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A Multifunctional Project Study for Elazig: Botanic Park, Pumped Irrigation Line, and Solar-Hydroelectric Power Plant

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Abstract: Urban centers serve as more than just hubs of economic activity; they are also focal points of community life and social interaction. It is incumbent upon local authorities to elevate the standard of living within these urban environments by establishing communal spaces conducive to enhancing the well-being of residents. To this end, botanical gardens and recreational areas have been established in numerous developed cities worldwide. These amenities not only enrich the lives of inhabitants and local fauna but also constitute significant contributors to the municipal economy. Recognizing their pivotal role in urban economies, the imperative lies in implementing projects that optimize the utilization of available water resources. The prospect of establishing such a facility in the heart of Elazig holds promise. This study undertakes a preliminary assessment of the feasibility of establishing a botanical garden within the designated area, exploring avenues such as tapping into the Keban Dam reservoir, constructing a micro-hydroelectric power plant utilizing downstream water, and other potential initiatives.

Key words: Hydrology, micro-hydroelectric power plant, pumped transmission, recreation area.

Elazığ için Çok Fonksiyonlu Bir Proje Çalışması: Botanik Park, Pompa Sulama Hattı ve Güneş-Hidroelektrik Santrali

Öz: Kentsel merkezler, sadece ekonomik faaliyetlerin merkezleri olmakla kalmaz; aynı zamanda topluluk yaşamı ve sosyal etkileşimin odak noktalarıdır. Bu kentsel ortamlardaki yaşam standartlarını yükseltmek, yerel yönetimlerin sorumluluğundadır. Bu amaçla, birçok gelişmiş şehirde botanik bahçeleri ve rekreasyon alanları kurulmuştur. Bu tesisler, sadece yerel halkın ve faunanın yaşamını zenginleştirmekle kalmaz, aynı zamanda yerel ekonomiye de önemli katkılarda bulunurlar. Kent ekonomilerindeki bu önemli rolü tanıyarak, Elazığ'ın merkezinde böyle bir tesis kurma gerekliliği ortaya çıkmaktadır. Bu çalışma, belirlenen alan içinde bir botanik bahçesi kurulmasının fizibilitesinin ön değerlendirmesini yapmakta olup, Keban Barajı rezervuarından su kullanımı, aşağı akış sularını değerlendiren mikro-hidroelektrik santral inşası gibi çeşitli projeleri incelemektedir.

Anahtar kelimeler: Hidroloji, mikro-hidroelektrik santral, pompa iletimi, rekreasyon alanı.

1. Introduction

In cities, green areas are decreasing and disappearing due to overpopulation, developing industry, new roads and settlements. Therefore, it is extremely important to protect the green areas in the centers of settlements and to increase them if possible [1]. Despite the possibility of creating artificial water surfaces for recreational purposes in landlocked settlements, nearby reservoirs or rivers are also important resources that can be used for this purpose [2]. Recently, due to the increasing interest in recreation and sports activities in lakes and reservoirs and the opportunity to relax away from the stress of the city, especially in seaside cities, the arrangements to be made in these areas and their surroundings have started to be emphasized [3]. The first modern designed botanical park was built in Italy in 1545. Currently, there are around 2500 botanical gardens in the world [4]. These botanical gardens play a central role in the conservation and research of plant biodiversity [5]. This role is likely to become more important as the effects of global warming become more severe [6].

It is important to develop planning policies that produce solutions to the problems of society and for maximum benefit for recreation areas to be built in reservoirs and their surroundings in order to ensure the use of society's resources that cannot be used efficiently [7].

Botanical parks, which function as special recreational areas in cities, are open-air museums or plant collections where a wide variety of plant species are brought together and are a part of the outdoor system open to the public [8]. Botanical parks not only promote the importance of plants, habitats, and conservation awareness but also provide visitors with experiences that influence their movement, behavior, and social values [9].

