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Micro Water Structures As A Renewable Energy Source; A Case Study In Maçka Trabzon In Turkey

Yenilenebilir Enerji Kaynağı Olarak Mikro Su Yapıları; Maçka'da Örnek Bir Çalışma

Veli SÜME*

Recep Tayyip Erdogan University, Faculty of Engineering, Department of Civil Engineering (Hydraulic), 53100, Rize

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Abstract

Obtaining energy from water as a renewable energy resource is gaining importance day by day. One of the most important reasons of this situation is that it has a low effect on the environment compared to the methods of gaining other energy resources. For the reasons such as less environmental impact, facilitating of small-scale energy production, being practical and easy to set up the system, using the produced energy by people in the region and economic support for the region, micro-water structures have been brought back to the agenda. In this study, five pieces of micro water structure (traditional water-mill) located in the Sümela valley in were discussed. In addition to the technical characteristics of these structures, hydraulic data such as the flow rate of water, fall-height, the channel dimensions, etc. were measured. According to the data, of the selected five pieces of micro-water micro-structure of water bodies in the study area, potential energy production was identified, projected separately and made into structures that can be obtained energy as a novelty of this region. Micro water structures defined as having an important role in electricity production and the viability to all available water facilities in the region were discussed.

Keywords: Micro-Water Structures, Water Power, Potential Energy, Fall Height, Sümela Valley

Öz

Yenilenebilir bir enerji kaynağı olarak sudan enerji elde edilmesi diğer enerji kaynaklarına kıyasla gün geçtikçe önem kazanmaktadır. Bu durumun en önemli sebeplerinden biri, çevre üzerinde düşük bir etkiye sahip olmasıdır. Mikro su yapıları çevresel etkilerinin az olması, küçük ölçekli enerji üretiminin kolaylaştırılması, sistemin pratik ve kolay kurulması, üretilen enerjinin bölgedeki insanlar tarafından kullanılması ve bölgeye ekonomik destek sağlaması gibi nedenlerle, son zamanlarda gündemi meşgul etmektedir. Bu çalışmada, Sümela vadisinde yer alan beş adet mikro su yapısı (geleneksel su değirmeni) çalışılmış, bu yapıların teknik özelliklerine ek olarak, suyun akış hızı, düşme yüksekliği, kanal boyutları vb. gibi hidrolik veriler ölçülmüştür. Elde edilen verilere göre, çalışma bölgesindeki bulunan beş adet mikro su yapısı projelendirilmiş, ayrı ayrı enerji üretim potansiyelleri belirlenmiştir. Elektrik üretiminde önemli rol oynayan mikro su yapıları olarak geleneksel su değirmenlerine uygulanabilirliği tartışılmış ve bölgede bol miktarda bulunan geleneksel su değirmenlerinin yenilenebilir enerji kaynağı olarak enerji elde edebilecek yapılara dönüştürülmesine örnek teşkil edecek bir çalışma ortaya konmuştur.

***Anahtar kelimeler**: Mikro Su Yapıları, Su Potansiyeli, Potansiyel Enerji, Düşü Yüksekliği, Sümela Vadisi*

* Veli SÜME; veli.sume@erdogan.edu.tr; Tel: (0464) 213 75 18; orcid.org/0000-0001-8251-2461

1. Introduction

The mechanical device used to convert the rotary motion into linear motion of the water that flows in or poured is called simply water wheel. It consists primarily of a wheel mounted at the periphery of the pallet. It operates on the principle of the force exerted by the water wheel to move the pallet within the machine and so that it passes through the rotation to the center of the impeller shaft. The water wheel as the first mechanical energy source replacing human or animal power is used for different purposes such as high removal of water, milling of grains like corn, barley, wheat (water mills), etc. Such hydraulic structures made to operate and protect this system are called micro water bodies. According to the position of the paddles, there are horizontal paddle wheels and vertical paddle wheels (Abay et al., 2010).

