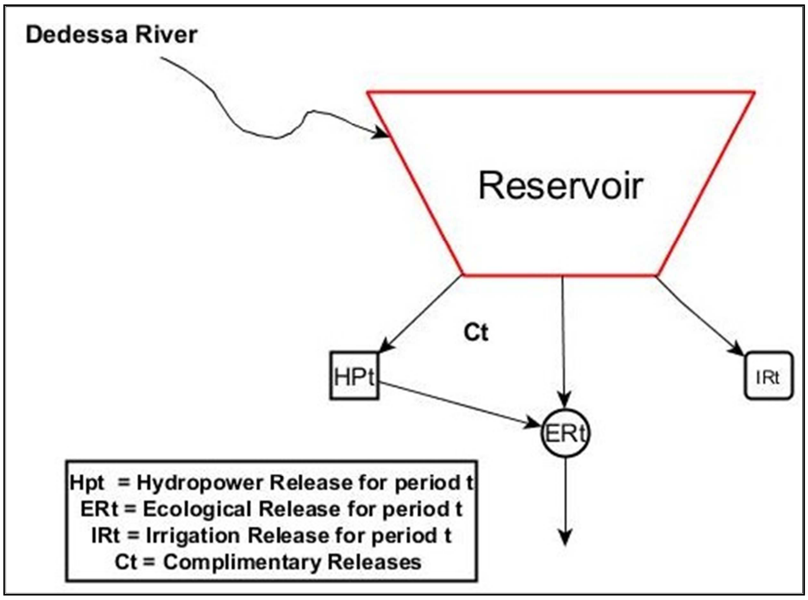

Figure 3. *System Diagram of the study for Scenario of Complimentary Hydropower release.*

2.3.6. Objective Function

The objective function is the maximization of the total annual energy generation TE, as presented in Equations 4 and 5. This has also been adopted, and the constraints for the scenario complimentary hydropower releases are given as follows:

2.3.7. Model Constraints

The constraints in equations (8) – (12) are also applicable in this scenario, but the constraints on the upper and lower releases change

$$TR_t = IR_t + C_t + HP_t \leq Upper\ limit. \quad (13)$$

$$TR_t = IR_t + C_t + HP_t \geq Lowe\ limit. \quad (14)$$

$$C_t + HP_t \geq ER_t. \quad (15)$$

Where:

Ct: Monthly complimentary release (Mm^3)

3. Result and Discussion

3.1. Yield Function

The storage yield function for the Arjo Dedessa dam is presented in Table 1. The maximum monthly draft that can be withdrawn from the reservoir with live storage of 1515.81 Mm^3 was found to be 284.5Mm^3. The corresponding values of possible total releases for live storage of 1000 Mm^3 and 2000 Mm^3 were determined to be about 216.55 Mm^3 and 285.74 Mm^3, respectively. The extra storage can be taken from the flood storage zone of the reservoir (when there is no tendency for the occurrence of the flood) for hydropower generation.

Table 1. *Model solutions for specified values of active storage.*

Storage (Mm^3)	10	40	70	100	200	400	600	800	1000	1200	1400	1600
Yield (Mm^3)	43.24	53.24	61.64	69.14	92.2	125.53	158.87	187.98	216.55	245	270	285.74

The storage yield function has a plot of live storage capacity (K) for different yield Y has presented in Table 1. This is an increasing function of yield Y, up to some maximum feasible value of Y. Beyond this, the problem becomes infeasible, meaning there is no enough water to yield Y in full each time. From table 1 we present that the storage capacity increases from 10 Mm^3 to 1520Mm^3, and the yield also increases from 43.24 Mm^3 to 285 Mm^3, respectively. After 1521Mm^3 of the storage capacity, the yield has a constant value of 285.74Mm^3. This means if building the reservoir beyond 285.74 Mm^3, it is all raised as far as the meeting yield is constant. The yield from the reservoir will not be any more than 285.74Mm^3, no matter how big reservoir is. 285.74Mm^3 is a constant release that can you maintain all through the year from the particular inflow segment. No matter how big the reservoir is well not be able to maintain a yield of more than 285.74Mm^3.