Botanical parks are versatile recreational facilities with different qualified units such as walking paths, seating and viewing areas, water surfaces, organised plant collections, cafeterias and restaurants, zoos and playgrounds

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[10]. People live in an environment and the qualities of this environment affect their activities [11, 12]. It has been determined that environments intertwined with nature and designed landscapes in cities produce very positive effects on people [13, 14]. Botanical gardens are facilities with significant plant collections, and access to sufficient water is essential for healthy and well-maintained plants as well as daily organizational needs. Nevertheless, this also entails significant water consumption. The need for water, which is an indispensable source of life for humans and all other living things, is increasing day by day. Since this source of life is not unlimited and even decreasing, the available water should be used more efficiently to some studies.

Urban water management is recognized for its high energy intensity. Therefore, engineers are looking for ways to recover the energy contained in water networks and their treatment plants that collect water from drinking water, sewage, and recreational facilities [15-18]. This potential remains largely unexplored. Recently, the increasing need for energy worldwide and rising energy costs are compelling engineers to exploit this alternative energy source.

In this study, the construction possibilities of a botanical facility with benefits such as drinking water, recreation, and energy production for the city with the ponds to be built on the Calgan Stream flowing in the North-South direction from Nurali Village in the upper part of the Firat University campus area located in the city center of Elazig were investigated. Through this multi-purpose vision project, it was evaluated that benefits such as positive social contribution, energy and tourism income, and flood protection could be provided.

1.1. Environmental effects

It is known that green areas such as botanical parks contribute positively to climate and hydrological processes, reduce pollutants [19], and significantly reduce the heat island effect frequently encountered in urban areas. In addition to providing shelter for living things, they also have important effects on increasing biodiversity. Erosion control, dust stabilisation and noise pollution reduction are other important environmental benefits [20].

According to a study conducted by Xinian in Beijing, a natural green area of 20.000 ha absorbs 4 million tonnes of CO_2 and returns about 400 million tonnes of water vapour to the atmosphere annually [21]. This contributes to reducing the effects of global warming and climate change [19].

Despite the positive environmental impacts mentioned here, a detailed environmental impact assessment report should be prepared in order to minimise the negativities to be experienced during the construction process of the botanical parks. This detailed report, which should be prepared according to the characteristics of plants, insects and other living things living in the region where the park is planned to be built, will minimize the possible negativities during the construction process.

2. Materials and Methods

The project area is located in the city center of Elazig (Turkey). It consists of a valley with elevations ranging from 1.000 m to 1.500 m above sea level (see Figure 1). The park area of approximately 20 km^2 is divided into a core and a buffer zone, accounting for 66% and 34% of the area respectively. The primary ecosystem components within the park area comprise forests (34%), grass-covered landscapes (31%), and rocky terrain (35%). The project location is shown below.

2.1. Hydrology

Generally, continental climate conditions are valid in Elazig province. The rainfall area of the basin is completely characterized by the Eastern Anatolian climate. Summer months exhibit hot and arid conditions, while winters are marked by snowfall, and spring experiences increased precipitation. The average annual temperature in the basin is 12.9 °C. Basin parameters are shown in Table 1.

2.2. Rainfall-runoff modeling

The watershed model is derived from a Digital Elevation Model (DEM). The discretization is based both on the spatial distribution of physiographic factors (i.e., lithology, soils, cover type, hydrological conditions and slope) that determine a homogeneous hydrological response, and on control sections where dendro-geomorphological data are available. The use of simulation methods for the various processes involved is based on the information available for the basin. The curve number method (CN 89) was utilized to estimate initial water abstractions, considering land use, land cover type, and hydrological soil group.

The storage coefficient was calculated assuming it represents 0.6 tc. The Muskingum-Cunge method was applied for flood wave routing due to the lack of observed flow data. Muskingum-Cunge parameters were calculated based on flow and channel characteristics.

Figure 1. General view of the project site.

Table 1. Basin parameters.