In addition, vertical pallet wheels can be classified as above, in the middle and below according to the point which it first touches the top of the water. Horizontal water wheels do not require much equipment, so that it is particularly adapted to the grinding work by placing a millstone on the vertical shaft. Micro-water structures are made to benefit from low-flow streams. They provide electric energy up to 100 kW. Generally, it is a facility where the electricity network is not available, the installation of the system is costly and difficult and the demolition can be done to meet the basic needs of a small residential unit or facility such as a high plateau and avenue. It has recently become even more attractive for reasons such as its low environmental impact, ease of small scale energy production, practical and easy installation of the system, use of the generated energy by the people in the region and economic support for the region.

Micro-water structures are generally small-scale water power plants and they can be classified according to the criteria such as the fall height installed capacity of the installation and the network status (interconnected – isolated - independent) for water supply used (spring, transmission channels, rivers, lakes, etc.). However, installed capacity classification is often taken into consideration (Table 1).

This region is rich in water resources and in this region the water is highly being used in power and this rate has been increasing day by day recently. As the region's geographic structure is rugged, high falls occur over short distances.

Table 1. Classification of water power facilities.

Name	Installed power
Micro water structures	Up to 100 kW
Tiny water structures	100 - 500 kW
Small water structures	500 – 10,000 kW
Large water structures	> 10,000 kW

However, the rehabilitation of existing micro-water structure and repairing of the destroyed or demolished structures as a result of landslides and floods is quite difficult because of the terrain. Nevertheless, the Eastern Black Sea region is one of the areas where the micro-water structures are widely seen (Figure 2).

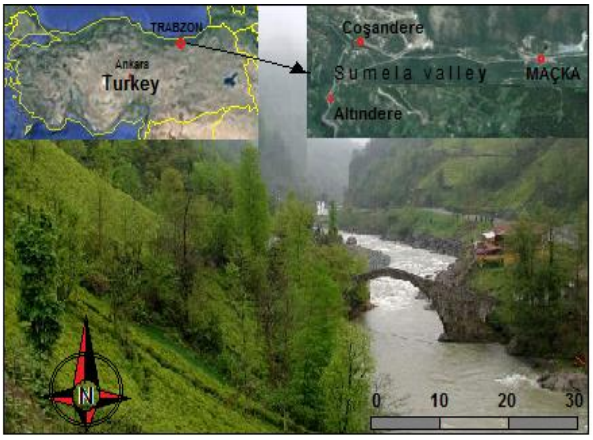

Figure 1. Study area (Sumela Valley)

The most important organization on small-scale water power plants is European Small Hydropower in Association (ESHA) and according to the classification adopted by the European Commission, small water power plants are classified as in Table 1 based on the installed capacity (Splash, 2005).

In Table 1, it is seen that the small-scale water power plants whose installed capacity is up to 100 kW is called as micro water structures (Figure 2).

These facilities can be easily installed in the riverbed of rivers, irrigation canals, weirs and on the transmission lines. The establishment and construction of the system are both practical and easy. Investment ease compared to larger plants, low environmental impact, and easiness for small-scale power generation, using the produced energy by people in rural areas and economic support to the region are among the reasons that make it attractive.

Figure 2. A view of micro-water structures in the Eastern Black Sea region (Watermill).

In addition, for the reasons such as increasing population and energy needs, they have come to the fore as clean, green, and renewable energy facilities.

The use of renewable energy sources is based on the previous century BC. In 600 BC Arabs started to use windmills. This could also be described as the invention of the mill. After 500 years from this date, water mills were started to be used in the former Yugoslavia and Albania. In the Roman Empire, it is known that water mill gear equipped was made by Vitruvius. There is very little information about the development of gear equipped watermill in the period from Vitruvius until the 12th century. One of the most important mills built in this period was a flour mill located in Barbegal (near to Arles, France). It is estimated that this mill with wood gear and 16 paddles had the water from the upside each 2 m in diameter grinding wheat for about 80 thousand people.

However, the real impact of them on the industry in the middle ages was seen in the Western European countries. After the 13th century, the water wheels having the water from the upside began to be used more widely than the water wheels having the water from the bottom. This system is also accepted as the first gear application actuated with a different power rather than manpower. This mill equipped with a paddle had the water at the bottom, as opposed to the middle or at the top impeller mills, could not benefit from the weight of water fallen. The water wheels and gear equipped mills that had the water from the upside or in the middle needed more equipment, but as it allowed the use of any water power, this mill was also widely used.

