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Renewable Energy for Pump Stations Operation in Delta Region Using GIS Technique "Study Case: El_Menoufia Governorate"

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Abstract

The paper analyzes replacement diesel fuel pump stations by the solar Photo Voltaic (PV) water pump stations in El_Menoufia Governorate. Due to declining of water levels in the Nile River with water pump stations are used along Nile River with its canals for irrigating agricultural land. About 600 pump stations networks are distributed all over the governorates in the Nile Delta. Every pump station consumed specific value of fuel; which might lead to further emissions of CO2 polluters to the environment. EL-Menoufia governorate has more than 20% from theses pump stations. In this paper, solar energy with the PV panels have been proposed and applied with the calculation of the needed area for installing the PV panels. Effect of pump operation using the diesel fuel on the environment is discussed. The emitted values of CO2, specify the polluted areas, and the degrees of pollutions are obtained. Digital elevation maps for the study region and a lot of data about the pumps were collected. Two models under Geographic Information System technique have been used. The results give a clear vision to the decision maker to apply the solar energy in all the distributed pump stations.

This paper presents a new technology of using solar PV water pumping in the Water Resources and Irrigation Ministry. The amount of generated solar power is calculated with specifying the Photo voltaic type, and the needed areas to install the PV panels. In addition the impact of used diesel pumps on the environment and the amount of CO2 emitted were obtained. Two models under Geographic Information System (GIS) technique have been used; (a) Geo-statistical and (b) Solar radiation models.

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Keywords: Pump Station; Solar Model; Geo-statistical Model.