Basin area (A)	8.7 km^2
Max. and min. heights of the basin (h_{max} / h_{min})	1395m/1100m
Basin direction	South-North
Basin average elevation (h_{ort})	1170 m
Basin harmonic slope (S)	0.0729
Hydrological soil type [CN (Hydrological soil type)]	89
Main sleeve length (L)	3.6 km
Distance from the projection of the basin center of gravity on the main tributary to the basin outlet (L_c)	1.75 km

2.3. Precipitation

According to the observation values in Elazig province, the average annual rainfall is around 600 mm. Precipitation is irregular according to the months, with the wettest month being April and the driest month being August. All three types of precipitation are observed in the region: convective, orographic, and frontal. There are precipitation observations at the meteorological stations in the Project area. The 60-year extreme distributions of the daily maximum precipitation of the precipitation stations in the vicinity of the project area were investigated, suitability tests were performed, and the recurring precipitation was calculated according to the appropriate distribution type.

Previous studies have advocated for the utilization of exceedance series to estimate the frequencies of extreme precipitation [22-24] that better fit the high range of the frequency function [25, 26] and have been applied to both runoff and precipitation forecasts. These exceedance series were derived from 24-hour rainfall events recorded in the day before and the day after the extreme rainfall event. On the basis of the results of the goodness of fit test (Kolmogorov-Smirnov test and Mean Square Error test), the function of the fit parameters estimated by the L-Moments method applied to the exceedance series above the threshold was selected. The Kolmogorov-Smirnov test shows very similar values for all distribution functions, with the Log Pearson 3 distribution having the lowest error value. The results are given in Table 2.

Table 2. Repeated rainfall calculation.

Distribution Type	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year	Acceptance
Normal Distribution	26.26	52.77	66.64	81.43	90.97	99.56	
Log-Normal (2 Parameters)	16.81	37.22	56.39	87.86	116.94	151.27	
Log-Normal (3 Parameters)	23.02	51.08	67.85	87.54	101.30	114.47	
Pearson Type-3 (Gama Type-3)	21.10	50.15	68.48	90.62	106.33	121.45	
Log-Pearson Type-3	29.98	40.37	47.02	55.22	61.19	67.02	****
Gumbel	15.23	51.19	74.99	105.07	127.38	149.53	

Repeated rainfall was calculated with the hourly pluviograph rates of the Elazig DMI (Turkish State Meteorological Service) meteorological station which has a pluviograph. In the calculation of the recurrent flood flows of Calgan Stream, which was selected according to the hydrological conditions of the drainage area from these rainfall, flow and incremental flows were calculated with the CN II (89) condition curve number and superposed with the unit hydrograph and recurrent flood hydrographs were drawn. The results of the DSI (General directorate of state hydraulic works) synthetic method were accepted for the project flood hydrograph and the unit hydrograph is given in Figure 2.

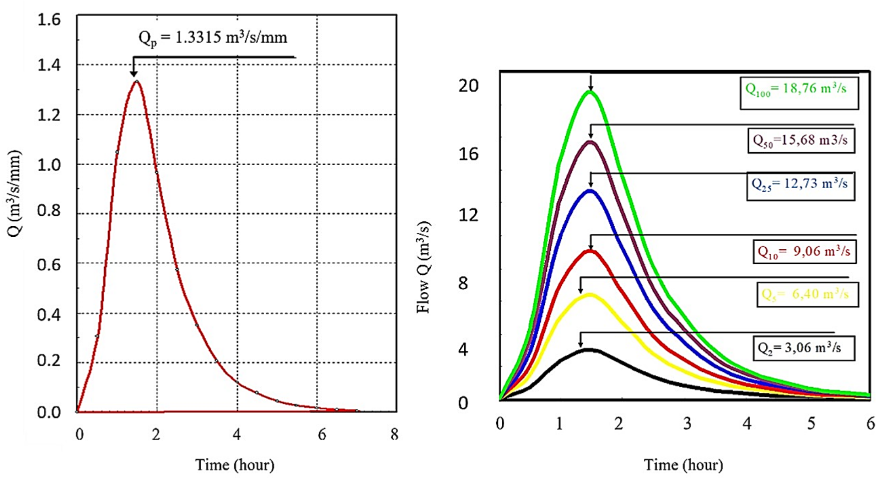

Figure 2. Unit and recurrence of flood hydrograph.