Even today, water micro structures used in ancient times are still functional. When the studies are analyzed, it is seemed that among the places where most of the work is done for benefiting from micro water structures, there are the Far Eastern countries, India, Nepal, Pakistan, Myanmar and China (Lumin et al., 2005; Bibek, 2012; Ishara, 2001; Katmandu, the nineth plan, 2002; Shrestha et al., 2002; REDP, 1997; Adhikari, 1998).

Today, it is seen that as well as traditional practices in the villages and towns, micro-water structures are used in the operation of low-power electric generator, the evacuation of sewage and some irrigation system. 238 units of micro-water structure were developed and modernized and electricity production capacities were improved in Nepal in 2005.

Partha and Subbarao have estimated that 200.000 units of micro-water structure exist in India. Similar micro-water structures are available all over the world as the United States, Britain, Europe, Africa and the Middle East and are still used in the textile and forestry industries (Parthan and Subbarau, 2001).

In Turkey, the most comprehensive research in terms of power and energy data associated with traditional water mills was carried out especially in the Eastern Black Sea region. 2.000 micro-water structures, which were made for grinding as well as obtaining electrical power, were examined using the modern research techniques (Süme, 2009).

2. Turkey’s Elecricity Generated and Water Power Potential

Although Turkey's total water power potential is 433 thousand GWh/year, in the 1950s, only 800 GWh/year (Gigawatt per hour) energy was produced. According to data from the year 2006, the production was determined as 188 thousand GWh/year (Kaplan et al, 2006), in 2007 as economically calculated by the official institutions, it was estimated as 126 thousand GWh/year; in 2009, it was stated about 190-200 thousand GWh/year (Önsoy et al., 2009).

Hydroelectric power generation is about 70 thousand GWh / year; today, the ratio has reached about 151 thousand per year GWh/year. With the installed capacity of 37 thousand five hundred MW/year (megawatts), 220 thousand GWh/year energy production per year is possible. For the reasons such as faults, maintenance, operation policy, economic stagnation, lack of demand, drought, yield and so on., 151 thousand GWh/year energy can be produced (TMMOB, 2015). As of April 2010 in Turkey, there are 74 small water power plants in the operation. Their total installed capacity is 192.95 MW and annual average production is at 722.28 GWh.

- Hydropower (Dam) 25%
- Hydropower(Streams) 10%
- Wind 5%
- Coal 20%
- Solar 1%
- Natural Gas + LNG 30%
- Thermal + Other 8%
- Geothermal 1%

In Turkey, the annual consumption of electricity per capita in the year 2004 was 2.100 kWh (kilowatt hours), while the world average was 2.500 kWh. This amount in the developed countries was 8.900 kWh; around 827 kWh in China and around 12.322 kWh in the US. When compared with other types, hydroelectric power plants have the lowest operating costs, the longest service life and maximum efficiency. There are a lot of economic, environmental and strategic reasons for Turkey to encourage prioritizing hydroelectric power plants that will use water as national resources relation to other energy alternatives. Turkey imports about 70 per cent of its energy demand. Until 2023, in order to meet the growing demand in Turkey in which about 120 billion dollars in the energy investment is needed, in electricity generation it has a share as below, (Figure 3).

The hydroelectric potential which is calculated based on the assumption that assessing all the natural flow to the country's borders or sea with 100% efficiency in a country is the gross theoretical hydropower potential of the country. However, with the existing technology it is not possible to use all available potential and the maximum potential that can be evaluated with the available technology can be called technical hydroelectric potential. Turkey's theoretical hydroelectric potential is 1% of the world theoretical potential and the economic potential is 16% of Europe's economic potential.

