

Integration between Geoinformatics and Programming for Evaluation of Potential Hydropower of Red Sea Hills in Egypt

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Abstract

Egypt has a huge potential for utilization methods to generate renewable energy. This paper aims to study the utilization of mixed pump-turbine system. Explanation behind its choice and its benefits would be discussed. The initial part of the research included studying the area and choosing a suitable location to act as a storage basin, then topographic and geographic information about the basins are then discussed in detail. The second part of the research involves deciding a suitable operating mechanism for the system. This would be performed by creation of a calculator script intended to simulate the operation of the system under different conditions. Results from these trials would then be compared with each other, in order to reach to an educated conclusion to the best method of operation to actualize such an idea.

Keywords: mixed pump, turbine system, renewable energy, operating mechanism, trials.

التكامل بين المعلوماتية الجغرافية والبرمجة لتقييم الطاقة الكهرومائية المحتملة لتلال البحر الأحمر في مصر

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مستخلص

تمتلك مصر إمكانات هائلة في طرق استغلال الطاقة المتجددة. ولهذا يهدف هذا البحث إلى دراسة الاستفادة من نظام المضخة والتوربين المختلط. وستتم مناقشة شرح سبب اختياره وفوائده. يتضمن الجزء الأولي من البحث دراسة المنطقة واختيار الموقع المناسب ليكون بمثابة حوض تخزين، ثم تمت مناقشة المعلومات الطبوغرافية والجغرافية عن الأحواض بشكل تفصيلي. الجزء الثاني من البحث يتضمن تحديد آلية التشغيل المناسبة للنظام. وسيتم تنفيذ ذلك عن طريق إنشاء برنامج نصي للآلة الحاسبة يهدف إلى محاكاة تشغيل النظام في ظل ظروف مختلفة. ويتم بعد ذلك مقارنة نتائج هذه التجارب مع بعضها البعض، من أجل الوصول إلى نتيجة مدروسة لأفضل طريقة تشغيل لتحقيق مثل هذه الفكرة.

الكلمات المفتاحية: المضخة المختلطة، النظام التوربيني، الطاقة المتجددة، آلية التشغيل، التجارب.

(1) دكتوراه في الجغرافيا الطبيعية.

(2) ماجستير الهندسة الهيدروليكية.

(3) أستاذ مساعد بقسم الهندسة المدنية كلية هندسة المطرية جامعة حلوان.

1 Introduction:

The substantial increase in power generation from variable renewable sources has been led to extreme interest in energy storage. Pumped hydropower remains the only mature and widely-adopted utility scale energy storage technology. However, the selection and development of new pumped hydropower sites are heavily influenced by physical constraints such as terrain, as well as non-physical considerations (**Fitzgerald et al., 2012**).

Electricity generation from hydropower remains the first source of renewable energy. Development of energy from the renewable source is one of the important steps in reduction of CO₂ emission that could mitigate the effect of climate change (**Wali U., G., 2013**).

Renewable energy represents a critical method of increasing energy production through which the ever-increasing demands of the nation could be satisfied. This is especially true for Egypt, where energy derived from natural sources is very limited (**Bartle, 2002**). This process requires in-depth knowledge of possible means by which the energy manifested in these mediums can be converted into a usable form and transported. Natural sources of energy provide additional advantages when properly harvested. Also they are completely renewable and cleaner than traditional sources of energy such as coal and gas, which in turn reduces pollution and harm to the environment (**Sorensen, 2004**).

On the other hand, natural or renewable energy is difficult to harvest into a form that is easily transported and usable in accordance to the popular habits of energy consumption. The way by which this obstacle is overcome is by utilizing specialized machinery and technology that is specifically designed and manufactured to be of suitable use in regards to the environment it is placed in and the purpose it aims to achieve. This results in an extremely high initial cost for setting up a system of natural sources of energy, although that cost is gradually being reduced with modern technological developments (**Sorensen, 2004**).

Another concern regarding natural energy in general is the fact that changes within the environment can cause unreliability with the extraction of such energy. These changes within the environment can be seasonal or nannual, and even due to rare occurrences of natural disasters or calamities caused by man. Nevertheless, the constant endangerment to the environment which is caused by pollution from the traditional processes of energy production by coal and biomass had encouraged numerous individuals and research facilities to research the viability of integrating natural sources of energy along with the traditional systems of energy production, in an effort to move towards more environmental friendly solutions and to also reducing the impact of the depletion of the non-renewable energy sources.

1- The area of the study:

El-Malha reservoir is figure (1) considered the mouth of El-Malha Wadi , which locates in the Eastern Desert of Egypt , and bounded by coordinates $33^{\circ} 20' 13''$ to $33^{\circ} 31' 1''$ E and $27^{\circ} 26' 43''$ to $27^{\circ} 39' 49''$ N. Its area is estimated 140.98 km^2 , with its shortest distance to the coast measuring 4.4 km, and elevated from 50 to 289 m. The reservoir is surrounded by Bili Wadi (**Al-masalmeh and Eizeldin , 2019**) in the south border , the red sea at the east border , El-malha Wadi and Red Sea Hills in the west border , and Abu Had Wadi in the north border .

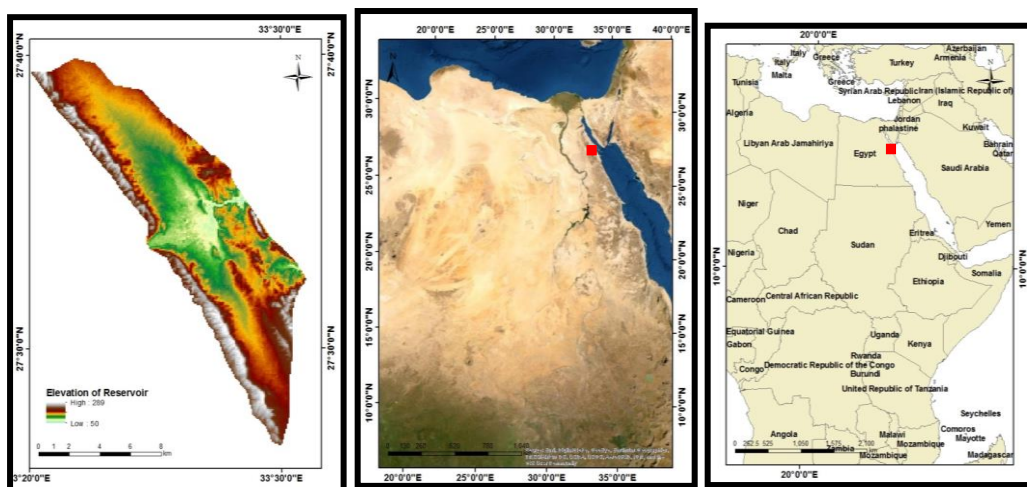


Figure (1): Location of El-Malha reservoir

2-Methodology:

The proposed methodology is divided in two main phases:

Initial phase represents selection the reservoir location started by collecting the relevant data ; Topographic map with scale 1:25000 NG 36-4 & NG 36-3 & NG 36-2 which cover study area issued by (**Army Map Service, 1991**) and the Digital Elevation Model (DEM) of 30 m resolution, released in November 2011 under the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) program (**Meti and Nasa, 2011**). GIS techniques used for selecting reservoir area and assessing this location as it provides a flexible environment and a powerful tool for manipulating and analysis the spatial information, thus GIS spatial analyses had allowed developing a number of methodologies to calculate hydropower potentials (**Feizizadeh and Haslauer, 2012**). So, Esri Arc Map 10.5 software has been used to analyse the data.

Second phase : integrate between GIS and MATLAB which has the primary advantage of its extreme utilisation of matrices and their various functions which is necessary due to the nature of the required script. Nearly all variables that contribute to changes within the reservoir and power outage can be described as a string of numbers, such as number of months for running, number of initial water level at which the calculation is performed, different discharge and duration combinations. All of these variables can be easily written in a suitable array of rows and columns which in turn can easily be utilized by the computing environment (the script programmed by MAT Lab) in order to yield results for multiple runs and iterations.

