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HYDROPOWER GENERATED FROM WASTEWATER FLOW OF SEWAGE SYSTEM IN MOUNTAIN CITIES: TAIF CITY AS A CASE STUDY

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ABSTRACT: A Hydro-Power potential (HPP) is defined by the head profile and the value of discharge. However, the absence of information on aspects such as discharge data, elevation, and head along sewers installed in the hilly and mountainous city is a significant barrier to effective design and implementation of a suitable HPP. In this research, GIS approach within new methodology is used to determine potential sites for installation of HPPs by analyzing spatial data. Head calculation was conducted using neighborhood statistical method with topography data from the municipality of Taif while sewage discharge was approached using the theory of simplifying sewage system. Findings indicated that Taif city has a total of 37 potential HPP sites with power outputs ranging from 8.83kW to 3.7MW. However, this approach is only effective in the determination of potential sites rather than the actual implementation of HPP systems. The present study finds that prospects of HP generation from wastewater flows in Taif City are feasible, hence deeper research into an actual implementation plan is recommended.

Keywords: Hydro-Power potential (HPP); GIS approach; Wastewater discharge; Mountainous city.

1. INTRODUCTION

In the wake of ever increasing cost of oil and uncertainty in supply of oil since the mid-1960s , utilization of energy from water has gained appreciable momentum and is being widely disseminated for displacement of oil-produced energy, and eventually to reduce the catastrophic effects of fossil fuel energy on the environment. Literature indicates that water energy (being free, sustainable, site-dependent, promising, non-polluting and benign) is being rigorously pursued by a number of developed and developing countries, in an effort to reduce their dependence on fossil-based non-renewable fuels [1]. Global renewable generation capacity increased by 167 GW and reached 2,179 GW worldwide as of 2018.

Currently, the price of generating energy using commercial is in the range of 4 to 5 cents per kWh [2]. The technology of the hydropower machines has improved remarkably over the last five years. Environmental pollution and energy depletion are emerging issues of concern in modern society. These critical issues primarily arise from unsustainable human activities such as transportation, mining, and resource extraction. In particular, modern man has developed heavy reliance on fossil fuels as sources of energy for utilization in various economic activities [1]. Even though oil, coal, and natural gas (fossil fuels) have previously been regarded as critical sources of energy, the rise of energy source depletion and sustainability concerns have led to a demand for much more sustainable means of energy generation [2].

Furthermore, the exponential rise in oil energy prices that probably commenced in the 1960s has necessitated the development of alternative means of energy generation [2]. The various potential sustainable alternatives that have been developed include wind energy (wind turbines), solar energy (solar panels), and hydro-electric power (water turbines) [3]. However, the most common form of sustainable power generation is the hydro-electric power generation approach [1]. For instance, by the year 1999, approximately 11% of all the energy generated in the United States came from Hydro-electricity [3].

Considering the potential problems posed by over-reliance on fossil fuels as the main sources of energy, more developed and developing countries are shifting their focus to hydro-electric power generation. Countries are also implementing environmental conservation policies that limit the production of machines and systems that rely on non-renewable sources of energy. In Germany, for instance, motor vehicle manufacturers are being constrained to adopt more environmentally sensitive strategies for vehicle design. Corporations such as Daimler AG have successfully tested and implemented preliminary electric engine prototypes. From an analytic perspective, these advances are geared towards embracement of renewable energy as a better alternative to existing unsustainable energy sources. Hydro-electric power generation, alongside solar and wind power generation, is given priority as the main sources of electrical energy for utilization in systems green energy systems such as electric engines.

The principal goal that countries actively engaged in green energy initiatives wish to achieve is reduced reliance on non-renewable sources, which are not only undergoing depletion but also carry serious environmental pollution implications. Consequently, developing a culture of dependence on renewable energy sources is a step toward curbing the challenges of environmental degradation and global warming. Even though the literature on renewable energy has been an area of interest among researchers in the current century, this trend has not been observed in Saudi Arabia [1-7]. This literature gap in Saudi Arabia comes at a time when the electricity demand in the region is increasing rapidly. In particular, the most compelling reasons for an increase in energy demand in Saudi Arabia are the rapid industrialization in the country and rapid population increase. While the demand for electricity is expected to hit a staggering 55,000 MW per annum by 2020, the current generating capacity is fixed at only 45,000MW per annum[4]. Saudi Arabia approximately holds 20% of the world's oil reserves. In 2008, oil and natural gas had shares of 56% and 44% in power production respectively [5]. While the need for HPP as one of the best forms of renewable energy generation is being recommended, conventional production of HPP relies on the availability of water [6]. Unfortunately, Saudi Arabia is an arid and semi-arid country with short cold winters and long hot summers [5]. However, topographical features could allow the flow of wastewater by gravity. In essence, Saudi Arabia is characterized by a hilly and mountainous topography [7]. The Kingdom of Saudi Arabia (KSA) is located within latitude 16 degrees North and latitude 32 degrees North [8] and has a very mountainous city known as Taif city. Taif city has been identified as a potential HPP site primarily due to its topography.

