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Energy Demands Estimation in Certain Districts of South Bihar for Irrigation Operations

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A B S T R A C T

During the 21st century adoption of electric motor for irrigation operation will be much more resulting a sharp rise in demand for electricity. The electricity requirement for planning, design and operation of irrigation and water resources systems is necessary. It is a parameter of prime importance in formulating the policy for distribution of electricity as well as decision making in day by day operation and management of electricity distribution network. The study was done for the year 2010-11. Average rainfall of the selected districts Arwal, Nawada, Gaya, Jehanabad, and Aurangabad varies from 950 to 1100 mm. Maximum temperature rise upto 45°C and minimum falls to 2°C. The study was conducted on maize, rice, wheat, sugarcane and potato crops. The cropping intensity of the Bihar state was found 146 %. Information about area cultivated under different crop, cropping system, crop yields, rainfall, climatic parameters, water table depth below ground surface were obtained from different Departments. These data were used to calculate the electricity requirements by using ENIRRMOD (Energy IRRigation MODel) model for irrigation operation. Total ground water pumpag required in study area was found 33.63 million ha-m. The total electricity requirement by electricity operated tubewells for irrigation operations in Kharif season from June to October was found 1469.00 million kWh and during Rabi season from November to May its requirement was 238.40 million kWh. The energy requirements for Aurangabad district was found 536.91 million kWh which was highest among the study area. The energy expenditure in the month of June was found maximum and least in the month of May. The average electricity requirements to apply one hectare meter of water (Irrigation Energy Intensity) in study area was 696.79 kWh/ha-m.

Introduction

Indian population about more than 65% is mainly dependent on agriculture and its related activities. Crops need water which is the most essential key inputs, sufficient and well-timed supply of which is compulsory all through the crop growing stage for their optimum growth. Due to inadequate and uneven distribution of rainfall during the growth period of crops it becomes necessary to apply additional water to the soil in the form of irrigation for plant use. Irrigation consumes large amount of water and energy. The growth of agriculture has been possible because of timely and adequate supply of

water as a result ground water irrigation started assuming greater importance as compared to canal irrigation. During current year, Indian agricultural has knowledgeable phenomenal increase in mechanization so, the energy requirements have increased many times. A very conventional estimation reveals the necessity of about 68 billion kWh of electricity for Indian agriculture by the year 2020 (Panesar, 2000). Electricity in the agricultural sector is generally used in pumping water for irrigating the land for operating farm machines etc. In India the percentage share of electricity consumption by agriculture sector has increased significantly from 3.9 per cent in 1950-51 to 21.73 per cent in 2005-06.

The energy demand per hectare of irrigated land varies with the amount of water needed for crop growth, the depth of pumped water and the type of irrigation system. This is very serious for a country like India where agriculture sector contributes 18 per cent towards GDP and employs about 56.6 per cent of the total population. Therefore, to avoid any adverse effect to the national economy, proper planning of energy requirements in the agricultural sector is very essential.

The present study is designed to calculate energy demands for irrigation operations and reveal its applications through the modelling combining the numerous equations and correlations. The data used were collected from the previous years' crop production history and literature. The model effectively calculated the amount of water needed and the energy expenditure.

Materials and Methods

The brief description of the study area, ENIRRMOD (Energy IRRigation MODel) model used for estimation of energy requirements (Bhagat, 2001), collection of

data and procedures followed in determining various components of energy requirements for irrigation operation are discussed in following sub-sections.

Irrigation water requirement and energy demand

The assessment of irrigation water requirement involves combining evapotranspiration with effective rainfall and miscellaneous water requirements that must be supplied during irrigation for a winning crop production (Fig. 1). The irrigation water requirements for a crop season can be predictable from the water balance equation, written for the volume of root zone and plant canopy (Svehlik 1987). For water requirement the formulas, correlations and different values for parameters have been written in Table 1 are used for the evaluation of water and energy requirements.

Energy requirements for irrigation operation

ENIRRMOD (Energy IRRigationMODel) model used for estimation of energy requirements (Bhagat, 2001), collection of data and procedures followed in determining various components of energy requirements for irrigation operation.

Results and Discussion

Irrigation water requirements

The quantity of irrigation water essential to meet the irrigation water needs of crop was estimated by using equation (10). Based upon the area under different crops, area wise ground water pumpage is given in Table 2. The total crop water requirement of area and ground water pumpage irrigated by electricity operated tubewells in state can be found for different months.