3-Results and discussion:

The goal of this paper is proposing the construction of a pump-turbine system within the chosen area of basins and to study the different possible operation schemes of this system, also for its energy production.

3.1. Reservoir volume at different levels.

The reservoir volume was calculated using geo-processing algorithms of Arc-Map 10.5 software on the basis of ASTER DEM. Calculation of the storage volume by subtracting the elevation of the DEM from the water surface elevation of the reservoir created by the dam ,(table1), and then summing up the storage volume (RVEM, 2011).

Table (1): Reservoir volume at different levels.

Level	Area/km ²	Volume/km ³
80	1.7	0.008
100	12.6	0.129
120	28	0.52
140	47.5	1.2
160	77.9	2.5

This table shows that when reservoir is filled with water at a level of 80 m, the water will cover 1.7 km² of reservoir area, then water volume will be estimated at 0.008 km³, while when it is filled, the reservoir at the level of 100 m will increase the area covered with water to 12.6 km² and the water volume will be 0.129 km³, and if the reservoir is filled up to the level of 120 m it will increase the covered area to 28 km², and the water volume will be estimated at 0.52 km³, and if the reservoir is filled, the level of 140 m will fill the covered area will be 47.5 km² and estimated The volume of water is 1.2 km³, finally when we fill the reservoir to the level 160 m, the covered area will be 77.9 km², and the volume will be 2.5 km³. The correlation coefficient between the stored water level and the area covered by the reservoir is 0.98. This confirms the existence of a strong correlation between them, record correlation coefficient between the water level and the amount of stored water is 0.936. This confirms that there is a very strong correlation between them, figures (2 and 3) indicate 3rd model for the reservoir.

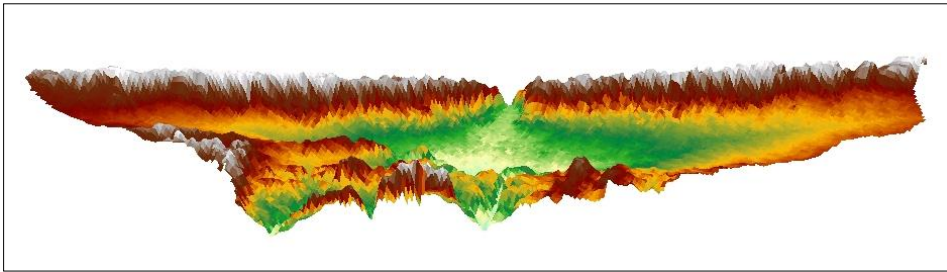


Figure (2): Reservoir of 3rd model.

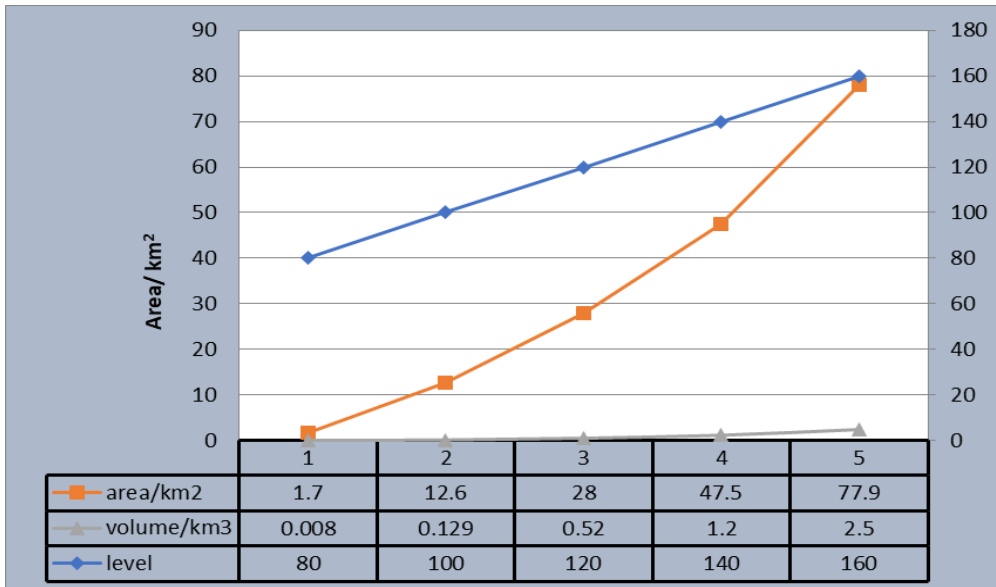


Figure (3): Correlation between reservoir area, level and volume.

3.2 Creating an environment for trial runs:

MAT Lab has the primary advantage of its extreme utilisation of matrices and their various functions which is necessary due to the nature of the required script. Nearly all variables that contribute to changes within the reservoir and power outage can be described as strings of numbers, such as number of months for running, number of initial water level at which the calculation is performed, different discharge and duration combinations, and more. All of these variables can easily be written in a suitable array of rows and

columns which in turn can easily be utilized by the computing environment (the script programmed by MATLAB) in order to yield results for multiple runs and iterations.

The following sections describe the creation process for the script, explaining the mind map of the running code as well as a detailed description of each segment of coding.

In order to integrate the chosen reservoir into the computing environment for it to be the basis of computation, it was necessary to determine the parameters by which the reservoir would be accurately described for the script. This can be done in multiple ways using graphs or even the simulation of the three dimensional inner surface of the reservoir using equations. In order for the latter option to be viable and properly implemented would require extreme amounts of effort, which would prove to be a separate endeavour in its own rights.

This is reason for choosing this method of integrating the reservoir into the script. This was done by defining three particular parameters to be known and understood within the computational environment, namely the water level within the reservoir as well as the surface area and volume of the water at any certain level. Achieving this can be done by utilizing any of multiple mathematical methods, which include but are not limited to interpolation, polynomial, power, sum of sine and smoothing spline. Smoothing spline was the chosen method for creating an entire series of data between the five given points. A smoothing spline can be defined as a piecewise polynomial computed based on a smoothing parameter. The reason smoothing spline was the chosen method was due to its ability to obtain estimates from noisy observations. Given the fact the provided observations were of acceptable accuracy, the extracted curve was reasonable and reflected the expected behaviour from the provided observations. A smoothing parameter of (1) was chosen for the data, which represented the largest smoothing factor, providing a curve that follows closely to the provided points. The provided data of water level, surface area, and water volume were then integrated within the

computing environment, relating every level to its respective water surface area and water volume.

The primary equation through which the script runs focuses on the net quantity of water moving through the basin, whether to it or from it. That is to say that the change of volume was the primary variable through which all other parameters were determined. The equation for change of volume is represented as **(M.A and M.B, 2006)**:

$$\Delta S_{\text{month}} = \frac{[(Q_{\text{in}} * t_{\text{in}} - Q_{\text{out}} * t_{\text{out}}) * 3600 * 30 + (P - E) * 30 * 10^{-3} * A * 10^6]}{10^9}$$

Where:

ΔS = Change of volume within the basin per month, in km³.

Q_{in} & Q_{out} = Discharge into and out of the basin respectively, in m³/sec.

t_{in} & t_{out} = time for moving water in and out of the basin respectively, in hours.

P = Average monthly precipitation within the area of the basin, in mm/day.

E = Average monthly evaporation within the area of the basin, in mm/day.

A = Surface area of the water within the basin within current month, in km².

Simplifying the equation by dividing the numerator and denominator yields:

$$\Delta S_{\text{month}} = \frac{[(Q_{\text{in}} * t_{\text{in}} - Q_{\text{out}} * t_{\text{out}}) * 10.8 + (P - E) * A * 3]}{10^5}$$

Given a specific value for incoming and outgoing volumes of water and the durations of operation for either phase of filling and emptying during the day, as well as specifying the operation duration in months, it was then fairly simple to be able to determine the properties of the basin. This can be achieved for any number of months of operation, under any discharge conditions, and with any desired initial level of water.

The main parameters of focus resulting from the running an iteration are represented in the level of water surface, the volume of water within the basin, the surface area of the water, as well as the net volume of moved water, whether out of or into the basin.