Taif city, a small city located in Makkah region in Saudi Arabia, was selected as a study case due to its geographical terrain that favors HP generation. Taif City is hilly and mountainous and allows the existence of natural waterfalls, which are key features of interest in HP generation. However, the most important element in this research was a generation of HP from wastewater flows in the region. Considering the mountainous terrain of Taif City, flowing wastewater carries a lot of energy that could be converted into electrical energy using basic hydro-electric power generation techniques.

The flow of water by gravity would facilitate energy extraction of HP energy from the wastewater rather than the strategic location of natural rivers, a process that would be quite challenging. The present study is pursuing a special methodology designed to determine the potential HP power in the flowing wastewater. In this study, sewage water networks data of Taif City has been collected from the municipality of Taif and ministry of statistics then treated by using GIS to assess the potential sites likely to be used for the development of water power plant (small hydropower station).

2. MATERIALS AND METHODS

2.1 Materials

Data of sewage network and master plan of Taif city including pipe network locations and diameters with all manholes are sourced from the municipality of Taif City as AutoCAD file to ease head calculation and location of potential sites as shown in Fig.1. ASTER Digital Elevation Model (DEM) with a spatial resolution of 30 m × 30 m [9] was implemented in the generation of contour lines and to evaluate the geographical features of Taif city. A number of houses and population information and water consumption of each area within Taif city are provided from the ministry of the housing to calculate the expected wastewater discharge from each area to the sewage network.

2.2 Head Calculation and Methodology

Using the conventional potential energy formula, two critical factors define HPP; discharge value and head value. In calculating the head of the sewage network, the research employs the GIS approach. This study clips DEM data, which has information on elevations, to the network map of the sewer system of Taif city as shown in Fig. 1. The result is a topographical profile of Taif city as well as a sewer network. This study then uses neighborhood analytics implement in ArcGIS as shown in Fig. 2,3.

This method of head calculation is a slight enhancement of the approaches employed by Malmros and Bergstrom [5]. Figure 1 shows the methodology and the outline of current research. This methodology consists of two approaches; one of them depends on the digital elevation model, and the other on data obtained from the field or government sector, for example, surveying maps.

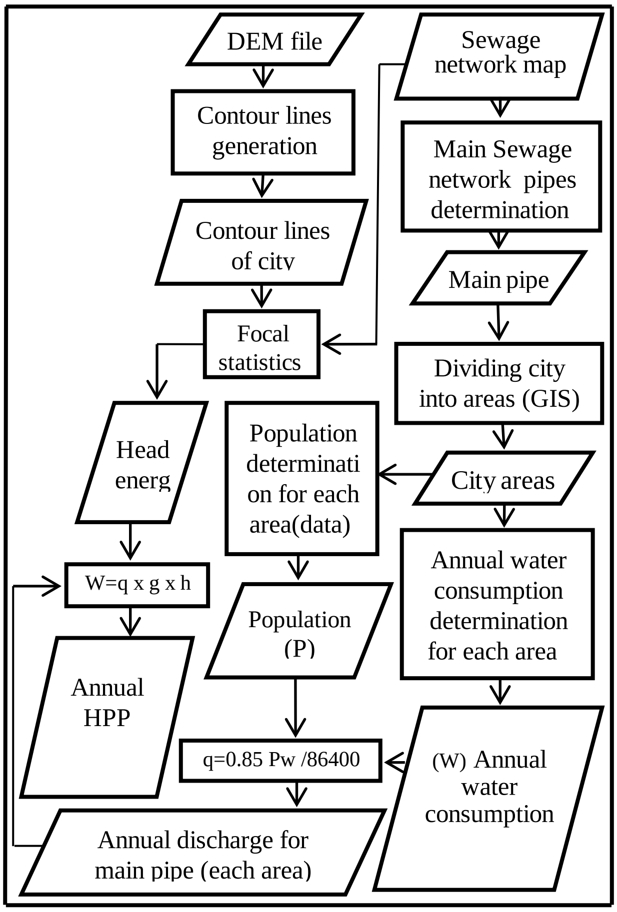

Fig.1 The Research Outline.

2.3 Discharge Calculation

From the plan drawings of Taif City sewer system, it is clear that the system followed the theory of simplified sewage system. Therefore, wastewater flow from each area can be estimated based on the same theory.