Nomenclature

GIS : Geographic Information System

CO_2 : Carbon Dioxide

NREL: National Renewable Energy Laboratory

PVP : Photo Voltaic Pump

DP : Diesel Pump

NPC : Net Price Cost

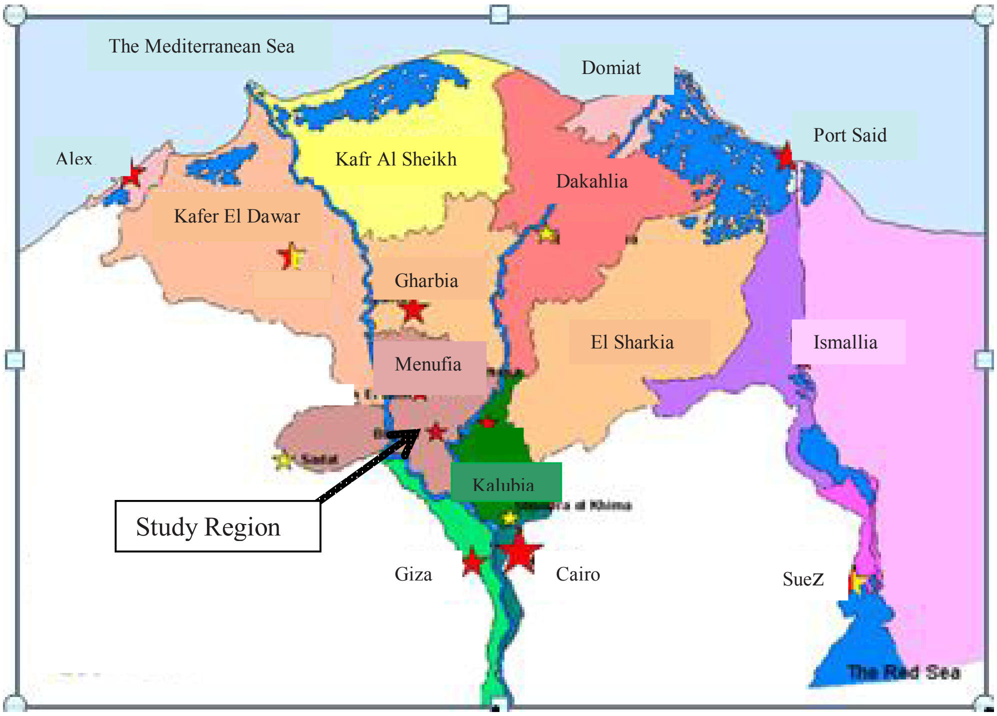
1. Introduction

Egypt is relatively modest in its resources of conventional energies (oil and gas) as compared with most of the Arab Countries. Around 600 pump stations distributed in whole delta region, 40% from them, operate by using fossil fuel caused Co_2 emission. It is expected that the country routs their efforts to the renewable energy, especially because of Egypt's excellent resources of hydro, wind, and sun powers. The expertise said, Egypt belongs to the global sun-belt, it gets about 3863 hours of sunlight per year, [2]. Pump stations are considered the most sources of Co_2, where it burns the fusel fuel. There are many types of pump stations. The most famous types are the centrifugal and spiral pumps. The centrifugal type is the most widely in the irrigation usages, [3]. An economical comparison between the diesel and solar photo voltaic water pumping system has been studied in many international researches, [4 – 6]. These studies were carried out in our concerned field and also in different climatic conditions. There is a great different between the two power sources; diesel and solar driven engine in terms of cost and reliability. Determination of the operation cost of diesel pumps need to know the amount of fuel used and the volume of water pumps. By the national developed program which is called "a sophisticated simulation program" that optimizes the most economic energy choices per specific project inputs. In this example SELF has used HOMER to model choices for a pumping system that is designed to pump 5,000 gallons/day from a total head of around 30.5 m. It compared a solar array of 1900 watts against a 4 kW diesel generator. The two types of pump system consumed approximately the same power (1 HP each). The last study assumed that fuel cost equal 1.2 $/liter and annual average of 4-6 peak sun hours per day. It is concluded in this study that; the usage of PV-Pumping system is more economically if it is compared by the diesel pump system. This result is indicated that solar option is approximately one fourth the net present cost of the diesel option. These studies give a good indication to make rehabilitation to all distribution networks of pump stations and make a serious study to replace the diesel pumps by PV-Pump system.

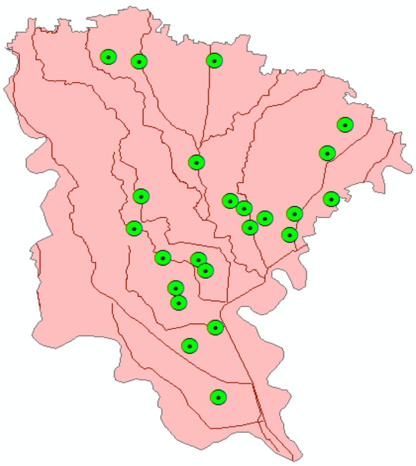
The research assesses the negative impacts of the use of diesel pumps in irrigation on the local environment and proposes solar energy as a source to feed the irrigation pumps. To achieve the goal of the study two models are carried out; solar radiation model to study the PV-Pump system and Geo-statistical model to assess the emission of Co_2 from pump stations operation and its concentration.

2. Accumulative data and study area description

El_Menoufia governorate is located in Delta of the Nile with El Gharbia Governorate in south and Cairo in north. It is regarded as one of the most densely populated areas in Egypt and its capital is Shebin El-Kom City. It encloses a wide range of agricultural lands. Its major economic resources are mainly driven from agriculture. Around 20% of the total pumps stations in delta distributed in the entire governorate. It is about. One third of these number of water pumps use diesel fuel as a source. All diesel pump stations which are used in irrigation are very old, where their efficiency is ranged between 30 to 40%,[8]. Figure 1(a) shows the location of El-Menoufia Governorate in Delta region and figure 1(b) shows the distribution network of pump stations in Menufia Governorate. Most of data for pump stations were collected from different sources, some of these data were collected using Google Earth program, such as X, Y points for every location of the pumps. The technical details for every pump station were collected from many Authorities, [12] and [13]. Table (1) tabulates the locations, names, discharge, and the head for some of these pumps.