This information is represented for each month of operation of the pump-turbine system and stored within tables. The resulting information is also represented in the form of a graph showing each of the four mentioned parameters, with the duration represented in months along the abscissa. The following graphs are examples of this, representing a duration of 1 year, with an initial water level of 130 meters, an outgoing discharge from the reservoir of 125 m³/sec for 5 hours per day, and an incoming discharge to the reservoir of 75 m³/sec for 10 hours per day.

3.3 Power calculation:

Creation of a suitable computing script that closely represents the actual behavior of the reservoir in operation, and also determining a reservoir from between the three different possible basins of choice, it is therefore necessary to include calculations for the power consumption and power generation which occurs during filling and emptying of the reservoir, respectively. This can be represented with the following equation:

$$P = \gamma Q h$$

Where:

P: Power generated in Work/Time or Watts, represented as $\text{kg}\cdot\text{m}^2\cdot\text{s}^{-3}$

γ : Specific weight of water, which is equal to 9810 N/m^3

Q: Water discharge represented in m^3/sec

h: Water head, represented in meters

Analyzing the previous equation shows that the only parameter that is missing and needs to be calculated before being able to calculate the power generated or consumed is the water head (h). The water head is calculated differently for both the consumption and generation of energy, accounting for the difference between operating a pump and operating a turbine. Operation of the pump consequently means the filling of the reservoir and therefore the consumption of electricity, whereas operating the turbine is the reverse operation to that which entails the emptying of the reservoir and the generation of electricity. The water head for the operation of each of the pump and the turbine can therefore be represented with the following equations:

$$h_{\text{pump}} = \text{Water Head} + \text{Head Losses}$$

$$h_{\text{turbine}} = \text{Water Head} - \text{Head Losses}$$

Head losses can be separated into major head losses, which are frictional head losses throughout the length of the pipe, and minor head losses which occur due to pipe geometry. Calculating head losses within the system can be achieved by numerous ways. The most accurate method to achieve that would be by studying a proposed pipe system, for which the minor and major head losses can be effectively determined based on the details of the proposed pipe system such as its length, diameter, number of pipes, its friction coefficient based on its material, as well as the presence of any fittings or pipe geometry changes. This was an attempt but would prove to be beyond the scope of this research as it would require the creation of a pipe system which would then be analyzed and studied.

Nevertheless a brief overview is presented regarding the undertaken steps in this approach, to explain the faced difficulties with it, before presenting the simpler method which was chosen for calculating head losses.

In the presence of a pipe system, or the proposition of one such system based on research, the calculation of head losses would be focused on the utilization of the Darcy-Weisbach equation for the calculation of frictional losses and the calculation of the minor head losses based on the fittings and pipe geometry within the system. Head losses can be calculated by the following Darcy-Weisbach equation:

$$HL_f = f * \frac{L}{D} * \frac{V^2}{2g}$$

A pipe system was therefore assumed with the following properties:

Pipe Diameter: 2 meters

Pipe Length: 4400 meters

Number of pipes: 8

Coefficient of friction (f): 0.01

Nevertheless, due to these assumptions being based on the observation of similar projects, they resulted in unreasonable and unacceptable values for head losses.

Head losses were therefore calculated based on an empirical assumption of being equal to 1/3 of the level of water within the basin. This greatly simplified the process of calculating head losses to a degree that is reasonable for the scope of the project and lead to much more reasonable results.

The power equation of pump and turbine can be therefore presented as the following:

$$P_{Consumed} = 9810 * Q_{in} * \left(Level + \frac{1}{3} * level \right) * 10^{-6}$$

$$P_{Generated} = 9810 * Q_{out} * \left(Level - \frac{1}{3} * level \right) * 10^{-6}$$

Where $P_{consumed}$ refers to the power consumed by the pump during filling and $P_{generated}$ refers to the power generated from the turbine during emptying the basin. The results are presented in Mega Watts.

This lead to calculation of the value of power generated and consumed yearly, in GWatthr/year, according to the following equations:

$$P_{Con.year} = 9810 * Q_{in} * \left(Level + \frac{1}{3} * level \right) * 10^{-9} * Dur_{filling} * 365$$

$$P_{Gen.year} = 9810 * Q_{out} * \left(Level - \frac{1}{3} * level \right) * 10^{-9} * Dur_{emptying} * 365$$

Therefore the rate of power consumption for each of the processes of filling and emptying the reservoir can be calculated and documented in tables, and also presented in graphs, for each trial run of the script. This provides a clear idea about the amount of electricity that can be generated from such a project for each cycle of emptying and filling, as well as throughout the entire operation duration during a trial tables (2, 3).

Table (2): power calculation

Level (m)/Vol	Qout (m ³ /sec)	Qin (m ³ /sec)	Ratio (%)	Level Range	Difference (m)	P Consumed (MWatt)	P Extracted (MWatt)	Est/Con Min.	Est/Con Max.	P Consumed (TWhatt/yr)	P Extracted (TWhatt/yr)	
80/0.0080	100.00	50.35	1.0070	80.00	82.50	2.50	52.70	54.40	52.32	54.00	96.25	99.25
	150.00	75.35	1.0047	80.00	82.50	2.50	78.85	81.25	78.50	80.95	143.90	148.50
	200.00	100.35	1.0035	80.00	82.50	2.50	105.00	108.37	104.65	108.00	191.65	191.00
	250.00	125.35	1.0028	80.00	82.50	2.50	131.20	135.50	130.80	135.15	239.45	247.35
	300.00	150.35	1.0023	80.00	82.50	2.50	157.40	162.40	157.00	161.95	287.10	296.20
	350.00	175.35	1.0020	80.00	82.50	2.50	183.50	189.50	183.10	189.15	334.90	345.90
	400.00	200.35	1.0018	80.00	82.50	2.50	209.65	216.50	209.35	216.10	382.60	395.10
	450.00	225.35	1.0016	80.00	82.50	2.50	235.85	243.65	235.50	243.30	430.40	444.55
	500.00	250.35	1.0014	80.00	82.50	2.50	262.00	270.50	261.55	270.10	479.10	493.70
	1000.00	500.35	1.0007	80.00	82.50	2.50	524.55	541.10	523.25	540.80	955.50	987.55
85/0.0235	100.00	50.48	1.0096	84.14	85.37	1.23	55.54	56.39	55.00	55.85	101.35	102.90
	150.00	75.50	1.0067	84.14	85.47	1.33	83.12	84.45	82.56	83.88	151.69	154.50
	200.00	100.50	1.0050	84.18	85.51	1.33	110.62	112.38	110.06	111.83	201.88	205.10
	250.00	125.50	1.0040	84.18	85.50	1.32	138.15	140.40	137.60	139.85	252.14	256.22
	300.00	150.50	1.0033	84.18	85.50	1.32	165.69	168.35	165.14	167.78	302.39	307.21
	350.00	175.52	1.0030	84.22	85.55	1.33	193.35	196.45	192.75	195.88	352.85	358.55
	400.00	200.50	1.0025	84.18	85.54	1.36	220.69	224.25	220.14	223.70	402.75	409.25
	450.00	225.50	1.0022	84.15	85.52	1.37	248.15	252.31	247.60	251.75	452.88	460.50
	500.00	250.52	1.0021	84.21	85.65	1.44	275.89	280.62	275.30	280.05	503.50	512.15
	1000.00	500.53	1.0011	84.23	85.70	1.47	551.30	560.65	550.85	560.00	1006.25	1023.15
90/0.0450	100.00	50.90	1.0180	89.15	90.65	1.50	59.34	60.38	58.28	59.32	108.30	110.20
	150.00	75.90	1.0120	89.18	90.70	1.52	88.55	90.08	87.47	89.02	161.58	164.40
	200.00	100.90	1.0090	89.19	90.70	1.51	117.60	119.73	116.75	118.63	214.64	218.44
	250.00	125.90	1.0072	89.18	90.71	1.53	146.78	149.27	145.72	148.20	267.85	272.40
	300.00	150.89	1.0059	89.10	90.63	1.53	175.95	179.00	174.90	177.94	321.10	326.68
	350.00	175.87	1.0050	89.10	90.65	1.55	204.98	208.30	203.98	207.28	374.10	380.15
	400.00	200.87	1.0044	89.09	90.60	1.52	234.09	238.09	233.09	237.03	427.20	434.45
	450.00	225.86	1.0038	89.09	90.50	1.41	263.14	267.60	262.14	266.59	480.21	488.39
	500.00	250.86	1.0034	89.10	90.53	1.43	292.28	297.10	291.28	296.00	533.40	542.05
	1000.00	500.90	1.0018	89.15	90.70	1.55	584.00	594.50	583.00	593.90	1065.95	1085.00
100/0.1290	100.00	51.75	1.0350	98.90	100.50	1.60	66.90	68.03	64.63	65.72	122.09	124.18
	200.00	101.75	1.0175	98.80	100.48	1.68	131.60	133.84	129.34	131.52	240.18	244.25
	300.00	151.75	1.0117	98.79	100.50	1.71	196.18	199.44	193.90	197.15	358.00	364.00
	400.00	201.75	1.0088	98.90	100.70	1.80	260.90	265.45	258.64	263.12	476.18	484.50
	450.00	226.75	1.0078	98.85	100.65	1.67	293.23	298.65	290.85	296.30	535.00	544.90
	500.00	251.75	1.0070	98.88	100.55	1.70	325.48	331.15	323.23	328.75	594.00	604.25
	1000.00	501.70	1.0034	98.89	100.50	1.61	648.20	658.75	645.90	656.50	1182.80	1202.25