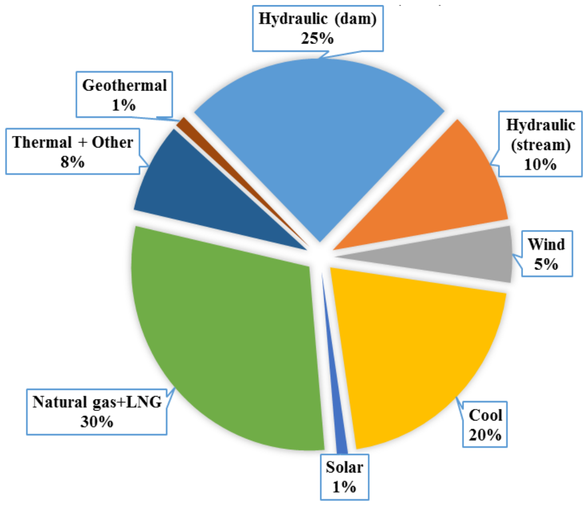

Figure 3. Percentage of electrical energy production in Turkey.

2.1. Geographical and Climatic Characteristics of the Sümela Valley

Sümela is within the borders of Trabzon with its 4685 km2 area in the Eastern Black Sea region in northern latitudes 40^{o}-33^{o} and 41^{o}-07^{o} and in eastern longitude 39^{o}-07^{o} and 40^{o}-30^{o}.

Gümüşhane, Giresun, and Rize are located in the south, west and east, respectively. Also, there is the Black Sea in the North. Height in the area rises starting from the sea level to the south and reaches 3000 meters (Haldizen Mountain at 3325m) (MGM, 2015). Sümela Valley is a historical and touristic region. Every year dozens of domestic and foreign tourists visit there. It is on the highway of Gümüşhane-Trabzon and far 29 km from Trabzon. The area of the valley which is 365 meters above sea level is 1000 km².

The Eastern Black Sea region has the maximum rainfall in Turkey. due to the presence of the Eastern Black Sea Mountains extending near shore as set, the winter months are fairly mild compared to the other areas in the same latitude.

Downfall is usually observed as rain inshore areas and snow in the middle and higher parts. In summer, damp land masses carried out from the Black Sea leads to aerographic downfalls, often in the form of torrential rains in the coastal areas, and in the highlands continuous and abundant rains are observed. The status and total seasonal downfall are given in Table 2.

In this study, the micro- water structure in the Sümela valley, which is still active and 5 other mills were selected as the sample application used for grinding. The energy potential was calculated and the sample was created as a sustainable energy source (Süme, 2014).

Table 2. Seasonal downfall (kg/m^2) distribution.

Seasons	Spring	Summer	Fall	Winter	Total
Trabzon	166.6	131.5	285.0	239.6	822.7
Maçka	223.3	136.6	167.4	166.5	693.8
Sümela (Meryemana)	291.2	266.2	204.4	145.2	907.0

3. Methods

On great rivers, identifying potential related to rivers, obtaining hydraulic data for this purpose and far projected have always been made and implemented. So, there are a lot of issues related to the method. Some methods need to be developed additionally related to small water streams and micro-water structures.

The most important aspect of that it is required to show as a significant source by making this micro-water structure from the electric potential of the small rivers. In this study, the following approach has been applied:

- It was obtained from the institutions and newsletters such as DMI, DSI and EIE that whether the region has been studied meteorologically and physically. Also if any, the flow measurement data, then the region's rainfall records and maps (Google maps, satellite maps) were acquired.
- Locations of the micro-water structures have been identified by using the 1:25000 topographic maps and the Google maps locations of MWS have been updated.
- Visiting the land with the research team, the availability of the MWS determined on the map is controlled.
- The depth of the existing transmission channel width was recorded measuring the data such as hydraulic water velocity and flow. Available measurements were made again as they are the basis of pre-feasibility studies.

Based on the obtained data micro hydro power potential was determined for each micro-water plant, 5 pieces micro-water structures were selected for the essential sampling. They were projected again, including the restoration of all data which are presented in the results table water structure, its sections and floor plans, and the section of the transmission channel (Figures 4-7).

Figure 4. Front View (MWS).