(a)



(b)

Fig. 1. (a) Delta Region Governorates; (b) Distribution network of pump Stations in Menufia Governorate

Table 1, Sample of data for pump stations in Menoufia Governorate

No	X	Y	Name	Q m3/sec	Suc.	Expu.
1	325521.8	3386845.84	AlyAbdegwad-Quweisna	0.1	6	6
2	303020.4	3395964.58	Tala	0.28	6	7
3	309020.5	3381928.08	Shebein-elKom	0.14	7	8
4	302881.9	3377348.66	Singerg	0.19	7	7
5	305130.6	3368913.85	Serce-ellayan	0.22	6.5	13

3. Theoretical Formulations and Methodology

Many processes were carried out to achieve the aim of this study. The Methodology depending on three modules using different programs; the first module take place using Excel sheet program; referring to three steps; (1) first step, calculation of the consumed traditional power, (2) second step, calculation of the amount of fuels for pumps driven and, (3) third step calculation of the carbon dioxide emitted due to the fuel burning. Second and third modules are carried out using GIS technique; second module presents the Geo-statistical model to determine the degrees of the pollution in map shape, and the third module presents the solar radiation model and specifies the amount of kW gained from the model.

3.1. First module: Calculation of Consumed Power in Pump stations, the Consumed Fuel and the amount of Carbon Dioxide Emitted from Pump stations:

3.1.1. Calculation of consumed power in pump station:

The electric power consumed by pump station is calculated using the global equation for power, [10] in two formulas; kW and Hp:

$$P = (Q \ x \ H \ x \ y)/102 \qquad kW \qquad (1)$$

$$P = (Q \, x \, H \, x \, y)/75 \qquad HP \qquad (2)$$

Where

P : is the consumed power in pumps in (kW or HP), Q : is the discharge in Pump in m^3/sec, H: is the differential head -calculated from Suc. andExpu. of pump in (m), γ : is the specific gravity for water density (1000 kg/$m^{3)}$

3.1.2. Calculation of the Consumed Fuel:

To calculate the consumed fuel practically, the engine must be run for 1/2 hour at its rated rotating speed to be stable. Then by using a stop watch the elapsed time for consuming a known amount of fuel by the engine is obtained. Because it is not available the pumps study will be calibrated theoretically with considering the efficiency of diesel pumps ranged from 30 to 40%, [9]. By using the following functions, this point is achieved by**:**

$$\boldsymbol{mf} = V * \gamma \qquad kg/sec \qquad (3)$$

Where

mf : the weight of fuel consumed, V : volume of liquid (diesel, petroleum) in m^3/sec, and γ : Specific weight of liquid in kg/m^3

Thermal power for fuel:

$$\boldsymbol{P_{th}} = mf * L.C.V \qquad (4)$$

Where,

L.C.V = Lower calories Value for fuel, it is estimated by (42000 kjoul/kg)

Efficiency of pumps: efficiency is calculated from this relation:

$$\eta = (output / input) \qquad (5)$$

Where main output is,[10]:

- Motor, Pumping (Hydraulic) & System energy efficiencies
- Motor, Pumping & Piping Losses
- Total Energy Consumption & Energy Cost
- CO2 Emissions
- Energy Performance Indicators
- Comparison of Actual Performance v/s Best Practice

Performance Certificate"te: the fuel must be in gallon.

In this approach all these factors can't be covered because the shortage of data, so it is considered the output is the required amount of electric power for the pump to raise a specific amount of water.

" Main Inputs is,[10]:- Electrical energy consumption (measured or nameplate)
- Run hours
- Static head (from drawings)
- Discharges pressure (from pressure gauge)
- Flow rate (from flow meter or estimate)
- Average unit price (electricity)"

Input in this approach is considered the amount of fuel which is used to run the pump.

3.1.3. Calculation of the amount of Co_2 emitted from pump stations:

A scientifically agreed formula is used to calculate the amount of Co_2 emitted from diesel, [11]:

$$Emitted\ value\ of\ Co_2 = (Quantity\ of\ fuel * Emission\ factor) \quad gram \tag{6}$$