Table (3): power calculation

Level (m)/Vol	Qout (m3/sec)	Qin (m3/sec)	Ratio (%)	Level Range	Difference (m)	P Consumed (MWatt)	P Extracted (MWatt)	Ext.(Con Min.	Ext.(Con Max.	P Consumed (TWatt/Hr/Yr)	P Extracted (TWatt/Hr/Yr)	
110/0.2938	100.00	52.82	1.0564	108.50	110.56	2.06	74.87	76.40	70.90	72.35	136.80	139.55
	200.00	102.85	1.0285	108.70	110.75	2.05	146.10	148.85	142.02	144.77	266.60	271.77
	300.00	152.85	1.0190	108.60	110.90	2.30	217.00	221.50	213.00	217.38	396.08	404.25
	400.00	202.82	1.0141	108.58	110.55	1.97	288.00	293.70	284.00	289.60	525.60	536.00
	450.00	227.85	1.0127	108.58	110.70	2.12	324.10	330.53	320.00	326.40	591.48	603.27
	500.00	252.85	1.0114	108.59	110.61	2.02	359.40	366.25	355.30	362.17	665.85	668.47
	1000.00	502.82	1.0056	108.59	110.50	1.91	713.90	727.50	709.90	723.48	1302.87	1327.80
	100.00	54.00	1.0800	118.19	120.61	2.42	83.47	85.23	77.32	78.88	152.34	155.54
	200.00	104.10	1.0410	118.60	121.24	2.64	161.37	164.75	155.00	158.50	294.50	306.65
	300.00	154.10	1.0273	118.43	120.93	2.50	238.90	244.15	232.53	237.60	436.00	445.50
120/0.5200	400.00	204.05	1.0203	118.27	120.90	2.63	315.75	322.14	309.50	315.75	576.50	587.90
	450.00	229.05	1.0180	118.30	120.85	2.55	354.60	362.00	348.27	355.65	647.10	660.72
	500.00	254.05	1.0162	118.20	121.03	2.83	392.75	401.07	386.50	394.68	716.75	732.00
	1000.00	504.05	1.0081	118.20	120.85	2.65	780.85	797.35	774.50	790.85	1425.00	1455.00
	100.00	55.37	1.1074	128.30	131.43	3.13	92.75	94.72	83.75	85.50	169.30	172.76
	200.00	105.37	1.0537	128.15	130.70	2.55	176.55	180.70	167.55	171.50	322.30	329.77
	300.00	155.38	1.0359	128.10	131.80	3.70	260.95	266.10	251.47	256.85	475.30	485.70
	400.00	205.38	1.0269	128.24	131.10	2.86	344.65	352.20	335.65	343.00	629.00	642.75
	450.00	230.40	1.0240	128.40	131.10	2.70	386.00	395.75	377.00	386.50	704.50	722.20
	500.00	255.38	1.0215	128.05	130.90	2.85	427.75	437.55	418.70	428.40	780.70	798.65
130/0.7965	1000.00	505.38	1.0108	128.30	131.05	2.75	847.70	867.50	838.65	858.25	1547.00	1583.00
	100.00	59.20	1.1840	148.05	151.10	3.05	114.60	117.52	96.75	99.25	209.18	214.50
	200.00	109.20	1.0920	148.05	151.30	3.25	211.18	215.78	193.35	197.68	385.38	393.98
	300.00	159.20	1.0613	148.20	151.10	2.90	308.48	314.22	290.65	296.00	562.95	573.40
	400.00	209.20	1.0460	147.95	151.20	3.25	405.30	413.77	387.50	395.60	739.73	755.25
	450.00	234.23	1.0410	148.05	151.60	3.55	453.50	464.83	435.60	446.50	827.70	848.40
	500.00	259.20	1.0368	148.30	151.45	3.15	501.25	512.50	483.47	494.45	914.60	935.50
	1000.00	509.20	1.0184	148.00	151.20	3.20	986.15	1008.73	968.40	990.50	1799.60	1841.00
	100.00	59.20	1.0184	148.00	151.20	3.20	986.15	1008.73	968.40	990.50	1799.60	1841.00
	200.00	109.20	1.0368	148.00	151.20	3.20	1972.30	2017.46	1936.80	1981.00	3599.20	3682.00
300.00	159.20	1.0552	148.00	151.20	3.20	2958.45	3017.19	2890.20	2940.50	5398.80	5523.00	
400.00	209.20	1.0736	148.00	151.20	3.20	3944.60	4016.26	3863.60	3914.00	7198.40	7364.00	
450.00	234.23	1.0920	148.00	151.20	3.20	4430.75	4516.51	4294.50	4370.00	8088.00	8296.00	
500.00	259.20	1.1104	148.00	151.20	3.20	4916.90	5016.26	4670.25	4755.00	8977.00	9186.00	
1000.00	509.20	1.0184	148.00	151.20	3.20	9833.80	10074.52	9668.00	9910.00	17992.00	18420.00	

3.3 Determining Optimal Operation Conditions:

Of the numerous parameters controlling the operation of such a system, the initial level of water within the basin was chosen to be the main bounding factor on which other parameters would be based. The optimal operation conditions for such a system at any level are the conditions that result in least fluctuations of water level, ensuring that the water level always remains as close as possible to the initial water level within the reservoir.

A constant value for the duration of emptying and filling has been set throughout all the trial runs. The emptying cycle of the reservoir lasts for a duration of 5 hours per day, whereas the filling cycle lasts for a duration of 10 hours. It is important to ensure that the filling cycle occurs during the hours of low energy consumption and therefore a low cost for the power consumed, whereas the cycle for generating electricity occurs during peak consumption hours where the cost of power is higher.

The second factor was therefore the outgoing discharge, which is the amount of water volume emptied from the basin per second (Q out). Thus for a set of different outgoing discharges, it is necessary to determine the accompanying incoming discharge which would result in least fluctuations of the water level throughout the duration of operation. This was performed for varying values of outgoing discharges. Multiple trial runs have been performed for each value of the outgoing discharges. This process was repeated at multiple initial water levels, to obtain a detailed view of the best operation conditions at different levels and discharges. The outgoing discharge values for which trial runs have been performed at each selected water level are the following : (**80 -85 – 90 – 100 – 110 – 120 – 130 -150 m**).

