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Potential for Solar Power to Pump Saline Groundwater and Management

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Abstract: The main factor contributing to shallow water tables is water leakage below farming systems. The potential for development of saline water pumping from depths of 7 and 14 m using solar energy was studied . Iraq is characterized by an arid to semi-arid climate. Daily climatological parameters were measured at five sites for 10 years, and monthly averages were calculated. The energy required to deliver a volume of water by solar pumping was estimated, and a cost-benefit analysis was used to evaluate the feasibility of such systems in the region of four sites. The most favourable site is Kut, where potential water output adds up to about 23% of the water produced from all sites combined. Results show that three other sites (Babylon, Alxanderia and Baghdad) can be considered favourable. The poorest site is Ramadi where the potential water output totals 16% of all sites combined.

Keywords: Groundwater; Iraq, solar pumping, shallow water.

I. INTRODUCTION

From their archaeological studies,[1] concluded that salinity of the upper soil profile in the Tigris and Euphrates river valleys in modern Iraq has increased over about 4500 years. In this region, almost equal amounts of wheat and barley were grown in 3500 B.C, but 1000 years later, only one-sixth of the total crop was wheat, and by 1700 B.C. the production of wheat was abandoned. This decline in wheat production and increase in relatively salt-tolerant barley coincides with increasing soil salinisation. Salt accumulation in soils is considered to be a factor in the demise of the Sumerian civilization.

Irrigation practices by the Sumerians were not greatly different from those practiced today. At the scale of irrigation furrows, there can be important differences in the salt content of soil immediately under a furrow and that at the top of the bed where crops are planted. Downward water movement under the furrow leaches the soil and reduces soil salinity whilst capillarity moves water to the top of the beds where salt accumulates as water evaporates.

At the regional scale, excessive furrow irrigation, monoculture systems and continuous farming in Iraq have increased leakage of irrigation water to groundwater, and evaporation from shallow water tables over thousands of years has resulted in a huge accumulation of salts in near-surface soils. The greatest effect of salinity on crops in Iraq is when soluble salts (Na, Ca, Mg, Cl, CO_3) accumulate in the plant root zone [2]Leakage of water beneath this zone (generally around 0.4 m depth) is affected by soil properties, topography, vegetation, climate and land management. In southern Iraq drainage is poor due to soil properties and this has contributed to the accumulation of salts in the near-surface soils of that region.
Saline water in an aquifer below the root zone may not be a problem to crops, but the upward movement of these salts by capillarity to maintain evapotranspiration can result in saline conditions within the root zone. Therefore the control of salinity is achieved by controlling the groundwater table and consequently the saline water movement (capillary action). The depth of the water table is successfully increased by pumping from shallow wells.

Deep groundwater in the eastern desert of Iraq is considered to be an important water resource, and in some areas it is the only source of water. Water pumping is a basic need for the population in these areas where the national electric grid and water network are not available. Traditionally water is provided by hand pumping or with the assistance of animals, while the principal source of mechanized power for rural areas is diesel engines. Solar energy is abundant in most regions of Iraq and it seems quite natural to use this resource for water pumping. Recently there has been a revival of interest in wind pumps as well as a growing interest in the new technology of solar powered water pumps.

Solar energy can be converted to the mechanical energy required for pumping by direct conversion of solar radiation to electricity that drives a motor/pump unit, or by conversion of solar energy to heat that can then be used to drive a heat engine. The latter approach has received widespread attention in research institutes, but so far no such systems have proved reliable. Consequently, at present the most suitable approach to solar water pumping is to use photovoltaic (PV) powered pumps [3] In 1985, the first project on the utilization of PV generators instead of diesel engines for water pumping in rural desert areas of Iraq was carried out. [4] worked on the three main applications for solar pumps:

1. A source of water for irrigation;
2. Lowering the water table to increase leaching; and
3. Water supplies for livestock and villages.

Pumping to control the water table depth is characterized by large variations of demand from month to month, peaking at around 100 m^3/day/ha in some months and dropping to zero in others. Water for irrigation supplies is characterized by a more constant demand. It is critical to have water available on demand, so irrigation systems generally include a storage tank. There are a number of computer models available for sizing photovoltaic and other pumping systems [2], but a simple procedure that involves a number of approximations has been developed.

In this paper, the potential of solar energy development for water pumping is investigated for five sites in Iraq. Beside the water pumping technique, approaches can be used to reduce water recharge such as increasing the use of deep rooted crops to remove water from the soil profile before it reaches groundwater. Eucalyptus is the best method to plant in the open fields for multipurpose benefits such as preventing or reducing the impact of dust storms that damage crops and infrastructure. Legumes are another choice of deep rooted crop.