3.2. Reservoir Inflow of Various Probabilities of Exceedance

The best fit probability distribution was done by Easy Fit software. There are different types of probability distribution, but in this research 11 (eleven) types of probability distribution of best fit were tested by Kolmogorov, Smirnov, Anderson, Darling, and Chi-square using Easy Fit software. Reservoir inflow was fitted into a lognormal distribution based on the monthly mean inflow at the dam site of the historical 30-year data and extended of 6-year data. The lognormal models obtained for January to December, the forecast reservoir inflow of 50%, 75%, and 90%, probabilities of exceedance, and statistical parameters are presented in Table 2.

Table 2. *Reservoir inflow of different reliabilities (probability of exceedance) and Statistical parameters.*

Probability of exceedance (reliability of inflow)					
Month	**P**	**50%**	**75%**	**90%**	**Mean Inflow (Mm^3)**
	K	**0**	**-0.6743**	**-1.28**	
Jan		47.73	31.08	21.14	56.83
Feb		29.32	17.37	10.86	37.48
Mar		31.00	16.34	9.20	41.66
Apr		33.84	21.83	14.72	40.58
May		70.57	46.11	31.46	84.82
Jun		217.79	155.11	114.35	244.08
Jul		523.18	430.44	361.24	543.55
Aug		836.44	693.84	586.60	868.14
Sept		673.49	392.81	242.02	770.56
Oct		401.26	259.73	175.72	477.67
Nov		144.02	103.06	76.30	162.66
Dec		83.45	61.44	46.67	91.82
Total		3092.08	2229.16	1690.29	3419.85

3.3. Head as a Function of the Reservoir's Storage

The elevation and storage data from the landscape map of an Arjo Dedessa reservoir's impounding area and the tailwater elevation was assumed to obtain the relationship between the head and reservoir storage. Dimensions at site I have assumed the tailwater elevation is the same to the dead storage elevation to below of 5.9 m (1320 m amsl). The generating head as the function of storage has presented in Figure 4.

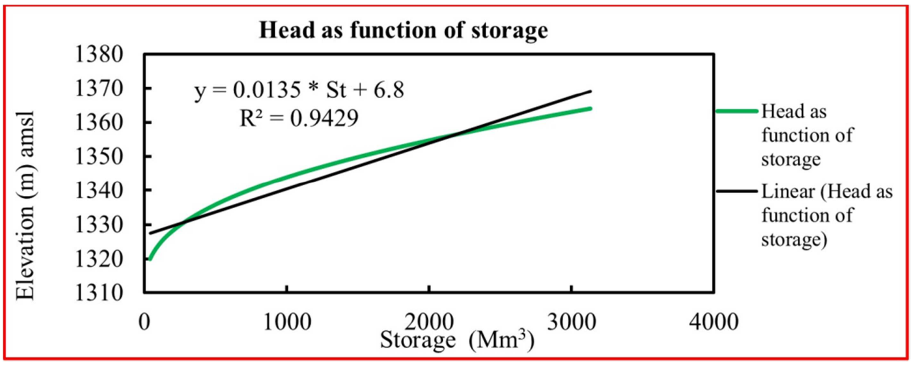

Figure 4. *Head as a function of storage for Arjo Dedessa Reservoir.*

The plot of the generating head against the reservoir storage was given an equation along with the coefficient of determination (R^2).

$$Linear\ Relationship\ H_t = 0.0135 * S_t + 6.8 \quad (16)$$

The coefficient of determination $R^2 = 0.943$

The objective function is to maximize the annual energy production from the existing reservoir by the integration of hydropower, which is also the fitness function. The equation of fitness function is shown in (16), where the average reservoir elevation is expressed as the function of the average storage, which is obtained using regression of reservoir elevation as a dependent variable and reservoir storage as a predictor.

3.4. The Optimal Hydropower Releases

The reservoir operation for this study was formulated using linear programming. The objective function has to maximize the annual energy generation potential with the constraints of irrigation release, ecological release, storage continuity, and the maximum and minimum yield. The release for irrigation and ecological has greater than the primary demand for irrigation and ecological, respectively. For the case of hydropower release, the constraint has a nonnegative value that means if the quantity water has insufficient for hydropower, it gives zero value, and otherwise it gives some value. This means the potential hydropower generation is not their primary priority, but the second is also called multipurpose scheme. This implies the integration of hydropower in the Arjo Dedessa dam while guaranteeing its primary function.