The only surface water source in the Project area is the Calgan Stream. There is no current observation station SGS (Stream gauging station) operated by any institution on the Calgan Stream. However, sporadic measurements were made by DSI. These measurements were utilized in the water potential studies of the regulator location. Monthly averages of these measurements were taken, and total flows are shown in Figure 3.

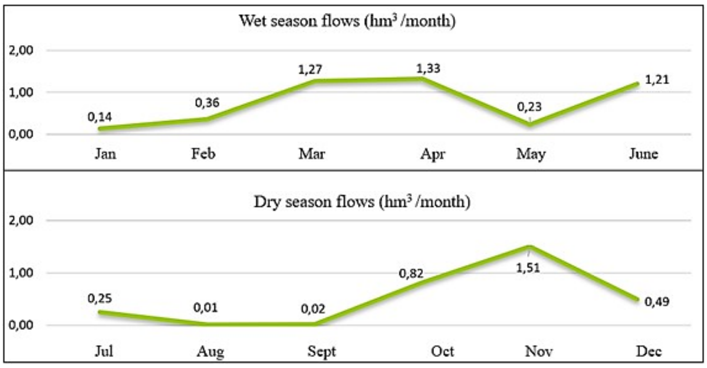

Figure 3. Monthly average flow rates of Calgan Stream.

2.4. Pumped from Keban Dam reservoir and botanical park

The sporadic measurements conducted by DSI indicate a natural annual flow of approximately 1 million m^3 in the Calgan Stream. As depicted in Figure 4, it is feasible to transport the required volume of water from the Keban reservoir to the Calgan Stream through a pumped transmission line spanning roughly 10 km in length. The water intake structure of the project draws from the Keban Dam Lake and features a reservoir capable of continuous water retention. Notably, the Keban Dam reservoir ranks among the largest in the country, boasting a storage capacity of approximately 30 billion m^3. The water extracted via the intake structure will be conveyed to the pumping station and subsequently to the regulation pool through penstock pipes. From there, it will be conveyed to the Calgan Stream basin via the transmission tunnel. The pipeline and reservoir are illustrated in the figure.

Figure 4. Pump station and Keban dam resorvoir.

As depicted in the Figure 4, the regulation pond at the terminus of the penstock transmission system will be designed with ample capacity to facilitate the necessary water regulation. It will store water during the operational hours of the solar power plant and will be adequately sized for this purpose. With the stored water, it will be feasible to procure water without the need to operate the pump during other periods.

The electrical energy required for the pumping process will be supplied by the solar power plant slated for installation in the area. An SPP (solar power plant) plant generating approximately 5 MW of power will be sufficient for each 1 m^3/s flow rate, given the region's favorable solar radiation conditions. According to the pvsyst simulation outlined in Table 3, a 1 MW AC power plant in the region is projected to produce 1752.6 MWh per year. Consequently, the total energy output from the proposed 5 MW power plant in the area is estimated to be approximately 10 million kWh.

Table 3. Project area 1 MW pvsyst energy simulation.

Time	Radiation	Temperature °C	Energy
Jan	55.8	-1.10	74.4
Feb	73.4	0.40	94.7
Mar	130.5	5.40	146.8
Apr	155.1	11.20	149.8
May	209.9	16.40	187.3
June	245.4	22.30	203.2
Jul	253.0	26.80	209.7
Aug	227.2	27.10	203.1
Sep	177.3	21.90	182.3
Oct	127.4	15.20	156.3
Nov	77.4	7.20	106.1
Dec	54.9	1.10	73.6
TOTAL	1787.2	12.86	1787.2

2.5. Electric power of the PV power plant

The hourly output power of solar PV array (Equation 1);

$$P_{pv} = \eta_{pv}.N_{pvp}.N_{pvs}.V_{pv}.I_{pv} \tag{1}$$

where ηpv the conversion efficiency of a PV module, V_{pv} the module operating voltage, Ipv the module operating current, N_{pvp}; N_{pvs}, the number of parallel and series solar cells, respectively.

2.6. Energy consumed by the pump

The calculation of energy consumed by the pump is shown in Equation 2

$$E_p = \frac{2.72.Q.H_{net}}{1000} \tag{2}$$

where Q is the average water flow (m^3/day) pumped from the Keban Dam reservoir into the Calgan Stream, and Hnet is the total head (water level difference in Calgan Stream and Keban reservoir, including losses) in meters.