II. Environment

The region between the Tigris and Euphrates rivers in Iraq is of primary interest in the investigation reported here. This is broad central lowland that provides most of the country's agricultural production with the rivers providing the principal source of water for irrigation.

Iraq is characterised by an arid to semi-arid climate, being arid in the Eastern part and less so in Mesopotamia. Rain seasons are short with annual means varying regionally from 150 to 450 mm. Almost all rain falls in winter (December to February). The region is characterised by clear skies during most of the year, and potential evaporation rates up to 25 mm/d in summer. Ambient temperatures range from 7 to 20 ^oC in winter and 30 to 47 ^oC in summer.

The soils of Iraq are Aridisols, Inceptisol, Vertisols, Milisols, and others. In the Euphrates valley, gypsiferous soils with high salt storage are widespread. The lowland region dips gently to the southeast with sediments becoming generally more fine-textured in the delta lands south of Baghdad.

Due to the aridity, wind erosion (mainly in eastern region) and water erosion (mainly in the southern region) occur frequently. Materials eroded by surface water flow are deposited in mud flats (small desert playa lakes).

Five sites were chosen for detailed study in the investigation reported here. They are Ramadi (34.30 N; 43.10 E), Baghdad (33.14 N; 44.14 E), Alxanderia (32.40 N; 44.40 E), Babylon (32.00 N; 44.35 E) and Kut (31.00 N; 46.20 E). These are regions where the national electricity grid is not available to power groundwater pumps.

In the southern Euphrates valley (Kut, Babylon and Alxanderia) groundwater is more saline (up to 14 000 mg/L) due to slow to moderate groundwater through flow. Salt-tolerant perennials (Date Palms) are economical in these areas. Less salt-tolerant annual crops (small grains, vegetables, citrus and legumes) are traditionally farmed in the areas of Ramadi and Baghdad where groundwater gradients are relatively high and salinity is lower.

The latitude of these sites is close to that of Koorda, Quarading, Pingelly, Wagin and Kendenup respectively, or much of the wheatbelt in southwest WA where similar levels of solar radiation are expected.

Recharge to groundwater varies between the experimental sites. It is higher in deep soils (Ramadi and Baghdad) and locations with poor water holding capacity (light soils), but less in soils with high water holding capacity (heavy soils of the Alxanderia, Babylon and Kut locations). All sites studied have very low groundwater gradients and consequently very low rates of lateral groundwater flow.

Groundwater salinity at the sites studied ranges from around 10 000 mg/L (Ramadi) to 14 000 mg/L (Kut).

III. Energy for water pumping

Saline water tables rise to within 5 m of the soil surface in the southern region (Kut) and 10 to 15 m in the upper Euphrates valley. Water pumping is seen as one means to reduce the impact of the salinity and water logging in specific groundwater leakage regions.

Solar pumping allows water to flow continuously to the surface by energy released from the photovoltaic system. This power is renewed by capture of solar radiation and converted to mechanical energy or stored in batteries to be used at night and during cloudy days.

The pumping (hydraulic) energy required to deliver a volume of water is given by

$$\mathbf{E_h = \rho_w\, g\, V\, H}$$

where E_h is the required hydraulic energy [ML^2/T^2], V the required volume of water [L^3], H the total head [m], ρ_w the density of water [M/L^3] and g the gravitational acceleration [L/T^2].

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The input energy for the pumping system undergoes several conversions before it is made available as useful hydraulic energy. The input energy requirements for pumping are generally much greater than the useful hydraulic energy output because of the energy losses associated with each conversion. The power P_w [ML^2/T^3] required to lift water at a rate Q [L^3/T] is given in the form

$$\mathbf{P_h = \rho_w\, g\, H\, Q}$$

The total head comprises the sum of the static head and head loss in pipes, which depends on pipe diameter and flow rate.

The photovoltaic surface area of was calculated as follows

$$\mathbf{S = P_h/(R_s\, \eta_c)}$$

where S (m^2) is the surface area of the photovoltaic system, R_s is total solar radiation, (MJ/m^2), η_c is the photovoltaic efficiency (~10%) and P_h (MJ) is the required pump power.

IV. Economy Assessment

Economic considerations are important when comparing methods and these will differ between Iraq and Australia. Solar PV pumps are technically viable but where alternatives exist, the evaluation of these must include both economic and technical considerations. There are three common criteria that are used for making an economical evaluation: the payback period, rate of return, and life cycle costs. The purpose of cost appraisal is to calculate the unit water cost.

The methodology can be used to compare costs of the major alternative pumping methods: solar pumps, wind pumps, engine driven pumps, animal powered pumps and hand pumps. The calculations in these methods involve the use of discount rate, which reflects the cost of capital [5].

In the review of existing surveys on financial evaluation methods for solar water pumping systems, the following limitations were observed:

- The problem of calculating revenues;
- Determination of interest rate for discounting;
- The problem of cost calculations for solar water pumping systems; and
- Estimation of the lifetime of solar water pumping components or of the system itself.