The reason for why the outgoing discharge is chosen to be the second bounding parameter, rather than the incoming discharge, is due to the fact that controlling the outgoing discharge results in controlling the rate of generated electricity, making it possible to set

it at a constant value that is easily measurable. Nevertheless within the greater scope of the project, choosing either of the outgoing or incoming discharges to be the bounding parameter would result in little differences, as long as it is controlled and adjusted to produce the required levels of power. Therefore it becomes necessary to determine the value of the incoming discharge which would result in the least fluctuation when in operation with the outgoing discharge. It is also necessary to determine the factor between the incoming to the outgoing discharge, which can be done by the following equation:

$$Factor = \frac{Q_{in} * Dur_{in}}{Q_{out} * Dur_{out}}$$

A lower factor between the incoming to the outgoing discharge is preferable as it translates to a smaller amount of water being lost due to evaporation and seepage, and therefore a smaller loss in revenue, as any volume of water is translated to generated revenue. Higher values for incoming and outgoing discharges result in a smaller factor, due to the amount of evaporated water remaining constant, whereas the amount of water in circulation is increased, resulting in a higher rate of efficiency of water volumes. Lower elevations within the reservoir also result in a smaller incoming to outgoing factor as the lower elevations contribute to a smaller surface area, and therefore lower rates of evaporation. The volume of water moved into the reservoir will always be greater than the volume of water moved out of the reservoir, if left to the natural condition of an uncovered surface of water.

Any of the two parameters that need to be determined, the factor between discharges or the incoming discharge, can be obtained first. This is performed through the process of trial and error, by assuming an initial value and running multiple trials until a suitable value is determined that results in least fluctuations in water level. Examples of both scenarios are presented within the following graphs.

3.4 Determining Discharge Factors First:

Figure (4) represents a case where the factor of incoming to outgoing discharge was first determined through multiple trials, after which the suitable incoming discharge was determined. Each individual line that is graphed represents an individual set of incoming and outgoing discharges. The data numbering follows the same order in which the discharges are presented in table (4), with the outgoing discharges remaining at the constant values presented in the table and the incoming discharges being determined according to the ratio between them.

It is possible to determine the most preferred discharge values and the ratio between them at any level within the reservoir.

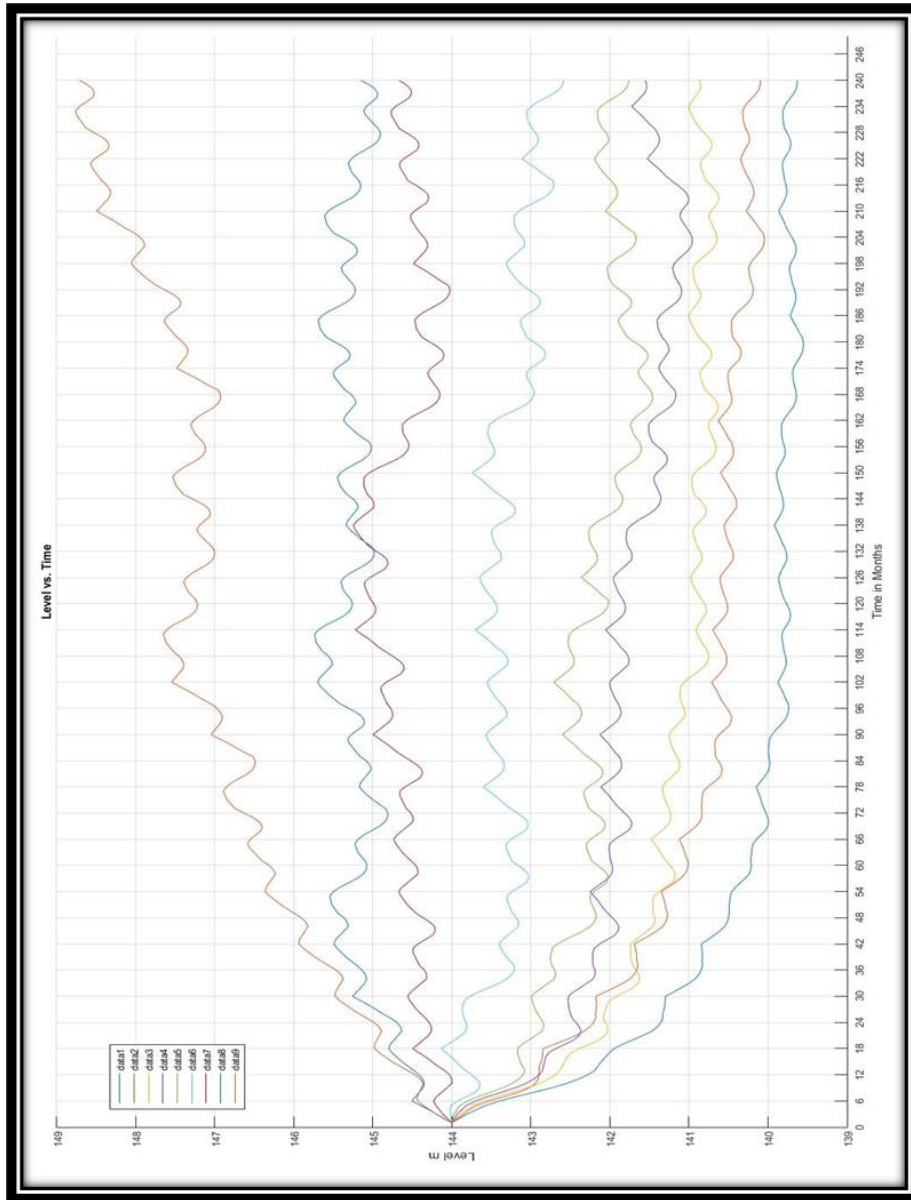


Figure 4: Determining suitable discharge values based on the determined ratio

This figure represents the ratio of incoming to outgoing discharges of 1.125, at an initial level of 144 meters. It can be deduced from the figure that the most preferred data set within the graph due to it having the least fluctuations and remaining as close as possible to the initial water level.

3.5 Determining incoming discharge first:

Another example could be presented for the case of first determining the incoming discharge that would result in least fluctuation of the initial water level, and following it calculating the factor between the incoming and outgoing discharges. This is performed through multiple runs of trial and error, in order to determine the most suitable discharge combination. Presented within the figure (5) is an example for that. Contrary to figure (4) where each graphed line represents a distinct incoming and outgoing discharge set that satisfies the chosen ratio, each graphed data line within figure (3) represents a different trial run that was performed under the same conditions of discharge. Thus all graphed lines within figure (5) represent the exact same set of incoming and outgoing discharges, creating a good estimation for the minimum and maximum fluctuations of water levels around the initial level. This procedure of presenting the results of multiple trial runs that were performed under the same conditions is representative of a sensitivity analysis that clearly presents the maximum and minimum bounds of water levels which could occur under the proposed conditions of operation, such as discharge values and their durations. The example in figure (3) represents an initial water level of 110 meters, an incoming discharge of $300 \text{ m}^3/\text{sec}$ for the duration of 5 hours per day, an outgoing discharge of $152.85 \text{ m}^3/\text{sec}$ for the duration of 10 hours per day, which was determined to be the most suitable for least fluctuations in water level through trial and error. Therefore this results in an incoming to outgoing discharge ratio of 1.019.