Table.1 Expressions for ground water pumpage

Formula/ Correlation	Authors
$I_n = ET_m - ER + W_n + W_c + W_s$ -------------- ------------------------------------(1) I_n is Net irrigation water requirement in (mm), ET_m is Crop evapotranspiration in (mm), ER is Effective rainfall in (mm), Wn is Water requirement for seed bed preparation and other special needs in (mm), W_c is Upward movement of water into the root zone (mm), W_s is Carry over soil moisture (mm);	Svehlik 1987
$I_n = ET_m - ER + W_n$ ----------------- --(2) Under normal conditions, contribution of upward movement of water into the root zone (W_c) and carry over soil moisture (W_s) to seasonal water requirement is negligible.	
$(1 - \frac{Y_a}{Y_m}) = K_y(1 - \frac{ET_a}{ET_m})$ --(3) Ya is Actual crop yield (tonne/ha), Ym is Maximum potential crop yield at ETm (tonne/ha), Ky is Crop yield response factor, ETa is Actual evapotranspiration (mm), ETm is Crop evapotranspiration (mm). Experimental values of Ky for different crops given by Doorenbos and Kassam (1979); Ky is 1.1 (rice), 1.0 (wheat), 1.3 (maize), 1.2 (sugarcane), 1.1 (Potato). Actual crop yields (Ya) of 2010-11 for major irrigated crop of selected area were obtained from related departments. The maximum attainable yield (Y_m) for a given crop, grown under farming conditions, can be estimated from existing local record in the area under consideration.	(Prihar and Sandhu 1987)
$IR = ET_a - ER + W_n$ ---(4) IR is the average amount of irrigation water applied and used to meet water demands of plants.	
$IR = [1 - \frac{1}{K_y}(1 - \frac{Y_a}{Y_m})] ET_m - ER + W_n$ -----------------------------(5) (using eqn. 3 and 4)	
$W_n = \sum_{i=1}^{3} W_i$ --(6) W_1 is Amount of water required for nursery raising for rice crop (mm), W_2 is Water requirement for seed bed preparation (mm), W_3 isDeep percolation loss in rice fields (mm).	
$IR_s = \frac{IR}{\eta_a \times \eta_c}$---(7) IRs is amount of water drawn from the water source; η_a: water application efficiency (is the ratio of quantity of water stored in the root zone of the crops to the quantity of water delivered to the fields.); η_c: water conveyance efficiency (It is the ratio of quantity of water delivered to the fields to the quantity of water diverted from the source.)	Here, η_c=75%, η_a=50% (Sandhu et al. 1992)
$IR_s = \frac{1}{\eta_a \times \eta_c}[\{1 - \frac{1}{K_y}(1 - \frac{Y_a}{Y_m})\} ET_m - ER + \eta_a \sum_{i=1}^{3} W_1]$ --------------------(8)	
$a_t = P_i \times a$ $Q = \frac{0.001 a_t}{\eta_a \times \eta_c}[\{1 - \frac{1}{K_y}(1 - \frac{Y_a}{Y_m})\} ET_m - ER + \eta_a \sum_{i=1}^{3} W_1]$ ----------------------(9)	
$Q = \frac{0.001 a_t}{\eta_a \times \eta_c}[\{\{1 - \frac{1}{K_y}(1 - \frac{Y_a}{Y_m})\} ET_m - ER\}S + \eta_a \sum_{i=1}^{3} W_1]$ --------------------(10) Q is total amount of water required (ha-m), a is Irrigated area of crop (ha), P_i is Fraction of tubewells irrigated area (per cent), a_t is Tubewell irrigated area (ha), S is Soil factor for the area.	
$ET_m(j) = K_c(i,l) \times ET_o(l, j)$ ----------------------------------(11) $ET_o(l, j) = 5.625 \{e_{amax}(l, j) - e_{amin}-2(l, j)\}$ ETo (l, j) is Reference evapotranspiration in l[th] month for j[th] district (mm), ETm (j) is total crop evapotranspiration for j[th] district (mm), e_{amax} is Saturated vapour pressure in millibar at monthly maximum air temperature in c^o , e_{amin-2} is Saturated vapour pressure in millibar at monthly minimum air temperature minus 2 c^o ,Kc (i,l) is Crop co-efficient for i[th] crop in l[th] month.	Papadakis (1965)
$ER = f(D) [1.25 P^{0.824} - 2.98] . 10^{0.0000955 ET_m}$ -----------------------------(12) $f(D) = 1.0$ for $D \le 75$mm; $= \{0.53 + 0.0116D - 8.94 \times 10^{-5}D^2 + 2.32 \times 10^{-7}D^3$ for $D > 75$mm ER is Monthly effective rainfall (mm), D is Depth of water depletion in root zone prior to precipitation (mm), P is Actually monthly rainfall (mm);	USDA- SCS (1970) method