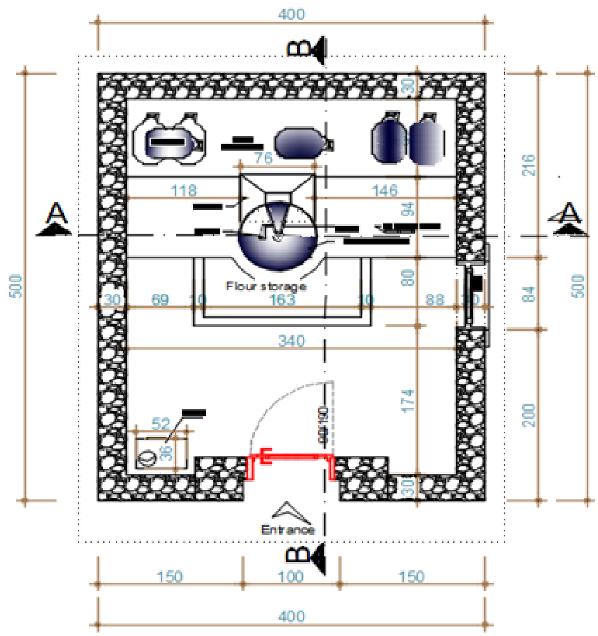

Figure 5. Floor Plan (MWS).

3.1.Determination of Estimated Energy Potential Criteria

Micro-water power potential (MWPP) requires detailed calculation, an extensive project work and dedication. The MWS results obtained in this study will provide major benefits in making the first study on the preparation of certain projects and plans. Some of the following several criteria consist of the planning of an economic plant.

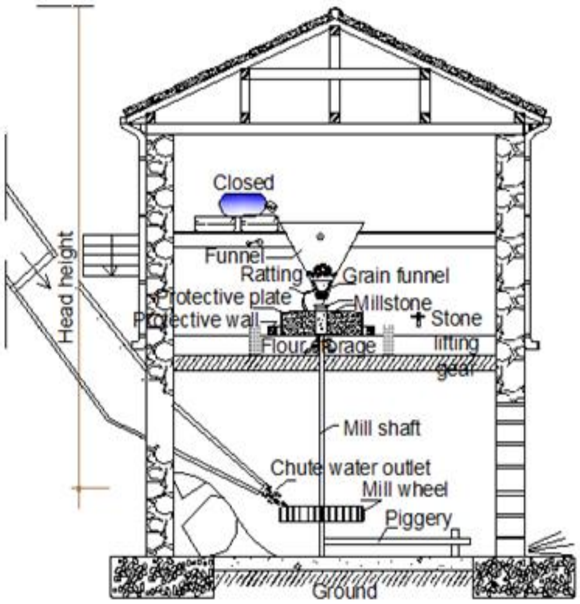

Figure 6. Cross Section (MWS).

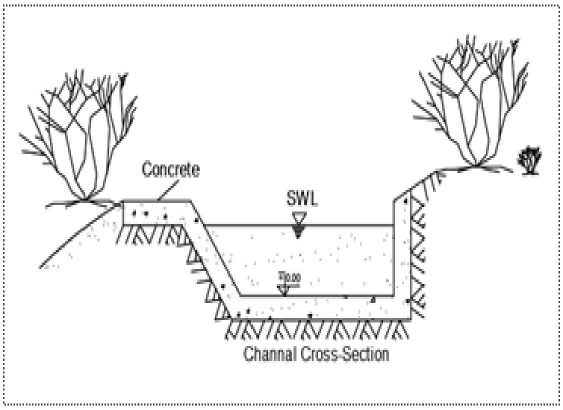

Figure 7. Channel Cross Section (MWS).

a) Environmental (environmental impact assessment) planning,
b) The amount of water (flow), such as falls from height and the power grid factors that should be considered,
c) Planning the facility location, topography of the facility location and its geomorphology,
d) Evaluation of water resources, determining the energy potential and basic drawings
e) Technological planning (turbine, generator, control equipment, connection place and if necessary the transformer selection),
f) Planning appropriate facility location and technology selection, accordingly developing plans,
g) Taking necessary permits (environmental, construction and energy, power supply) and energy sales,
h) Economically, construction costs, operating expenses and financial-maintenance-repair-control applications.