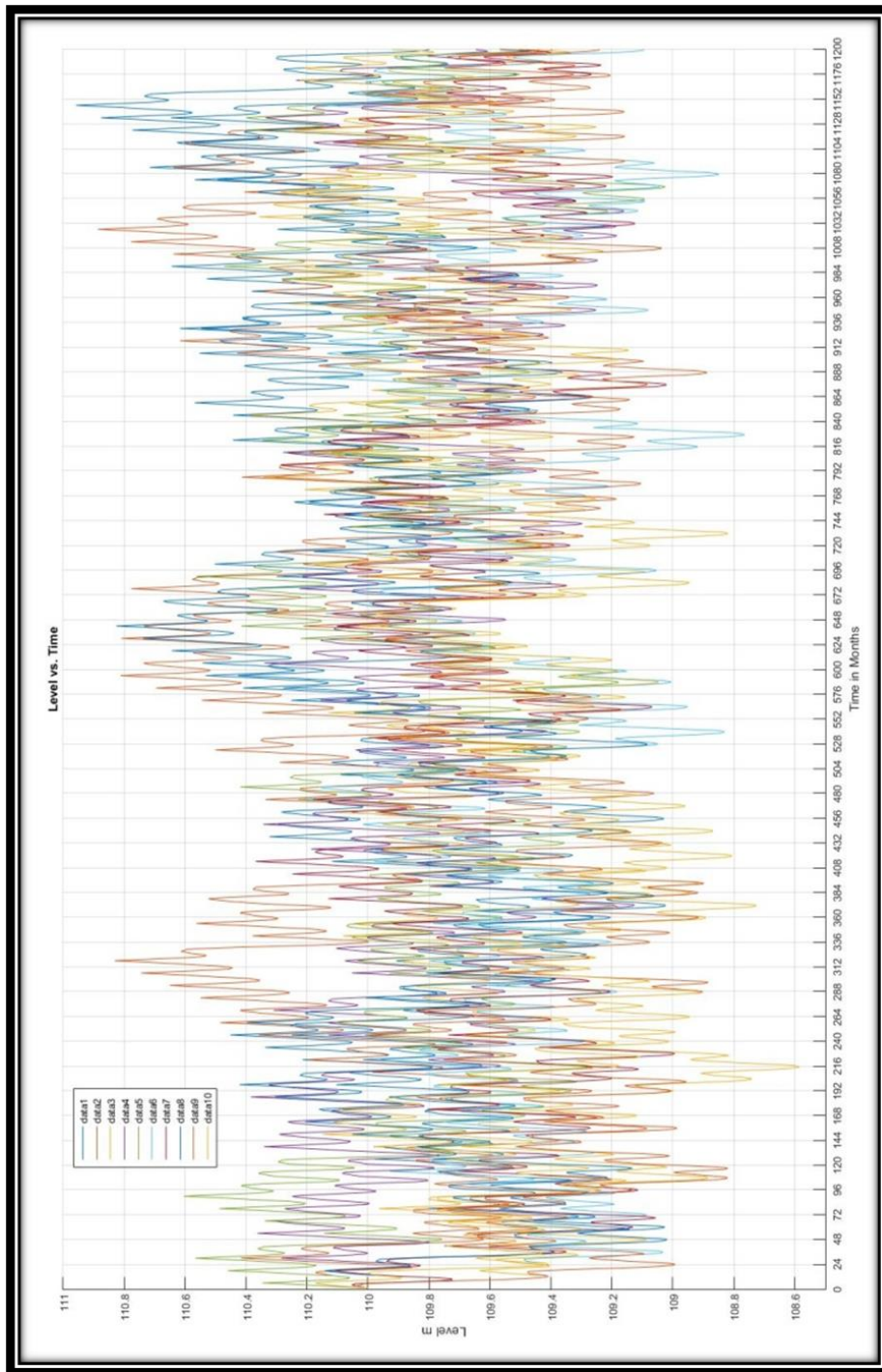


Figure (5): Determining suitable discharge ratio based on the determined discharge values

This process was repeated throughout multiple initial water levels within the entrance reservoir, where the most suitable incoming and outgoing discharges were determined and the ratio between them was calculated. This was performed with a filling duration of 10 hours per day and an emptying duration of 5 hours per day. A comprehensive table of data has therefore been created, representing the most suitable discharges and their factors at multiple water levels. The minimum and maximum water levels that may occur due to fluctuations have also been determined from within the graph and recorded. The table (4) represents a small example of such data, whereas the rest of the data is documented in an excel sheet, along with the accompanying MAT-Lab graphs from which the information was obtained.

Table (4): Optimal operation conditions at different levels and discharges

Level (m)	Vol. (m ³)	Qout (m ³ /sec)	Qin (m ³ /sec)	Factor in/out	Min. Level	Max. Level
85	0.0235	100	50.48	1.0096	84.14	85.37
		150	75.50	1.0067	84.14	85.47
		200	100.50	1.0050	84.18	85.51
		250	125.50	1.0040	84.18	85.50
		300	150.50	1.0033	84.18	85.50
		350	175.52	1.0030	84.22	85.55
		400	200.50	1.0025	84.18	85.54
		450	225.50	1.0022	84.15	85.52
		500	250.52	1.0021	84.21	85.65
		1000	500.53	1.0011	84.23	85.70
110	0.2938	100	52.82	1.0564	108.50	110.56
		200	102.85	1.0285	108.70	110.75
		300	152.85	1.0190	108.60	110.90
		400	202.82	1.0141	108.58	110.55
		450	227.85	1.0127	108.58	110.70
		500	252.85	1.0114	108.59	110.61
		1000	502.82	1.0056	108.59	110.50

The determination of the most suitable operating conditions in terms of discharges at multiple levels makes it is possible to compare between the factors of incoming to outgoing discharges at the different levels and discharges. This helps in presenting the information in an easy to understand format and hold comparisons between different scenarios. An example of this is shown in figure (6), where the ratios of incoming to outgoing discharges for different sets of discharge at different initial water elevations are presented.

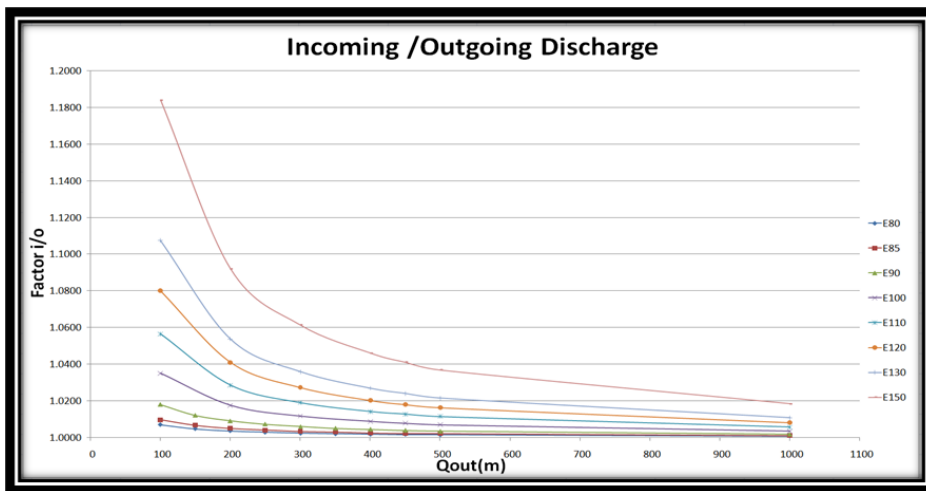


Figure (6): Incoming/ outgoing discharge.

This chart proves the factor between incoming to outgoing discharges decreases as the initial water level decreases and the discharge values increases, therefore a smaller factor represents a smaller volume of lost water.

3.6 -Calculating consumed and generated power:

After determining the multiple optimal operation conditions for the reservoir, it is then only a matter of determining the amount of power generated and consumed during the daily cycles of emptying and filling. This can be done relatively easily based on the previously presented equations for the calculation of power.

The rates of both power consumption and power generation, which occur during the daily emptying and filling cycles respectively, are represented by a range of a maximum and minimum value for each of them, which has been shortened to only a single value for each of both cycles. These maximum and minimum values for each cycle have been derived from a sensitivity analysis graph for consumed power and generated power separately, where the results of multiple trials have been presented within a chart to easily determine the possible maximum and minimum values. Figures (7 and 8) , (table 5) represent thus graphs, for consumed power as well as generated power respectively. Both graphs are for the operation at an initial water level of 110 m, with incoming and outgoing discharges of 300m³/sec and 152.85 m³/sec and the same operation durations as within the previous charts. The following table presents the rates of power consumption and generation in M Watts for the discharge combinations presented within the previous table.

Table (5): Power Consumption and generation at different operation Levels and discharges.