**Table.2** Irrigation energy intensity for electricity operated tubewells irrigated area during 2010-11

District	Ground water pumpage (ha-m)	Energy requirement (kWh)	Energy Intensity (kWh/ ha-m)
Gaya	334772.23	237457374.11	684.60
Arwal	804138.27	613938319.75	641.74
Jehanabad	117062.83	85725202.97	686.39
Nawada	31655013	233366611.51	669.22
Aurangabad	718144.02	536914361.76	701.97
Average			**696.79**

Table.3 Season wise energy requirements for electricity operated tubewells irrigated area during 2010-11

(million kWh)

			Kharif season			
Months	**Gaya**	**Jehanabad**	**Arwal**	**Nawada**	**Aurangabad**	**Total**
June	129.37	29.06	578.29	125.03	351.96	1213.70
July	16.09	3.93	8.05	14.97	45.89	88.94
August	12.37	3.60	5.67	11.07	31.25	63.96
September	14.62	4.53	6.93	13.98	32.64	72.70
October	6.37	2.57	3.12	2.58	15.07	29.71
Total	**178.82**	**43.69**	**602.06**	**167.62**	**476.81**	**1469.00**

			Rabi season			
November	4.90	2.56	1.25	4.38	6.05	19.14
December	7.03	4.46	1.33	8.11	5.79	26.72
January	9.85	6.17	1.27	10.59	10.05	37.94
February	12.89	8.88	2.34	13.47	12.53	50.11
March	13.14	11.91	3.45	18.38	15.80	62.68
April	10.22	7.56	2.03	10.31	9.30	39.41
May	0.61	0.50	0.21	0.51	0.58	2.40
Total	**58.64**	**42.03**	**11.88**	**65.75**	**60.10**	**238.40**
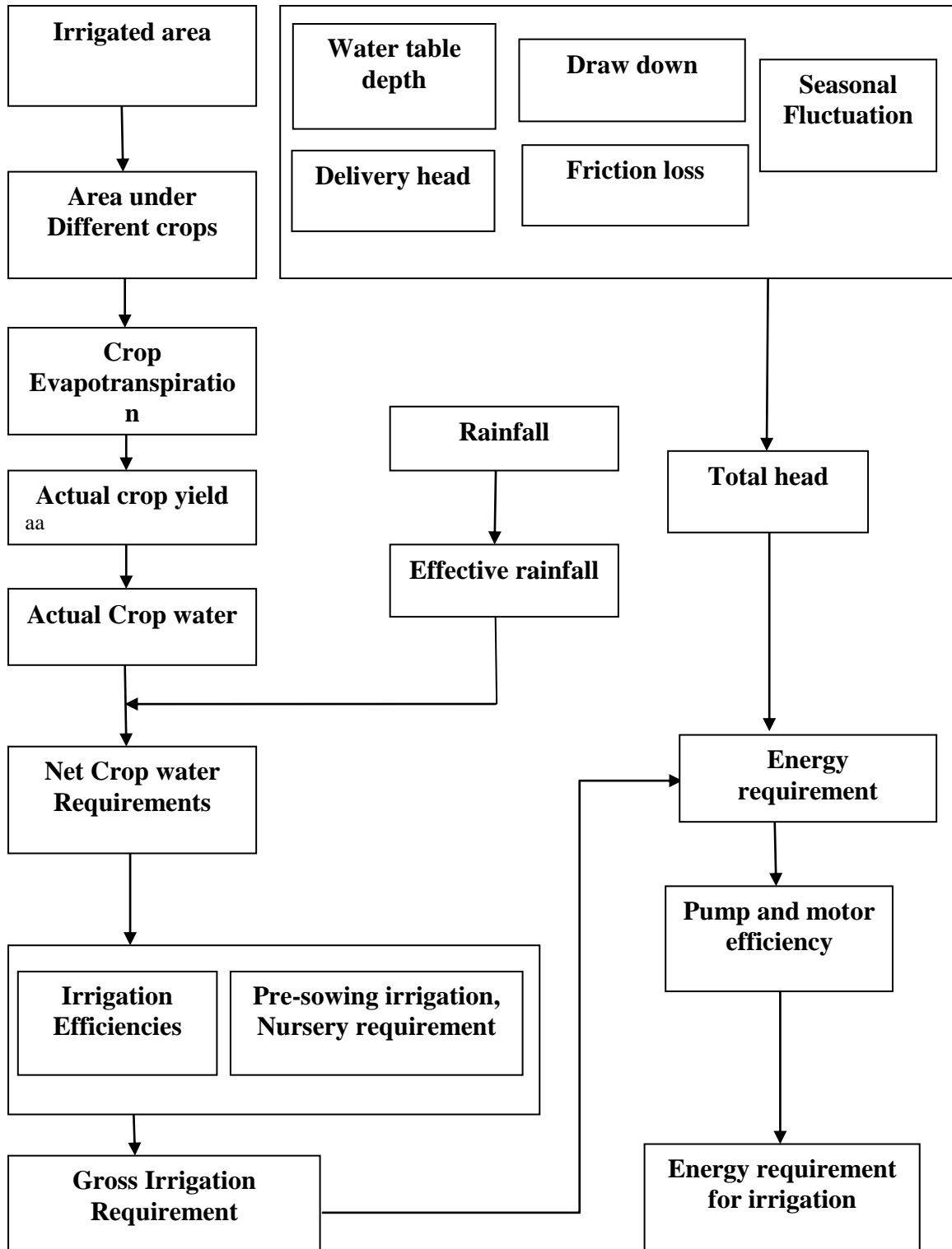
Fig.1 Flow chart for calculation of irrigation and energy requirements