To determine the location of potential sites, Taif city is divided into 93 sections depending on the main pipe layout of each area as shown in Fig. 2 and Table 1. The value of the sewage flow used for small dimensions of sewer systems is the regular peak flow. This can be estimated as follows:

$$q = k1\, k2\, Pw / 8640 \qquad (1)$$

Where,
q = daily peak flow, l/s ;
P = population ,capita;
w = Annual water consumption, m³/year.

A suitable value for k1 for simplified sewerage is 1 and k2 may be taken as 0.85. Thus Eq. (1), which denotes annual discharge for each area or main pipe, becomes;

$$q = k1\, k2\, Pw / 8640 \qquad (2)$$

This equation appears in the methodology as shown in Fig.1.

Table 1 and Fig.2 illustrate the Zones and Population in Taif city and the Number of neighborhoods based on data obtained from the municipality of Taif city by using GIS approach according to this research methodology as shown in Fig. 1. The results showed that there was a decrease in the population at the center of the city. The Population of each neighborhood will be used in the calculation of the discharge and consequently, the potential energy determination as per the methodology presented in Fig. 1.

Table 1 Population and Zones' Data

Population	Number of neighborhoods
0-8600	8
8600-51120	51
54880-177480	26
185440-429080	11

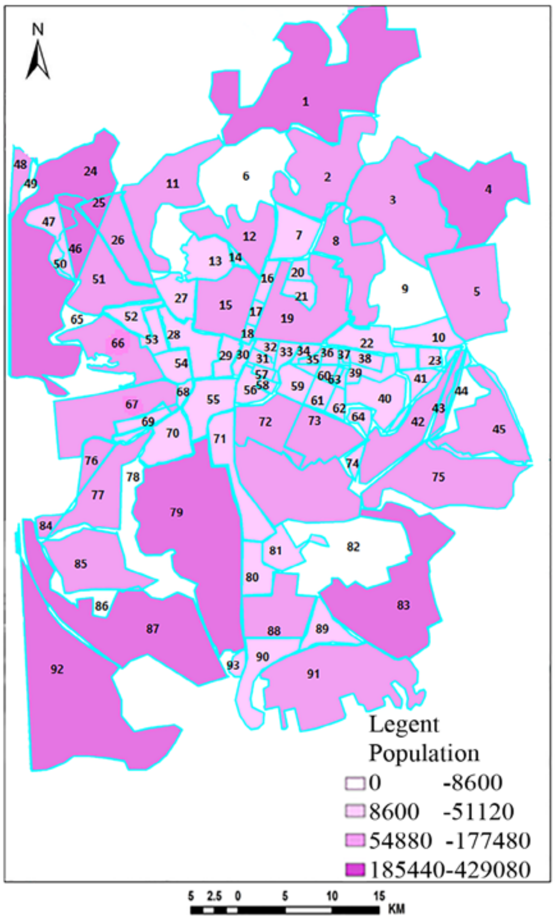

Fig.2 Zones in Taif city

Wastewater network has an intake pipe from houses and branches which deliver the water to main pipes. Therefore, main pipes have single water sources as shown in Fig.3.

2.4 Hydroelectric Power Potential (HPP)

The power potential of wastewater is the potential energy contained in the running wastewater.

HPP, measured in watts (Joules per second), was determined using the conventional potential energy formula,

$$W = m \times g \times h \quad (3)$$

This equation appears in the methodology as shown in Fig.1

Where,

m = mass of wastewater passing a given point per unit time (discharge),

g = acceleration due to gravity

h = energy head.

However, transmission losses, generator losses, and turbine losses were not included in the calculation of HPP because, calculation of these aspects would be conducted when the right time for actual implementation of the HP generation system in Taif City, these calculations will be made.

3. RESULTS AND DISCUSSION

The study area has buildings located on a range of hills. Considering the general hilly terrain of the area, gravity sewers were chosen as the most convenient sewers since wastewater is simply transported by gravity rather than energy. However, the main concept, in this case, is that wastewater is delivered from the higher regions to lower regions, hence it contains an unused form of potential energy similar to that found in waterfalls, which have been the conventional forms of hydroelectric power generation. Therefore, Current research applied methodology including GIS approach to determine hydropower potential sites in mountain cities as shown in Fig.1.

Figure 3 illustrates the locations of the sites with decent head according to the methodology demonstrated by Fig. 1. while Table 2 shows the Number of sites with decent head based on the results of the zonal analysis. These results showed that there were significant differences in elevations within Taif city. This may indicate that the development of hydropower plants in the city is useful for producing clean and sustainable energy. The effect of district area and population on potential energy locations does influence the expected potential energy.

Table 2 Number of sites with decent head based on the zonal analysis.