Gen/Con	PGen. (MWatt)	PCon. (MWatt)	Qin (m ³ /sec)	Qout (m ³ /sec)	Vol. (m ³)	Level (m)
0.9926	54.00	54.4	50.48	100	0.0235	85
0.9963	80.95	81.25	75.50	150		
0.9966	108.00	108.37	100.50	200		
0.9974	135.15	135.50	125.50	250		
0.9972	161.95	162.40	150.50	300		
0.9985	189.15	189.50	175.52	350		
0.9982	216.10	216.50	200.50	400		
0.9986	243.10	243.65	225.50	450		
0.9985	270.10	270.50	250.52	500		
0.9994	540.80	541.10	500.53	1000		
0.9470	70.35	76.40	52.82	100	0.2938	110
0.9726	144.77	148.85	102.85	200		
0.9814	217.38	221.50	152.85	300		
0.9860	289.60	293.70	202.82	400		
0.9875	326.40	330.53	227.85	450		
0.9889	362.17	366.25	252.85	500		
0.9945	723.48	727.50	502.82	1000		

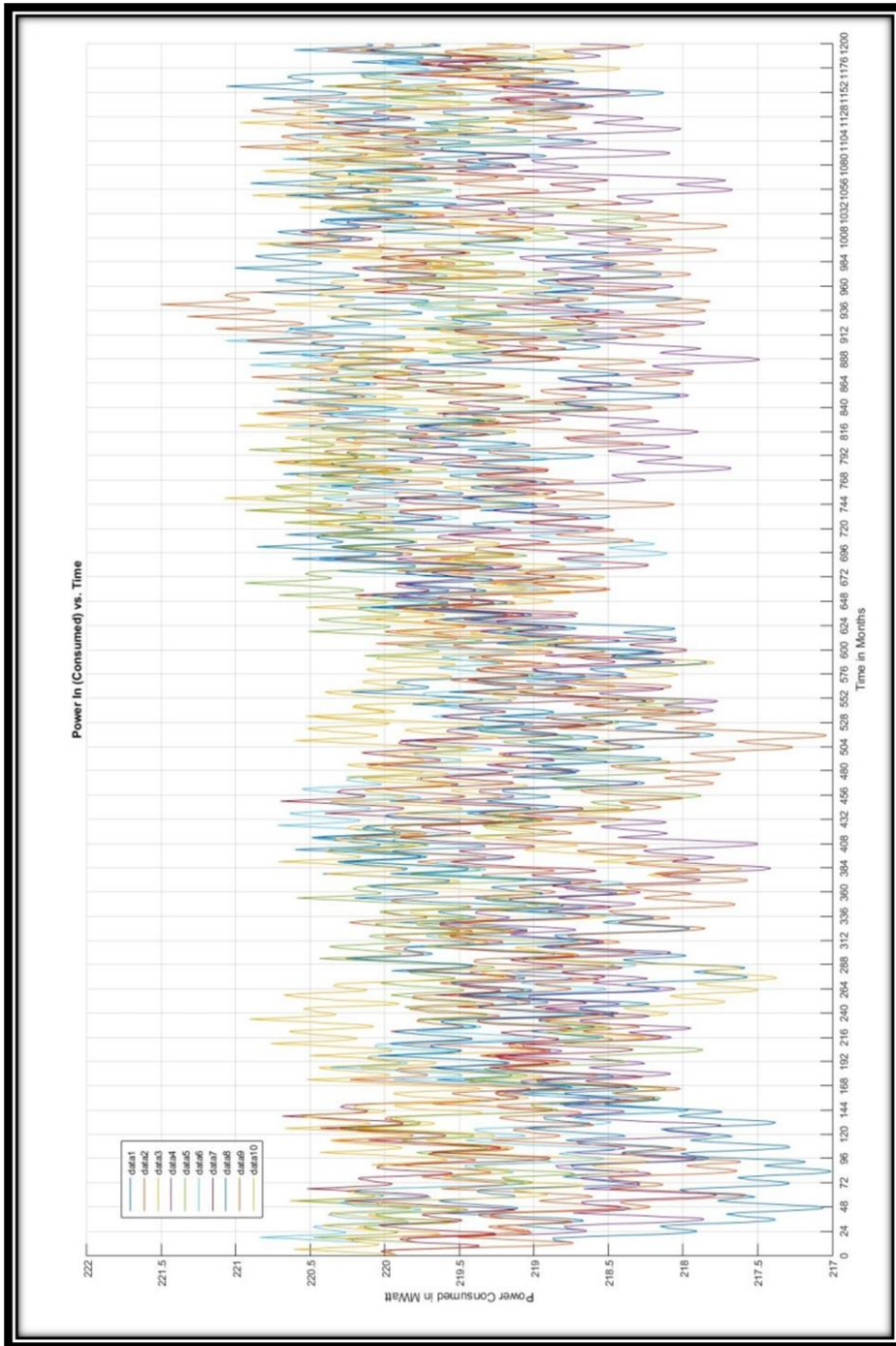


Figure 7: Sensitivity Analysis for Consumed Power

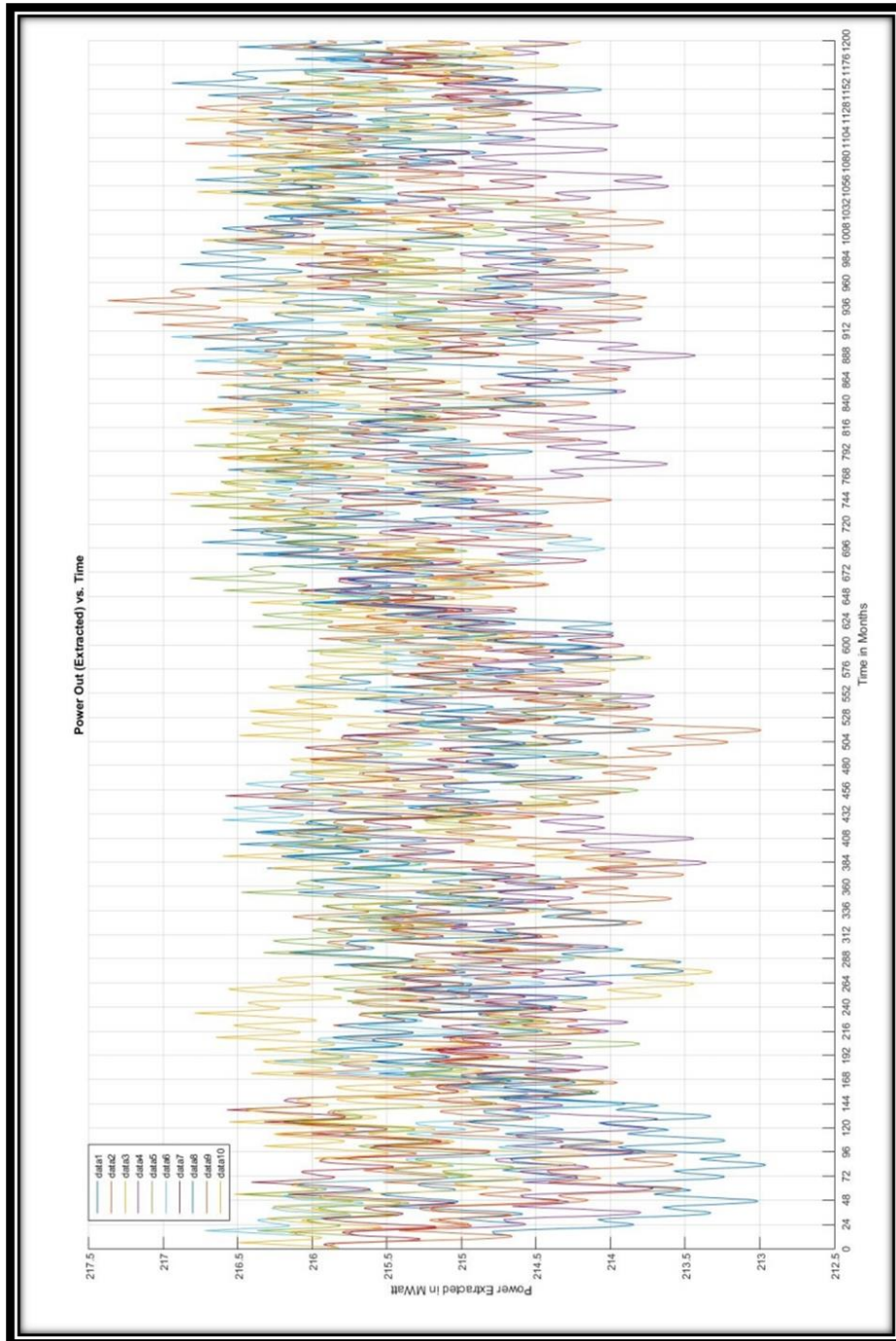


Figure (8): Sensitivity analysis for generated power

It is important to state the power presented within these graphs and table (5) are represented in the unit of M Watts and thus represents the amount of energy per second, rather than the entire amount of energy generated or consumed. The durations of both emptying and filling cycles need therefore to be taken into consideration when the point of interest is to calculate the net amount of energy generated and produced. This can be simply performed by the following equation, where the duration is in hours:

$$Energy_{con.or\ gen.} = Power_{con.or\ gen.} * 3600 * Duration_{con.or\ gen.}$$

Following the calculation of generated and consumed power values during the filling and emptying cycles of the reservoir, it becomes simple to hold comparison between the ratio of generated to consumed power as also shown within table (5). Figure (9) presents a graph showing a comparison for the power generated by the power consumed for multiple operation scenarios of different discharges and elevations.