Note that; Value of emission factorvary depending on fueltype, diesel emission factor is calculated as:

$$Emission\ factor\ of\ diesel = 2.778 * 0.99 * (44/12) \tag{7}$$

3.2. Second Module; Geo-statistical Model to Specify the Polluted Area and the Degrees of Pollution Due to Co2 Emission:

By using thismodule the amount of the emitted of Co2 will be evaluated, in order to assess the decision maker a clear vision to the current environmental situation. Geo-statistical model is a statistical technique used for estimation, prediction and simulation of information correlated spatially. Whoever the data stored in a point–feature layer or by using the polygon, [12].Geo-statistical model gives the structural analysis which means calculation and modeling of the surface properties of nearby locations and also surface prediction and assessment of results. Its theory is based on how to choose sample points. These points are at different locationsin a landscape and create (interpolates) a continuous surface. The most commonly used surface type is a digital elevation model of terrain. The sample points are the measurements of the emitted Co_2 due to burning of the fossil fuels. To get and predict the pollution map, many processes should be followed, [13]:

1. Explore the data: The environment allows to investigation graphically the dataset. It provides different views of data and displays it in separate window. This process occurred by using the Histogram. Which is displayed the distribution of data.

2. Selection of Geo-statistic of method; There are different methods can be used to choose sample points at different locations in a land space. Ordinary kriging method is the more suitable method to be used. It assumes the data output from a stationary stochastic process, based on linear least square estimation algorithms, [13].

3. Calculation of the area of the study region: This step is useful in Lag Size calculation. By using Spatial Statistics tool, lag size are obtained. The number of Lags are obtained by the following equation:

$$Area = (\ No.\ of\ Lags * Lag\ Size) \tag{8}$$

$$Lag\ Size = [(Expected\ Mean\ Distance + Observed\ Mean\ Distance)\ /\ 2] \tag{9}$$

Note: Area in this study is the El- Menufia Governorate

4. By using the Observed Mean Distance and Expected Mean Distance, the prediction map is generated in a suitable format.

From geo-statistical mdel output, the Root Mean Square Standarised is equal to 0.9663 (near to one value), while the Mean Standarised is equal to 0.01817 (near to zero value). The Root Mean Square is equal to 17930 and the Average Standard Error is 18540 (small difference), which means that good and satisfactory results are obtained from this model.

3.3. Third Module; Solar Radiation Model to Estimate the Amount of Solar Energy Required, Type and Needed Area of PV Panels:

The amounts of electric energy generated that reach the spot points on earth's surface vary according to the following factors, [14]:

a)Geographic location, b)sunshine hours of day, c)Season, d)Local landscape, e)Local weather. The required amount of solar energy to fuel the pumps are obtained using the following procedures:

3.3.1. Procedure

Depends mainly on the evaluation of the solar energy resource in the region, using Remote sensing programs, Land sat orbit, and Digital Elevation Model (DEM) for El_Menufia governorate. The total amount of radiation depending on sources of illumination on a slope in the solar spectrum;

(1) Directirradiance, which includes self-shadowing and shadows cast by nearby terrain;

(2) Diffuse sky irradiance ,where a portion of the overlying hemisphere may beobstructed by nearby terrain.

(3) Direct and diffuseirradiance reflected by nearby terrain toward the location ofinterest.

The calculations based on methods from the hemispherical viewed algorithm. Direct irradiance is a function of solar zenith angle and thesolar flux at the top of the atmosphere (exoatmospheric flux).Zenith angle and exoatmosphericflux vary by date, whiletransmittance is a function of absorbers and scatters that can vary greatly over time. Given an optical depth of τ0,theirradiance is, [13]:

$$\mu_0 s_0 e^{t0/\cos\theta_o} = \left[\cos\theta_0 \cos S + \sin\theta_0 \sin S \cos\varphi_0 - A\right] S_0 e^{t0/\cos\theta_0} \qquad (10)$$

Where, S_0 : is theexatmospheric solar flux, θ_0 : is the solar zenith angle, φ : is the solar azimuth, A is the azimuth of slope, S : is the slope angle

The diffuse radiation; depending on many factors such that; anisotropy in thediffuse irradiance, and the amount of sky visible at a point, can be concluded as the following:

$$V_d = F{\downarrow}\tau 0 \qquad (11)$$

Where F↓τ0is the average diffuse irradiance on a level surface at the elevation, and V_d is the sky view factor, where it varies from 1 to 0.