3.2. Determination of Estimated Water Power Potential

The equation (1) is used in calculating the plant flow of micro-water structure (MWS).

$$Q_0 = V_0 . A_0 \tag{1}$$

Utilizing the potential power available water flow and fall height is calculated from the equation (2).

$$\mathrm{P} = Q_0 . H_0 . \eta_{tur} . \eta_{gen} . \eta_{tra} . \mathrm{g} = Q_0 . H_0 . 0{,}81 . 9{,}81 \approx 8 . Q_0 . \mathrm{H}_0 \tag{2}$$

The concept of load factor related to the energy consumption is defined as the ratio of the average power (P_0) to the maximum (peak) power (P_a) (3).

$$Y_f = P_0 / P_a = Q_0 / Q_a \tag{3}$$

The energy to be generated at a certain time of water power plants can be found with (4) relation.

$$E = P_0 . t = P_a . t_0 = P_a . t . Y_f \tag{4}$$

Consequently, while planning the energy, if there is a water storage reservoir that the energy to be produced of the plant ($E = P_a . t$) is certain, it is appropriate to determine the installed capacity (P_a) by choosing the average operating time (t_0) according to requirements.

To achieve the maximum energy from a stream, the minimum flow, to be provided for 365 days a year, should be selected as the installation flow of the facility. But in the days of the selected plants now flow from the installation of larger energy flow cannot be obtained from all of the flow. Therefore, corresponding to % 50 (182.5 days = 4380 hour) flow (Q_{50}) has been selected as the flow of the facility (Abay et al., 2011).

The data obtained by the measurements in the study area, and each micro-structure of the energy potentials were calculated using the above equations (Table 3). The flow rate can be increased by enlarged flow channel dimensions in Table 2 on the condition of being reformed of micro-water structures (MWS). In this case, the total potential energy is increased in 2.91 fold (Table 4).

The power of the projected micro-water structures (MWS) is calculated as approximately 150.020 kW. As channel size magnification increases, the potential electrical power output can be increased from 150.020 kWh to 437.320 kWh.

Table 3. Estimated electric power of micro-water structure (MWS).

No	Name of micro water structure	Creek name	Dimensions of channel (m)		Cross section (Ao) (m^2)	Speed (V_o) (m/s)	Flow (Q_o) (m^3/s)	Drop (H_o) (m)	Av. effic. (η)	Grav. accel. (g) (m/s^2)	Power (P) (kWh)
			Wid.	Depth.							
1	Center (part 1)	Maçka stream	0.5	1.0	0.5	1.21	0.605	8.2	0.81	9.81	39.421
2	Center (part 2)	Maçka stream	0.5	1.0	0.5	0.98	0.49	8.2	0.81	9.81	31.927
3	Center (part 3)	Maçka stream	0.5	1.0	0.5	0.98	0.49	8.2	0.81	9.81	31.927
4	Altindere	Altın stream	0.4	0.9	0.36	1.04	0.374	7.4	0.81	9.81	22.015
5	Coşandere	Coşan stream	0.4	0.9	0.36	1.33	0.479	6.5	0.81	9.81	24.730
Total:											**150.020**

Table 4. Estimated electric power in MWS if the canal cross-section area is taken as 1.3m^2.

No	Name of micro water structure	Creek name	Dimensions of channel (m)		Cross section (Ao) (m^2)	Speed (V_o) (m/s)	Flow (Q_o) (m^3/s)	Drop (H_o) (m)	Av. effic. (η)	Grav. accel. (g) (m/s^2)	Power (P) (kWh)
			Wid.	Depth.							
1	Center (part 1)	Maçka creek	1.3	1.0	1.3	1.21	1.573	8.2	0.81	9.81	102.490
2	Center (part 2)	Maçka creek	1.3	1.0	1.3	0.98	1.274	8.2	0.81	9.81	83.010
3	Center (part 3)	Maçka creek	1.3	1.0	1.3	0.98	1.274	8.2	0.81	9.81	83.010
4	Altindere	Altındere	1.3	1.0	1.3	1.04	1.352	7.4	0.81	9.81	79.500
5	Coşandere	Coşandere	1.3	1.0	1.3	1.33	1.729	6.5	0.81	9.81	89.300
Total:											**437.320**

Figure 8 can be used in turbine selection. With the drop height value in the vertical axis, the flow value on the horizontal axis is combined with the straight lines. In which area the joined point is located, one of the remaining turbines in the surrounding area can be selected. For example, get the flow 2 m^3/s and the drop height 5m. The area in which they intersect gives guidance information that the one of the BANKİ or KAPLAN turbines should be selected (Figure 8).