The socio-economic evaluation included assessments of all gains and all losses of solar water pumping systems, which include the financial, social, cultural and ecological impacts. The most widely used method in socio-economic analysis is cost-benefit analysis. Although the assessment of socio-economic benefits and costs depends first of all on the data provided by the cash flow sheets, it is supplemented by socio-economic impacts from the field of welfare economics.

The Analytic Hierarchy Process (AHP) can be used as a practical approach for addressing these cost-benefit application issues [6] .It has been effective in structuring many types of complex multi-criterion problems. The AHP has been applied to evaluation of energy systems, choosing areas of R&D programs, and water polices [7, 8]. In a forthcoming paper, application of the AHP for study of the feasibility of solar water pumping systems in Jordan is to be reported.

V. Results and Discussion

Figure 1 shows monthly averages of total daily solar radiation that was measured for was measured for ten years (1989-2010) at the five study sites.

In terms of solar irradiance Kut, Babylon and Alexandria are the three most promising sites for solar powered pumps. Annual average solar radiation densities at these sites are 32, 32.8 33 MJm^2 /day for Alexandria, Babylon and Kut respectively (2219, 2177 and 2052 J/cm^2, respectively).

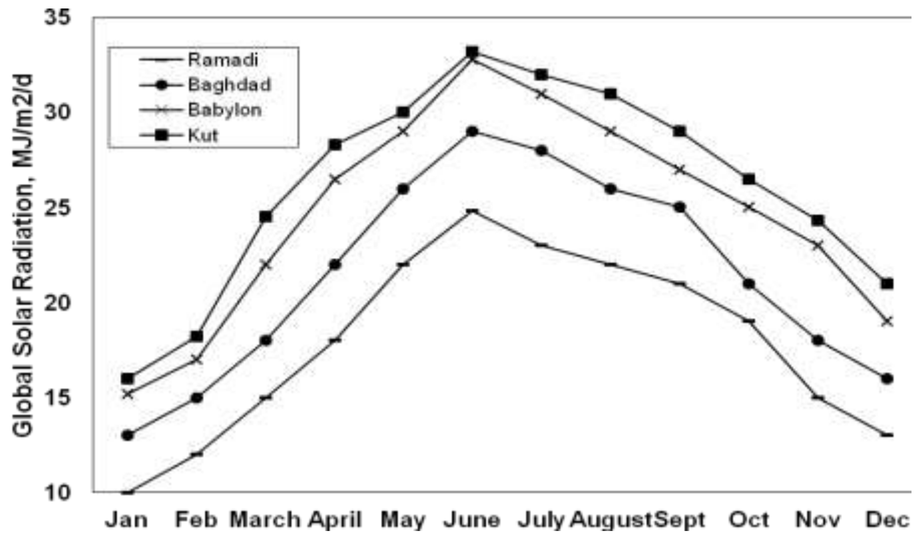

Figure 1: Average monthly global solar radiation at the sites studied.

Figure 2 shows calculated average daily values of the maximum mechanical energy available for pumping water at the sites studied.

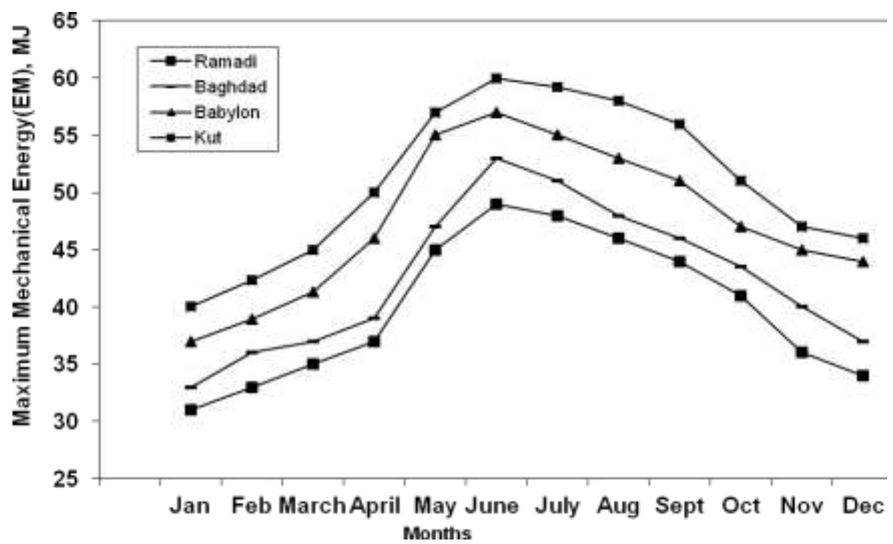

Figure 2: Maximum daily power required available for pumping.