The reflect irradiance; for each point reflects radiation is taken from surrounding terrain; its formula concluded as, [13]:

$$Ct = \frac{1+\cos S}{2} - V_d \qquad (12)$$

$$CtF{\uparrow}(\tau_0) = Ct\, R_0\, F{\downarrow}\tau 0 \qquad (13)$$

Where Ct : is the terrain configuration factor , F↑(τ0): is the amount of radiation reflected off the surface with an average reflectance of R_0.

From allabove, the total irradiance on a slope can be given as:

$$R{\downarrow}\ (slope) = [VdF{\downarrow}(\tau 0) + Ct\, F{\uparrow}(\tau 0) + \mu_s S_0\, e^{-\tau 0/\cos\theta 0}] \qquad (14)$$

Where, V_d,C_t ,and μ_s are all derived from digital elevation dataand all vary spatially.

-τ0: is the pressure function; thediffuse radiation will vary spatially with elevation, as will thedirect irradiance.

3.3.2. Procedure

PV type and controller [15],and [16] : There are two types of PV that are used for solar-PV water pumping: (a) multi crystalline, and (b) thin film. While thin film type is used with required high voltage. All pump stations in the study are classified into medium to high voltage motors. So the PV which is more suitablefor this study is thin film type. Second term in this point is the controller; using maximum power point tracking, to maximize the output power, irrespective of temperature and irradiation conditions and measured cell characteristics (current, voltage, power). Output of PV array is used to directly control the dc/dc converter and needed digital signal processor.

3.3.3. Procedure

Selection of pump type [6]: there are four types of pumps which have been powered by solar-PV: diaphragm, Piston, Helical, and Centrifugal. Centrifugal pumps classified as the high voltage motor and low pumping depth,Which are concerned in this study

3.3.4. Procedure

Specification and determination of the needed areas to install the PV panel at every location: required area can be estimated in terms of amount of electric power (in kW) and the solar radiation in specific point (in kW/m^2), Table 3 represents the results of this process.

4. Solar-Powered Water Pumping System Configurations

There are two basic types of solar-powered water pumping systems, battery-coupled and direct-coupled. Based on theirrigation system in Egypt, battery-coupled is more suitable. So the proposed system in this approach can be concluded as:

1) Photovoltaic (PV) arrays, using thin film type for covering the required areas, to generate the electric energy
2) Pump Controller; using maximum power point tracking, to maximize the output power
3) Charge control regulator, to control the amount of charge from a solar panel into a deep cycle battery bank.
4) Batteries, to saving energy and supply the electricity at any time.
5) Pressure switch, to maintain the range of the system pressure.
6) AC –pumps, using Centrifugal pumps to draw and pump the amount of required water.
7) Accessories: Cable, Connectors, Pipe and other Accessories

The electric current produced by PV panels during daylight hours charges the batteries, and the batteries in turn supply power to the pump anytime water is needed. The use of batteries spreads the pumping over a longer period of time by providing a steady operating voltage to the DC motor of the pump. Thus, during the night and low light periods, the system can still deliver a constant source of water for livestock.

5. Applications and Results

El-Menufia governorate has around 1/5 of the pump stations in Delta. These pumps use diesel fuel as it is recorded in the reports of Mechanical and Electrical Authority. Five mathematical modules have been suggested and presented to achieve the goals of this study;

5.1. First, second and third modules are referred to the calculations of the consumed power by the diesel fuel and the CO_2 emitted due to the fuel burning

Table (2) tabulates the results of the three modules. From this table; (1) the power consumed by 23 pumps are, 2317 Hp. (2) the diesel fuel used is 2472 gallon/day. 3) The emitted $Co_{2,}$ is 11.8 ton/day.

5.2. Fourth module represents the Geo-statistical model

To study the pollution. Pollution chart for El_Menufiagovernorate (figure (2)); its contours indicate; the concentration of pollution in western_north of the governorate and the key of chart represents the degrees of the pollutions.