To pump water from the Keban reservoir to the project site, a total head of 500 meters is required, necessitating a power input of 5.45 MW. This pumping operation will occur during the summer months, when water is scarce, for approximately 4300 hours per year.

With this project, water from the Keban Dam Lake will be redirected to the Calgan Stream basin, enabling the creation of one of the largest botanical parks and oasis valley projects in our country, located in the forested land above the university. The region's natural riches, such as waterfalls, enhance its suitability for this venture. Social amenities like promenades and restaurants around the pond will provide economic benefits to the municipality.

Since the reservoir area, body axis, and other structures will be situated entirely within public land, there will be no expropriation issues or costs. Additionally, the initial construction expenses are expected to be recouped in a short period through the development of social facilities around the pond, making the water infrastructure project highly profitable. The project area, already covered with pine trees, will gain even more aesthetic appeal with the addition of the pond and botanical park.

2.7. Tailwater and city wastewater micro HEPP

In the subsequent phase of the project, the downstream segment, an innovative wastewater hydroelectric power plant (HEPP) can be constructed, representing a pioneering initiative in Turkey, inspired by similar endeavors in many developed nations worldwide. The effluent from the downstream section of the botanical park project will be reintroduced into the Keban Dam Lake via the Sorsor Stream. Notably, the wastewater line discharge from the Elazig city center also traverses this area. These combined waters, sourced from the cemetery ridges at an elevation of 980 m, can be channelized and utilized to generate energy in the hydroelectric power plant to be erected, facilitated by a transmission conduit. Subsequently, the tailwater from the hydroelectric power plant can be reintegrated into the Keban Dam reservoir. It is estimated that the total wastewater volume from the city, in conjunction with the Calgan Stream, will amount to approximately 2-3 m^3/s. All elements and locations of this multifunctional project are shown in Figure 5.

Figure 5. Study area.

2.8. Hydroelectric plant power calculation

Hydropower generation depends on two basic inputs in addition to plant characteristics. Flow and head. Under these conditions, Equation 3 shows the total power (Watts) that can be generated as a function of water density, where: density ρ (kg/m^3); gravitational acceleration g (m/s^2); plant efficiency η (constant); water head, H (m); and flow through the turbines Q (m^3/s). The product of these values gives the installed power in watts.

$$\text{Power} = \rho.g.\eta.H.Q \quad (3)$$

Power multiplied by time, t (hours), gives the energy production (kWh) in a given period, ΔT (Equation 4).

$$\text{Energy} = \int_0^T \rho g \eta H(t) Q(t) dt \quad (4)$$

If the amount of energy produced is multiplied by the energy price, p(t) ($/kWh) hydroelectric revenue ($) will be obtained.

The water from the botanic park's tailwater and city wastewater is diverted by a weir to a transmission canal and then directed through a penstock to the turbines, with a total installed power of 3.06 MW and an annual energy generation of 20.80 GWh (14.2 GWh firm and 6.6 GWh secondary) in the HEPP powerhouse, located at an elevation of 840.00 m. Subsequently, the water is discharged back into the Keban Dam reservoir. The gross head of the project is 180 m, and the design flow is selected as 2.0 m^3/s.

2.9. Economic analysis

The levelized cost of energy (LCOE) is a unit of measurement used to compare electricity from renewable energy sources with other fossil-based electricity generating systems (Equation 5). This cost calculation includes the installation cost of the system, maintenance and operation costs, and country-specific fiscal rates. LCOE (The cost to value of energy) is also referred to as the ratio of the PV plant cost incurred during the system lifetime to the electrical energy generated during this period.

$$\mathrm{LCOE} = \frac{\text{Installation cost over the total system life}}{\text{Total energy generated during system life}} \tag{5}$$

The system life cycle costs comprise four main components: initial project costs, depreciation, annual operating costs, and residual value. The total system life cycle costs typically range between $15-18 per kW per year, depending on the system size. In power plants, the cost of in-house insulators constitutes approximately 9.5% of the initial investment cost, with an average lifespan of 10-13 years. Additionally, when considering depreciation and financial aspects, the initial installation cost of the system is multiplied by 1.4 to calculate the average system life cost. Losses within the system are estimated at 20%. Photovoltaic module manufacturers typically specify a module efficiency loss rate of 10% over 25 years.