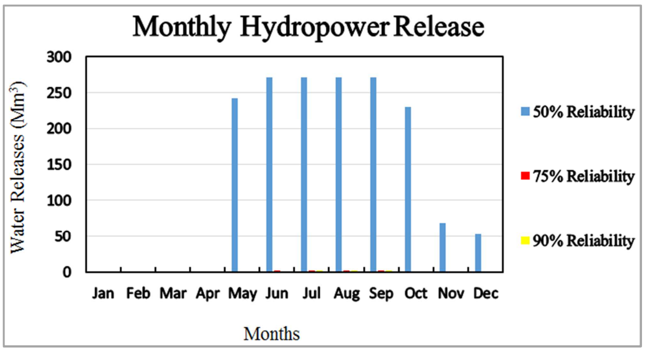

Figure 5. *Monthly Hydropower Release at different reliability for scenario of independent hydropower release at normal pool levels.*

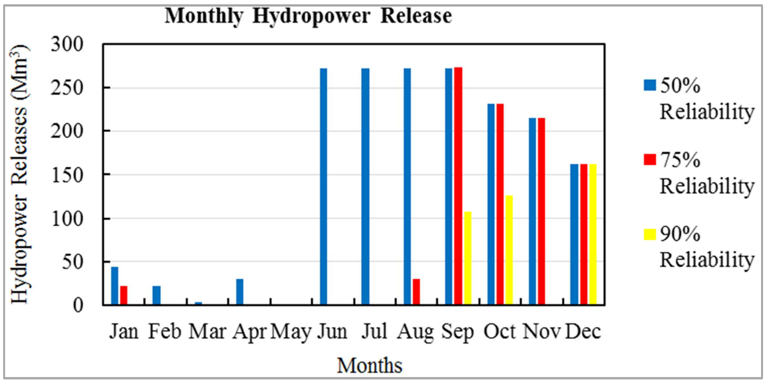

Figure 6. *Monthly Hydropower Release at different reliability for scenario of complimentary hydropower release at maximum water levels.*

3.4.1. For Scenario of Independent Hydropower Release

For the case of this scenario, the hydropower release has independent while the release, irrigation and ecological requirement have met the demands for irrigation and ecology. In this study, the scenario of independent hydropower release has considered the storage of the reservoir at a normal pool level and at the maximum water level. The result was presented in Figures 5 and 6.

As the figures indicate that for the case of the scenario of independent hydropower release with the zone flood storage (Area of water stored between above normal pool level and below the maximum water level), consider the hydropower release has more values than without flood considered. This shows that when the flood storage has stored, it gives more energy production. At the normal pool level, the hydropower power release of 75% and 90% reliability has very small, but at 50% reliability, the hydropower release has more during the period of May up to December.

At the maximum water level of the reservoir, the availability of water release for hydropower has occurred throughout the year except for both 75% and 50% reliability. At 90% reliability from January to August has no water release for hydropower.

3.4.2. For Scenario of Complimentary Hydropower Release

The procedure for solving the formulated problem is the same as the scenario of independent hydropower release but the difference is a complimentary release has been considered for this scenario. The hydropower and ecological release have complimentary releases. They solved a problem which has also considered two alternatives, i e., similar to the scenario of independent hydropower release, that means the reservoir at normal pool level and maximum water level present in Figures 7 and 8, respectively.