5.3. Fifth module calculate the amountof solar energy gained at every point and the determinationof the areas that covered by PV panels,

To supply the pump station by clean energy, Tables (3) and figure 2(a), and (b) illustrate the solar radiation map for the study region with the minimum and maximum value for two types of radiations, direct radiation and diffused radiation and the calculated areas. Moreover, the output of fifth module is compared by using the measured values. There is no metrological station in El_menufia governorate,so measured of nearest metrological station, "Cairo Station" is used in the comparison. The percentage of errors between output of model and measured values must not exceeds 10%. The calculated errors ranged between 7.1% to 8.4%,. Table (4) illustrates that..

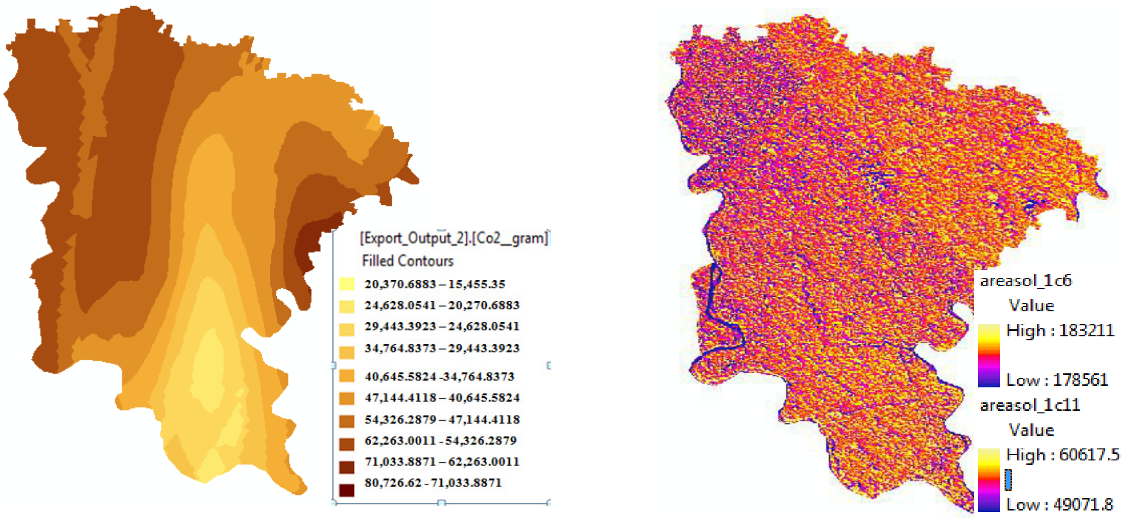


Fig. 2. (a) The prediction of pollution map, (b) Solar Radian Map for El_Menufia Governorate

Table 2, Power, Fuel Consumption and emission of Co2 from Pump Stations

No	Name	No. of units*	P Elec. Hp	P Elec. kW	Fuel Consume. gallon/h	Co_2 Emission kg
1	AlyAbdegwad-Quweisna	3	52.0	49.71	3.05	10.25
2	Tala	3	145.6	139.18	7.47	25.11
3	Shebein-elKom	1	28.0	26.76	1.92	19.32
4	Singerg	3	106.4	101.71	5.75	19.32
5	Serce-ellayan	3	148.7	109.35	8.03	20.77

*Number of pump's units in the station

Table 3. Sample from Output of Model and Areas Required for PV Panels at each Pump Location

Id Number	Name of Station	Output of Model (kWatt,H/m2) X (9)*	Req. Source kW	Area m2
1	AlyAbdegwad-Quweisna	17	50	2.9
2	Tala	16	139	8.7
3	Shebein-elKom	16.7	27	1.6
4	Singerg	20	102	5.1
5	Serce-ellayan	17.4	109	6.2

* (9) (the sun shine hours in summer (10.7) + the estimated in winter (7.5)) / 2

Table 4. Comparison between Measured data and The Model results

Months	Measured Data (w.h/day)	Model Results (w.h/day)	Error (%)
Jan.	2770	2189	7.9
Feb	4155	3038	7.3
Mar	4986	4158	8.3
Apr	6232.5	5162	8.3
May	6925	5795	8.4