The situation described above means that the height of the water drops more than its micro-structure (MWS) is given to the energy obtained with the existing network of 82.6% of the lighting needs of centers and villages can be met.

The generated energy, even for lighting purposes, can be given to the cable car commonly used in area to carry the load or for heating purposes to the homes without giving existing network (Kösoğlu, 2009; EMO, 2007). The most important thing is the economic superiority that is ensured.

Key factors to overcome the energy crisis in our country are the use of renewable energy sources.

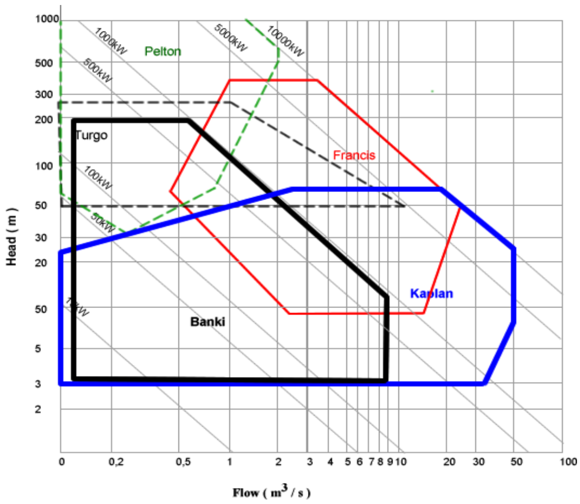

Figure 8. Turbine selection (Kaplan türbine, bounded area with blue line) (flow 0 to 50 m^3/s., head 0 to 200 m).

One of the most important advantages of these resources is our hydro-electric potential. Thus it is created a steady source of energy (Kirtay, 2011; Kocaer and Ahıskalı, 2011; Aras, 2012).

With this project, the destruction in the forests for heating can be prevented. Also as the local community will benefit from the energy derived from the region, it would contribute to the region's economy. The actual amount of water used in electricity production in our country is 35%. The remaining 65% of our water resources is still not available.

This potential can be used with only small and very small power plants. Filling this space with micro-water structures (MWS) is an unavoidable fact. The most appropriate turbine type can be used to generate electricity in micro water structures (MWS) is Kaplan-Banki turbine (Figures 8,9), (IJRET, 2011; Özdemir et al., 2006; Jiandong et al., 1997; Leckscheidt and Tijaroko, 2002; Öziş, 1991; Demirbaş, 2001; Süme and Koçyiğit, 2012).

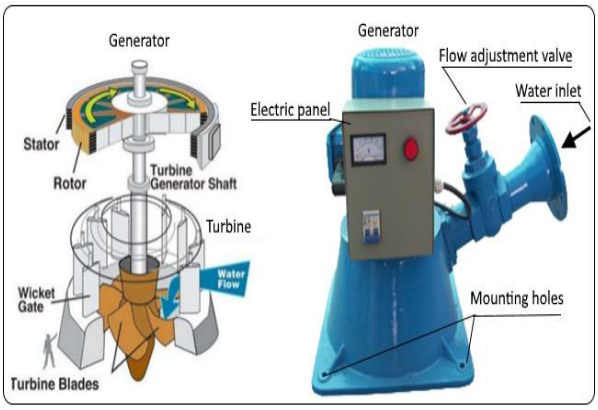

Figure 9. An example of a Kaplan turbine section and picture

4. Results and Discussion

With the using (MWS) micro-water structures electricity generation is growing along the worldwide so micro-water structures (MWS) method of power generation is simple, easy and cheap. Thus it is very important to inform people about this form of electricity generation.