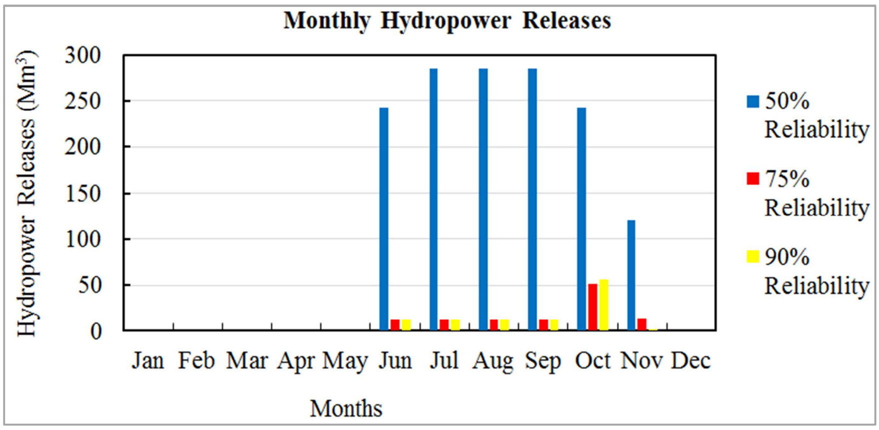

Figure 7. *Monthly Hydropower Release at different reliability for scenario of complimentary hydropower release at Normal pool levels.*

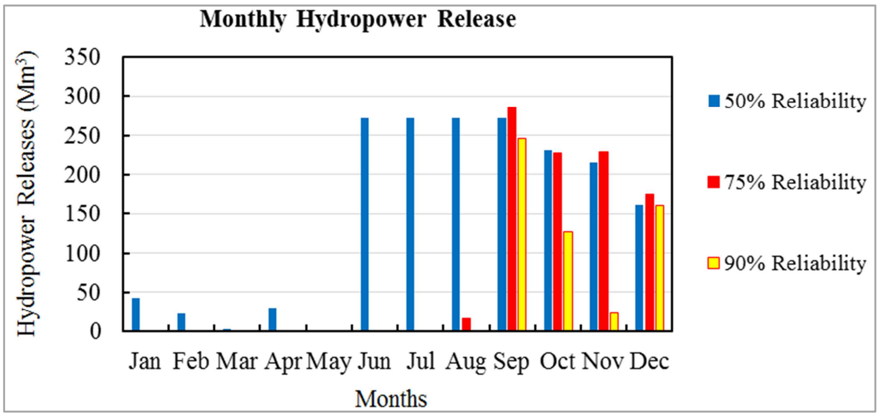

Figure 8. *Monthly Hydropower Release at different reliability for scenario of complimentary hydropower release at Maximum water levels.*

Overall, the result of the optimal hydropower release in both of the scenario independent hydropower release and complimentary hydropower release, it has indicated that the water release for hydropower in the scenario of complimentary hydropower release is greater than the scenario of independent hydropower release for both of the reservoir at normal pool level and maximum water level. The maximum hydropower release has occurred during the wet season while for the dry season the minimum hydropower release has been obtained. That means during the wet season the irrigation releases have almost zero and high irrigation release during the dry season because irrigation requirements have needed during the dry time, while during wet season no need for irrigation crop water requirements. The maximum water release for hydropower occurred for both scenarios independent hydropower release and complimentary hydropower release when the flood storage was considered. Therefore, the optimal hydropower generation has obtained also when flood storage has been considered for both scenarios.

3.5. Optimization Modeling

The optimization model has a maximization of hydropower generation as the objective function, while the reservoir's characteristics and other purposes are included in the constraints. The model formulated was solved using LINGO software. The model solutions of the hydropower potential for various reservoir inflows of 50%, 75%, and 90% are presented in Tables 3 and 4 for Scenarios Independent hydropower release and complimentary hydropower release respectively.

This is the general optimization model's formulation in the scenario of independent hydropower release. The monthly model is fully established and solved using LINGO 18.0. The model's solutions were determined in two categories. The results of the optimization showing the energy output are presented in Table 3.

Table 3. *Summary of hydropower potential (Scenario of Independent hydropower release).*

Upper limit Release (Mm^3)	Storage (Mm^3)	Hydropower for the flow of different reliabilities (MWH)		
		50%	75%	90%
284.45	1515.81	42072.3	38024.9	8652.77
285.74	1945.01	57037.5	39776.2	16947.4

The results of the optimization model for the scenario of complimentary hydropower release are presented in Table 4.