6. Conclusions and Recommendations

Five mathematical modules were carried out to achieve the research goal. Three modules were used for calculations of the consumed power, the consumed diesel fuel and the amount of CO_2 emitted. The other two modules (under GIS) are ; Geo-statistical module, to study the pollution from the diesel pump stations. Solar radiation module, to study the replacement of the diesel fuel for the irrigation pumps by PV pumps. The impact of using diesel fuel in irrigation pumps caused CO_2 emission which is estimated by 11.8 ton/day of CO_2. It causes negative effect on the environment and the human. Results of solar radiation model are compared with measured data from metrological Cairo station; it is found that; errors not exceeds 8.5% and this indicates Solar Radiation model under GIS is good. It is recommended that; PV pump stations need wide areas to be used, so the remote areas will be more suitable for them. Another model to calculate the amount of solar energy must be applied and its results compared with output of solar radiation model.

References.

[1] Goujan, H. Alkikat, Lutz, and Prommer." Population and human capital growth in Egypt Prrojection to 2051" Presented at the workshope on Population, human capital and water in Egypt, Cairo, March 2007.

[2] M.N.H. Comsan,"Solar Energy Perspectives in Egypt", Projects and Consultation Unit, Afaq Scientific, Cairo, Egypt, Proceedings of the 4th Environmental Physics Conference, Hurghada, Egypt, 10-14 March 2010.

[3] Human Resources Division, “Pumps Technology”, Engineering for the Petroleum and process Industries, Chapter 1, November/ December, 2010.

[4] Solar Electric Light Fund, (SELF), "A Cost and Reliability Comparison Between Solar and Diesel Powered Pumps", The U.S. National Renewable Laboratory, July, 2008.

[5] M.Abu-Aligah, "Design of Photovoltaic Water Pumping System and Compare it with Diesel Pump", Jordan Journal of Mechanical and Industrial Engineering, volume 5, No. 3, ISSN 1995-6665, pages 273 – 280, June 2011.

[6] Brian D. Vick, and R. Nolan Clark, "Determining the Optimum Solar Water Pumping System for Domestic Use, Livestock Watering or Irrigation", Conservation and Production Research Lab., Bushland, TX 79012.

[7] S. S. Zaghloul, Hussein Elwan, “Water Quality Deterioration of Middle Nile Delta Due to Urbanizations Expansion, Egypt”, Fifteenth International Water Technology Conference, IWTC-15, Alexandria, Egypt, 2011.

[8] Mechanical and electrical Institute, "Field Test for Irrigation Pumps for Irrigation Improvement Sector", Final Report, September – October, 2003.

[9] Mechanical and electrical Authority, “Data Base unit, Technical Specifications of Pump Station of Irrigation”, 2011.

[10] Pump Station Efficiency Calculation tool, this tool is based on a tool originally developed by Tipperary Energy Agency, Midlands Energy Agency & Kerry County Council.

[11] “Calculation of Allowable Co2”; is Available at Web Site;.ttp://greenecon.net/understanding-the-cost- solar-energy/energy_economics.html

[12] R. K. SHARMA, T. K. SHARMA, “Water Power Engineering”, Text book, S. Chand & Company Ltd., Ram Nagar, New Delhi – 110 055.

[13] Ing.Adriana Patricia, AlberHamersson, John Willington Libardo,”Applied Geostatistics to Studies of Environmental Contamination”, Alternative analysis viewpoints for air pollutants in Bogotá D.C.

[14] RalphDubayah and Paul M. Rich, "GIS-Based Solar Radiation Modeling", pp 129-134. In; MJ. Goodchild, L.T. Steyaert, B.O. Parks. GIS and environmental modeling: progress and research issues. GIS World Books. 1996.

[15] Lyon Van der Merwe, and Gawie J. Van der Merwe, ”Maximum Power Point Tracking – Implementation Strategies”, 0- 7803-4756-0/98, 1998 IEEE.

[16] M.Abu-Aligah, "Design of Photovoltaic Water Pumping System and Compare it with DieselPump", Jordan Journal of Mechanical and Industrial Engineering,volume 5, No. 3, ISSN 1995-6665, pages 273 – 280, June 2011