Micro-water structure ((MWS) is an indigenous resource. It can be easily used in rural areas, not included in the normal power grid from the local environment. This system can work wherever appropriate or a regular flow is available though it is necessary to make an arrangement that will be at least 1 meter drop height for the operation of the water turbine system this value can go up to head height of 8-10 meters in Sümela valley. For a house, power less than 1 kwh is more than enough in most cases. Generally, micro-hydroelectric plant will pay for itself in a period of approximately 4 years and at the same time becomes a source of energy that is more cost-effective and environmentally friendly.

With these aspects of renewable and harmless for the environment indications of this situation that, local people are start to produce their own energy locally by building turbines in many houses and even the companies in small creeks. Because of the potential power of water in Turkey and in the world, people consider the water as an important resource. The tendency for that resource is increasing day by day. As a result, the energy obtained from renewable energy sources are used in homes and industrial areas on a daily basis. Therefore, it is clear that new and more efficient renewable energy sources must be found, especially where micro water bodies in the region (MWS) using micro-scale hydro-electricity generation remains as a great alternative.

In this study, downfall data on micro water structure (MWS) in order to generate electrical energy which were obtained by measuring and calculating the amount of energy are given in Table2. Energy that can be obtained by enlarged dimensions of available channels is given in Table3. It is possible to apply this sample micro-water structure to the whole region given the view of in figure 5. According to the increase in flow energy charts in the fall of four different head height and the amount of energy obtained, turbine selection is made and Kaplan-Banki turbine have been selected as the most appropriate turbine for the production in Turkey.

As a result, annual electricity consumption in Maçka for the purpose of lighting is 1.48296 million kWh in the city center and the monetary value of that is £ 497.825 and in its villages the consumption is 3.090.773 kWh, the monetary equivalent of this is £ 961.163. In total, it is 4.573.733 kWh and monetary value is £ 1.440.988. For centers and villages 381.144.42 kWh is spent monthly on average and so it is £ 120.082. The heating is based on coal and wood (Aydın, 2015).

5. Conclusions

In micro-water structures (MWS) worked with per height is between 6.5-8.2 meters. Kaplan-Banki turbines can be used up to 200 meters height of fall. This micro water structures in its current form is about 150.020 kWh electric can generate. But if the channel dimensions are enlarged, the electricity production of these plants can be increased to 455.945 kWh. This means that approximately 540 households consuming 200 kW per month can benefit from this energy. If upgraded that canal dimensions, the energy is increased by 3 times and it is approximately 1600 households benefit from this energy. It is understood that such a great potential is not used when it is thought that there are 2000 micro-water structures (MWS) in the Eastern Black Sea region as a renewable energy source. These micro-water constructions need to be started to building quickly generate electricity. Installation and operating costs are low. Since the energy obtained will be used by the local people, a great contribution will be made to family economies.

Considering our country's growing need for more energy, this energy to be generated should not be underestimated. Moreover, existing micro-water structures (MWS) should be preferred to non-renewable energy sources as they are environmentally friendly, and have no harmful effects to the environment. In micro-water structures (MWS) worked with per drop is between 6.5-8.2 meters. Kaplan-Banki turbines can be used up to 25 meters height of fall. This work in its current form is about 150.020 kWh, but the channel's potential is calculated as 455.945 kWh if the dimensions enlarged. Considering our country's growing need for more energy, this energy to be generated should not be underestimated. Moreover, existing micro-water structures (MWS) should be preferred to non-renewable energy sources as they are environmentally friendly, and have no harmful effects to the environment.

Notation

E: Energy generated in a given time interval [kWh],
Q_o: Average useful flow of water [m^3/s],
Q_a: The maximum (peak) flow of water [m^3/s],
V_o: The average speed of the water [m/s],
A_o: Cross-sectional area of flowing water [m^2],
P_o: Average power [kW],
P_a: The maximum power [kW],
H_o: Net fall height [m]
t: Specific time [hour]
t_o: Average working time [hour]
Y_f : Load factor (It is a theoretical value taken in situations such as reduction and multiplication of production)
η_{tur}: Turbine efficiency
η_{gen}: Generator efficiency
η_{tra}: Transformers efficiency
η: Shows average efficiency ($\eta_{tur}+\eta_{gen}+\eta_{tra}$)/3.
g: Gravitational acceleration [m/s^2]

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