Potential (meters)	Number of sites
0-10	17
10-20	14
20-30	3
30-40	2
40-50	2

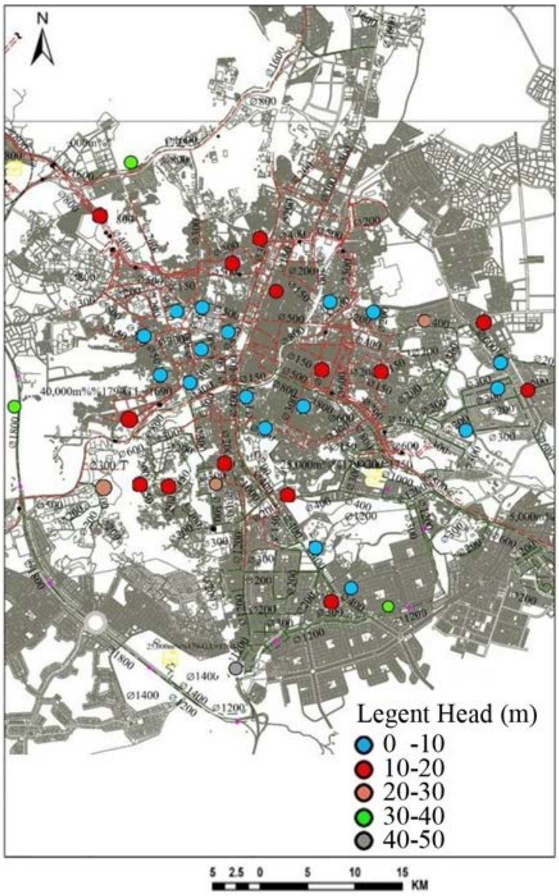

Fig.3 location of sites with decent head

Using the Eq. (3), the HP potential for various sites was calculated, ignoring generator and transmission line losses. Results of the calculations indicated that there were 21 potential sites whose expected HP varied from 800kW to 3.7MW as shown in Table 3 and Fig.3. Even though 48 sites had been considered earlier, generation of substantial amounts of HPP was found to be diminished due to their heads being less than 50 meters. The central area of the city is relatively flat and small; hence the amassed discharge is quite low. Precisely, the ultimate HPP calculated for this central part is approximately 800kW, hence it is not considered suitable for HP generation.

Table 3 Probable spots for HPP pigeonholed by wastewater discharge and a good head.

Potential (kg)	Number of sites
8.83-741	17
800-1480	14
1500-2220	3
2220-2960	2
3000-3700	2

Findings have also indicated that the North and South banks of the city have relatively greater HP potential and hydraulic head than other areas in Taif region as shown in Table 2 and Fig.3. By studying the topography of Taif city, the number of sites with potential HP generation from wastewater has been determined as shown in Table 2. However, the main assumption adopted in this case is that the rate of wastewater flow is considered as constant. Second, all the regions would release different volumes of wastewater depends on population and people's activities. The volume of wastewater is a critical parameter in the calculation of discharge, which in turn is essential in the determination of the power generated. Lastly, generator and transmission line losses were excluded since they would become much more meaningful in the actual design of Hydro power plants. Nevertheless, studying the topography of this city has shed some light on the possibility of generating hydropower plants from wastewater flow, a concept that has not been explored in contemporary literature on renewable and sustainable energy production.

4. CONCLUSION

The current research was undertaken with the principal objective of assessing the location and magnitude of hydropower generation from wastewater flows in Saudi Arabian cities. In this research, GIS approach within new methodology is used to determine potential sites for installation of HPPs by analyzing spatial data. Consequently, Taif city was selected as a case study to evaluate this approach. The city map was divided into 93 sections. Since wastewater flows form the basis of this hydro-electric concept, the sewerage system was clearly mapped and sewers in each of the 93 sections indicated properly. The flow in main sewers for each section was evaluated and the hydraulic potential of the wastewater determined. The investigation indicates that a total of 38 sites in Taif have hydraulic potential, and can be reliably used for power generation throughout the year.

In the course of undertaking the study, this study found that differences in height for various sections of the city have a positive impact on energy generation potentiality because hydropower plants purely depend on the flow of water by gravity, hence height difference of mountain cities facilitate this flow. The research method adopted in this case has efficaciously indicated prospective spots with relatively larger heads and discharge capacities. However, the research also indicated that not all sites with good heads have good discharge capacities. Analysis of head and discharge reveals 17 sites with power potentials below 8.83kw and 21 potential HPP spots with power potentials ranging between 8.83kW to 3.7MW. Nevertheless, the research still has some limitations. For instance, some zonal sites are considered to be separate, when they can be combined to become sites with greater power potentials. Additionally, the current research was only interested in the identification of hydropower potential sites. Since this study had only focused on determination of potential sites by using GIS approach rather than the actual implementation of HPP systems, it is recommended that further studies be carried out on the implementation of the final systems. Furthermore, future research could also study the economic and technical feasibility analysis of the actual implementation of HPP systems that attract the countries to use those clean energy.

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