It can be seen that the Alexandria, Babylon and Kut sites represent the most favorable regions for solar water pumping.

Figure 3 shows calculated potential monthly average rates of pumping from depths of 7 and 14 m at the three most favourable sites

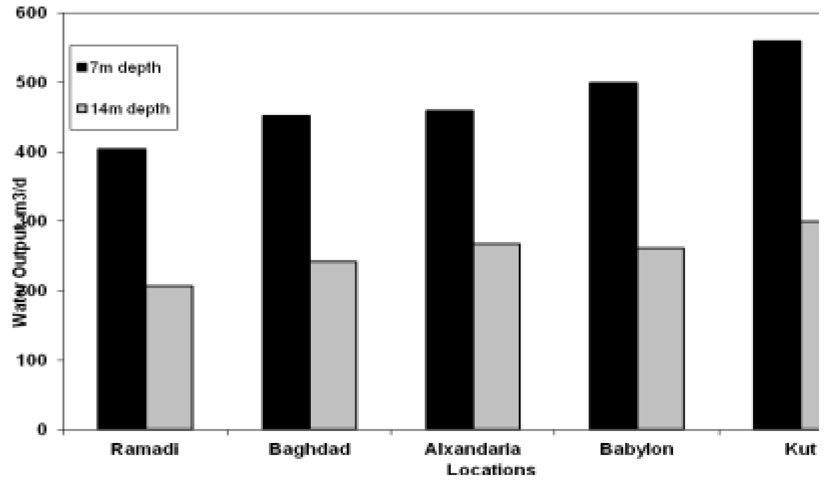

Figure 3: Monthly average rates of pumping.

Annual water output at the Alxanderia, Babylon and Kut sites can add up to 64% of water produced from all five sites combined. Kut produced the most water followed by Babylon and Alxanderia, which were very close to each other. Fifty five percent of the annual amount of water produced from the 7 m depth at these sites takes place during the months May through September. These months are dry, water consumption is high and the water requirement for irrigation is greatest. At these locations a solar powered pumping system would be an excellent choice, when water consumption is high.

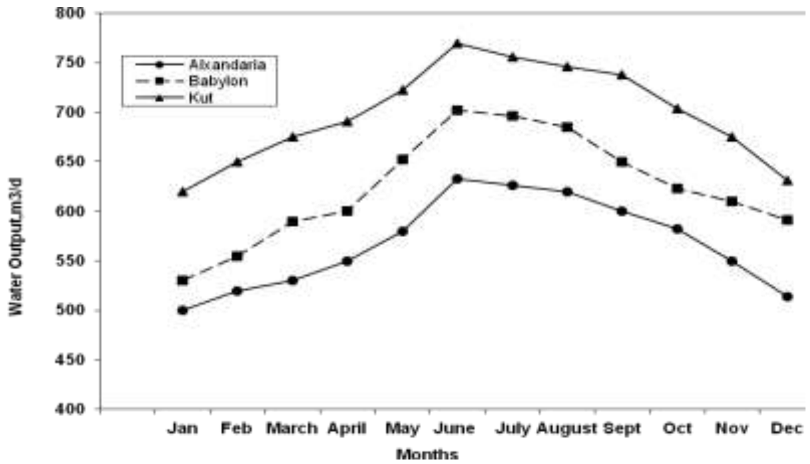

Figure 4: Monthly average rates of pumping from 7 m depth in the Alexandria, Babylon and Kut sites.

The maximum potential pumping rate at Kut during the month of June is 770 m^3/day and 410 m^3/day for water table depths of 7 and 14 m, (Fig.4). The poorest site is Ramadi where water output adds up to 16% of all sites combined. However, comparison between the most favourable and poorest sites, shows only a small difference, which means that solar water pumping is possible at all of the sites studied in Iraq.

In Ramadi, Baghdad and Alxanderia water salinity has EC ~1000 mS/m. Therefore the discharge water was reused in irrigation of salt-tolerant crops such as barley, or used for stock water supply. The more saline water at the Babylon and Kut locations was transferred 3000 m by polyethylene lined ditch to a natural pond where it is exposed to evaporation and solid salts are removed.

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Conclusion

The use of solar energy to lower groundwater levels by pumping is an environmentally friendly technique that has the potential to improve soil conditions and plant growth. Solar energy is abundant in most regions of Iraq and some sites have been shown to be suitable for solar powered pumping of groundwater. They include Kut, Babylon and Alexandria regions. Kut is the most favourable site for solar water pumping with a potential during June of 770 m^3/day and 410 m^3/day, for 7 m and 14 m heads, respectively. The latitude of these sites is similar to that in southwest WA where solar powered pumps may be suitable for lowering the water table in saline areas.

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