For the calculation of energy revenue in 2023, an assumed average sales value in the Turkish market of $0.073 per kWh is utilized. Based on these calculations, the hybrid power plant (solar+hydro) is projected to generate an annual average of 30.8 GWh of electricity, with 10 GWh generated by the solar power plant alone. The initial investment cost for the plants and pumps to be installed is estimated at $9.500.000. Consequently, the total energy revenue of the hybrid power plant is assessed as $3.500.400, and the annual solar energy gain is projected at $684.000. The energy expended for annual pumping amounts to 13 million kWh, with a monetary equivalent of $949.000. Various factors, including depreciation, operation and maintenance costs, and interest, are factored into the calculation of annual costs. The amortization period of the system is determined to be 3.8 years, based on calculations considering the annual return over the retail electricity sales price and the initial installation price. These calculations underscore the significant cost-effectiveness of the project's energy investments alone.

3. Results

The drinking water supply for Elazig city center currently relies on the Hamzabey Dam and wells located in Uluova. However, with the anticipated increase in global warming and climate change, there is growing uncertainty regarding the security of supply from these sources. The recent water cuts in our city serve as a stark reminder of this vulnerability. With the proposed project, water will be sourced from the Keban Dam reservoir, providing a much safer water supply for the city center and mitigating potential water shortages.

Currently, water from Hamzabey is pumped from the treatment plant at approximately 950-1000 m to higher neighborhoods at elevations of 1250-1300 m, incurring significant energy costs. In the project, energy expended for pumping will be offset by the energy produced in the micro-hydroelectric power plant (HEPP) utilizing wastewater. Moreover, the presence of water in the region presents significant recreational potential.

Establishing a botanical park in the Calgan Stream basin requires a significant amount of water, particularly during the summer months. The inclusion of social amenities such as restaurants and cafeterias in the surrounding area will also contribute substantially to the region's economy.

Furthermore, since the proposed recreational area will be situated on treasury land, there will be no land acquisition or expropriation costs. The profitability of the facilities is evident, as construction expenses are expected to be recouped quickly with the establishment of social amenities around the botanical park.

4. Conclusion

The multifunctional project proposed for Elazig, including the establishment of a botanical park, a pumped irrigation line, and a solar-hydroelectric power plant, presents a promising solution to several pressing issues faced by the city. By harnessing the potential of existing water resources and integrating renewable energy sources, this project aims to enhance the quality of life for residents while also addressing challenges related to water supply, energy generation, flood protection, and recreation.

The botanical park planned for the Calgan Stream basin promises to be a valuable asset for the city, offering not only recreational opportunities but also contributing to the conservation of biodiversity and environmental education. With careful planning and efficient water management, the park can provide a sustainable source of irrigation water for landscaping and agriculture, reducing dependence on scarce resources.

The integration of a pumped irrigation line from the Keban Dam reservoir to the botanical park demonstrates a creative approach to water supply management. By utilizing solar energy to power the pumping process, the project not only reduces reliance on fossil fuels but also generates additional revenue through the sale of excess energy. Furthermore, the inclusion of a micro-hydroelectric power plant downstream of the botanical park offers a further opportunity to harness renewable energy and offset operational costs.

In addition to the environmental and economic benefits, the project also addresses pressing issues related to water security and flood management in Elazig. By diversifying the city's water sources and implementing measures to protect against floods, the project enhances resilience to climate change and ensures the long-term sustainability of water resources.

Overall, the multifunctional project proposed for Elazig represents a holistic approach to urban development, integrating environmental conservation, renewable energy generation, and social welfare. By leveraging the synergies between different components of the project, it has the potential to transform the city's landscape and improve the quality of life for its residents, while also serving as a model for sustainable development in similar urban contexts.

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