The rates of power generated and consumed which have been calculated can also be presented in the form of G Watt hr/Year to better represent the yearly rates of power consumption and generation. This is done using the previously presented equations, and all associated data is documented within the excel sheets associated with this research as well as the related sensitivity analysis graphs for yearly power rates.

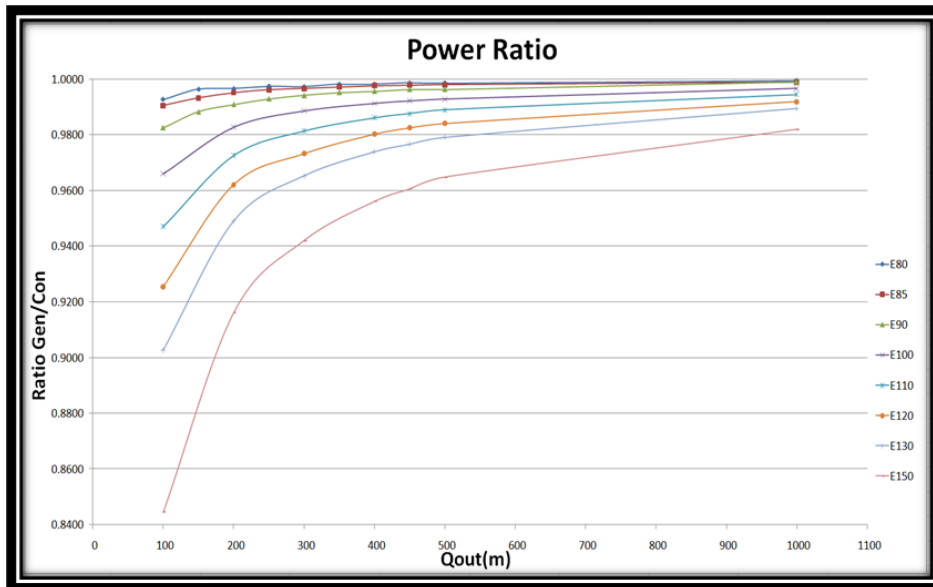


Figure (9): Power Ratio between generated and consumed Power.

3.7 Mechanisms of economic structure:

It is important to state that the main driving concept behind such a project and its implementation is the variance that exists within the price of power between peak consumption hours and low power consumption hours. The reason power prices are lower during night time is due to the reason that energy production cannot be stopped or halted, therefore this energy is presented at a lower cost. This turns the consumed power into revenue when power is generated and sold at a higher price. Although the amount of energy generated through such a method is lower than the energy consumed during its generation, it makes use of the fact that energy production continues through the hours of low energy consumption at a lower price. This is similar to storing an amount of energy for usage during later times.

An economic study for electricity prices during the different periods of the day would be needed in order to exactly determine the expected revenue from such a project as well as the duration after which it is expected to pay its own cost. Such an economic study is

beyond the scope of this research, which is mainly focused on studying the condition of the chosen basin location, as well as the most optimal operation schemes.

4- Conclusions and final remarks:

An in depth research for the proposed idea of utilizing reservoirs located at high altitudes in the form of a pump-turbine system proves the feasibility of such a project from geographical and geological standpoints as well as an operational standpoint. A pump-turbine facility could alleviate the energy needs of the region, as it is situated during the peak hours of energy consumption. Although the generated energy is of a lower amount than the energy consumed for the process, but this is the case within any attempt to store energy for use at a later period of time. Nevertheless the lower amount of energy generated does not translate to lost revenue because such energy would be generated within the hours of low energy consumption and be presented for usage at hours of peak consumption, thus the variance in energy and power prices between the two periods would be suitable to provide revenue from the operation of this project.

Although this system would require a high initial cost for implementation and construction, and is accompanied by a factor of risk due to its unpopularity within the region, the smaller reservoir located at the entrance to basin Malha could be a very suitable starting point for such a project. Being of a smaller volume that is more manageable would lead to a reduction of the initial costs of the project and provide suitable experimentation opportunities and experience. This experience can therefore be utilized for the operation of a larger basin and expanding the project to a larger scale.

References:

- Almasalmeh, O. and Eizeldin, M., (2019). *Quantitative analysis of watershed geomorphology and its hydrological implications using GIS: case study of Billi drainage basin, Egypt*, International Water Technology Journal, IWTJ , 141-165.
- Antal, B.A. (2014). *Pumped storage Hydropower: A technical Review*. Denver: Department of civil Engineering; university of Colorado Denver.
- Army Map Service, (1991). *Topographical Maps NG 36-2 & NG 36-3 & NG 36-3 scale 1:25,000*, Washington D. C.: Corps of Engineers, U.S. Army.
- Baghdadi, A. and Mobarak, A. (1989). *A Feasibility study for power Generation from the Qattara Depression using a Hydro – solar Scheme*, Energy Sources, 39-52.
- Bartle, A. (2002). *Hydropower Potential and Development Activities*. Energy Policy, 30, 1231-1239.
- El-Saman, M.I. (2016). *Evaporation Estimates In Front Of Hurghada City By Using Penman-Monteith Equation*, Red Sea, Egypt. Universal Journal of Environmental Research and technology, 1-7.
- Elsisi, M. (2019). *Plant of pumped storage power plant in Red Sea hills and Sinai of Egypt case studies*. Technischen Universität Berlin.
- Feizizadeh, B. and Haslauer, E.M. (2012). *GIS-Based Procedures of Hydropower Potential for Tabriz Basin, Iran*. International Journal, 495-502.
- Fitzgerald, N. & Lacal Arántegui, L. Roberto, Eamon, M. and Paul, L. (2012). [*A GIS-based model to calculate the potential for transforming conventional hydropower schemes and non-*](#)

[hydro reservoirs to pumped hydropower schemes,](#) " [Energy,](#) Elsevier, 41(1), 483-490.

- Irvem, A. (2011). *Application of GIS to Determine Storage Volume and Surface Area of Reservoirs: The Case Study of Buyuk Karacay Dam.* International Journal of Natural and Engineering Sciences, 5, 39-43.
- MESI and METI, (2011). *Digital Elevation Model,*science team.: USGS Earth Explorer.
- Moustafa,W., Hussien, R., and Nassar, N. (2018). *Evaluation of Potential Hazards Associated With Qattara Depression as a National Hydropower Project in Egypt.* Arab Journal of Nuclear Sciences and Applications, 51(2), 58-67. doi: 10.21608/ajnsa.2018.6511
- Resch, R. H., and Predpall, D. (1975). *Pumped Storage Site Selection: Engineering and Environmental Considerations.* In E. L. Armstrong, & T. W. Mermel, *Converting Existing Hydro-Electric Dams and Reservoirs into Pumped Storage Facilities,* New York: American Society of Civil Engineers, 39-40.
- Sorensen, B. (2004). *Renewable Energy.* Roskilde: Elsevier Academic Press.
- Wali, U.G. (2013). *Estimating Hydropower Potential of an Ungauged Stream ,* International Journal of Emerging Technology and Advanced Engineerin , 592-600.
- Warnick, C. C. (1984). *Hydropower Engineering.* New Jersey: Prentice Hall.