Table 4. *Summary of hydropower potential (Scenario of complimentary hydropower release).*

Upper limit Release (Mm^3)	Storage (Mm^3)	Hydropower for the flow of different reliabilities (MWH)		
		50%	75%	90%
284.45	1515.81	46141.5	39895.8	8762.77
285.74	1945.01	59143.1	40115.7	16992.7

3.6. Power Generation for the Scenarios

3.6.1. Scenario of Independent Hydropower Releases

The following inferences were drawn from the study based on the scenario of independent hydropower releases. The study establishes that the monthly maximum draft is 284.45Mm^3 with 50%, 75%, and 90% probabilities of exceedance being 4.44 MW, 0.031 MW, and 0.026 MW respectively.

The result indicates the reliability is greater than 75%, the annual hydropower has very small value, and there is no optimal power production with a satisfying reliability level of meeting the primary demand.

The hydropower power obtained with the upper limit of release of 285.74 Mm^3 and live storage of 1945.01 Mm^3 under reservoir inflow of 50%, 75%, and 90% probabilities of exceedance is 6.54 MW, 4.58 MW, and 2.01 MW respectively. From the results, one can find the maximum annual power that can produce by the powerhouse located at 1320m amsl for the specified reliability level of meeting irrigation demand with increasing the reservoir storage by considering the flood storage zone. The result indicates that the 50%, 75%, and 90% reliability there is annual hydropower has obtained and there is optimal power production with a satisfying reliability level of meeting primary demand.

3.6.2. Scenario of Complimentary Hydropower Releases

The following inferences were drawn from the study based on the scenario of complimentary hydropower releases. The hydropower energy obtained with the upper limit of release of 284.57Mm^3 and live storage of 1515.81Mm^3 under reservoir inflow of 50%, 75%, and 90% probabilities of exceedance is 4.59 MW, 0.4 MW, and 0.38 MW respectively. From the result, one can find the maximum annual power that can produce by the powerhouse located at 1320m amsl for a specified reliability level of meeting irrigation demand. The result indicates the reliability greater than 75%, the annual hydropower has very small value, and there is no optimal power production with a satisfying reliability level of meeting irrigation demand.

The hydropower energy obtained with the upper limit of release of 285.74Mm^3 and live storage of 1945.01Mm^3 under reservoir inflow of 50%, 75%, and 90% probabilities of exceedance is 6.78 MW, 4.62 MW, and 2.04 MW respectively.

From the result, one can find the maximum annual power that can produce by the powerhouse located at 1320m amsl for the specified reliability level of meeting irrigation demand with increasing the reservoir storage by considering the flood storage zone. The results indicates that the 50%, 75%, and 90% reliability there is annual hydropower has obtained and there is optimal power production with a satisfying reliability level of meeting primary demand.

The trend is that the greater the probability of exceedance (reliability), the smaller the reservoir inflow and the smaller the hydropower energy that can be generated.

4. Conclusions

From Optimization model, based on the optimization conducted on Arjo Dedessa dam by the integration of hydropower turbine the following conclusions have been made.

It is possible and is actually very wise to use irrigation dams for Small- electric energy generation so as to electrify the rural community without affecting the existing irrigation requirement by applying systems engineering as a planning tool.

The study has considered two scenarios for the optimization of hydropower generation potential of Arjo Dedessa dam with two alternative options of the live storage capacity of the dam using at normal water level and maximum water level storage. Scenario of independent hydropower is the release of water from the reservoir as the primary demand water required for irrigation and ecology while integration hydropower release independent. For scenario of complimentary releases, it is the same to scenario one but for ecology and hydropower generation the release has complimentary.

The optimal energy generation potential of the Arjo Dedessa dam is 57037.5 MWH (6.51MW) and 59143.1MWH (6.75MW) for scenarios independent hydropower release and complimentary hydropower release respectively.

Thus, the study has established that the Arjo Dedessa dam has other potential uses beyond irrigation and it is hoped that suitable for the production of hydroelectric power. The hydropower generated would enhance the quality of life of the people living in the Arjo community and improve the Arjo Dedessa irrigation scheme. This will eventually lead to a reduction in poverty since jobs will be available as small-scale industries spring up.

Conflict Interest

All the authors do not have any possible conflicts of interest.

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