Equations for calculation of energy demands by electricity operated tubewells

$$E = \frac{Mgh}{3600 \times 1000} \text{---(13)}$$

E is Energy input (kWh), M is Mass of water pumped out (kg), g is Acceleration due to gravity (m/s^2).

$$E = \frac{Q\rho gH}{3600 \times 1000} \text{--(14)}$$

$$E = \frac{V\,(ha-m) \times 10000 \times 1000 \times 9.8 \times H}{3600 \times 1000000} \text{---(15)}$$

V is the volume of water pumped out (ha-m), H is Total head in districts (m)

$$E = 27.25\,V\,(ha-m) \times H(m) \text{-----------------(16)}$$

$$E_t = \frac{2.7.25\,V\,(ha-m) \times H\,(m)}{\eta_p \times \eta_m} \text{--------------(17)} \quad \text{(Here, ha-m is unit of volume)}$$

$$E_t = \frac{0.02725 \times a_t \times H}{\eta_a \times \eta_c \times \eta_p \times \eta_m}\left[\left\{\left\{1 - \frac{1}{K_y}\left(1 - \frac{Y_a}{Y_m}\right)\right\} ET_m - ER\right\}S + \eta_a \sum_{i=1}^{3} W_i\right] \text{--------(18)}$$

E_t is Total energy requirements for irrigation operation (kWh), H is Total head in districts in (m), η_p is Pump efficiency (fraction), η_m is Motor efficiency (fraction), η_a is   water application efficiency; η_c is water conveyance efficiency

This deviation in crop water necessity and hence the ground water pumpage is due to variation in area under different crop, peak water requirement of different crop.

It is initiate that on the average energy requirement about 696.79 kWh to apply one hectare-meter of water in the South Bihar. The highest energy requirements for was found 536.91 million kWh in Aurangabad district. The high energy requirement is because of deep water table depth and large seasonal variation.

Energy is essential for agricultural production. To increase the production the sharp rise in demand for electricity is essential. The electricity requirement for irrigation operation is one of the principal parameters for planning, design and operation of irrigation and water resources systems (Table 3).

The study was done for the year 2010-11. Information about rainfall, climatic parameters, cropping system, crop yields, water table depth below ground surface, area cultivated under different crop were obtained from different departments and used to calculate the electricity requirements for irrigation operation. Based on the results of the study, the following conclusions could be drawn. The total ground water pumpage required for irrigation operation in the study area was found 33.63 million ha-m.

The average electricity requirements to apply one hectare meter of water (Irrigation Energy Intensity) in study area was 696.79 kWh/ha-m. Total ground water pumpag required in study area was found 33.63 million ha-m. The total electricity requirement by electricity operated tubewells for irrigation operations in Kharif season from June to October was found 1469.00 million kWh and during Rabi season from November to May its requirement was 238.40 million kWh. The energy requirements for Aurangabad district was found 536.91 million kWh which was highest among the study area. The energy

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