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Modelling of spatial variability of energy requirements of irrigated crops

Indu Bhushan Bhagat, BK Yadav and SK Sondhi

Abstract
Enirrmod (ENergy IRRigation MODel) was developed to predict energy requirements for irrigation. The developed model contains two elements namely crop water requirement model and energy requirements model. The crop water requirement model was developed after analyzing relationship between actual crop yield, potential crop yield, crop yield response factor and soil factor. The computer program was written in C^{++} to estimate energy requirements. The validation study of model was conducted for the Punjab State. The results indicate that the annual electricity requirements for electricity operated tubewells for irrigation operation during rice growing period (June to October) i.e. *kharif* season was 64.2 percent of total annual electricity requirements. The predicted consumption of electricity for the Punjab was 3863 M kWh against 4598 M kWh of actual consumption. The actual consumption is 16 percent higher than the predicted consumption. It may be due to free electricity in the state.
Energy required supplying one hectare meter of irrigation water in Punjab state was estimated to vary between 771.85 kWh/ha-m to 1287.56 kWh/ha-m. The variation in energy requirements is attributed due to change in cropping pattern and water table depth in some area of the state. The spatial analysis of total electricity requirement is grouped into three sets of high, medium and low energy requirements. The low level electricity requiring districts (less than 100 M kWh) during *kharif* were Hoshiarpur, Ropar, Faridkot and Bathinda, the medium energy requirement districts (100 to 200 M kWh) were Kapurthala and Sangrur and the region of high energy requirement (greater than 200 M kWh) were in central plain covering districts of Jalandhar, Ludhiana, Amritsar, Gurdaspur, Patiala and Ferozepur.

Keywords: Tubewells irrigated area, energy requirement, ground water, spatial variability, irrigation intensity

Introduction

Energy is essential for agricultural production. In India it has experienced phenomenal growth in mechanization and energy needs have increased many times. A very conservative estimate reveals the requirement of about 68 billion kWh of electricity for Indian agriculture by the year 1999 [1]. The increased energy use in agriculture sector is directly associated with utilization of ground water for irrigation purpose. The groundwater abstraction structures in India increased from 4 million in 1951 to 17 million in 1997. Energy is used for pumping water. The pumped water is mainly used as surface irrigation method. The adoption of pressurized irrigation requires additional energy to support on farm irrigation application. The additional energy is also required in the manufacture of irrigation equipment's, its transportation to farms, installation of equipment's, drilling of tubewells, levelling of fields and making and removing border ridges and furrows. Further, change in the cropping pattern in northern region especially in the states of Punjab and Haryana has led into sharp increase in the use of energy during *Kharif* season to meet the irrigation demand of the rice crop. The consumption of electricity in the agriculture sector during these 4 to 5 months (June-October) is as high as 60 percent of the total consumption during the whole year [2]. The demand of the agriculture sector is so high during these months that the pump sets have to be given power in the groups by rotation. Assessment of spatial variability of energy requirement for irrigated area is needed to evaluate energy strategies for regional planning.

Methods and Materials

The irrigation water requirement involves combining evapotranspiration with effective rainfall and miscellaneous water requirements that must be supplied through irrigation for successful crop production. The irrigation water requirements for a given period of time can be estimated from water balance equation, written for the volume of root zone and plant canopy [3] as

$$IR = ET_a - ER + W_n \tag{1}$$

Where, IR is the irrigation water requirement, mm; ET_a is the actual evapotranspiration, mm; ER is the effective rainfall, mm; W_n is the water requirement for seed bed preparation and other special needs (amount of water required to meet nursery requirement of paddy crop seed bed preparation and deep percolation loss in paddy fields), mm. The actual evapotranspiration (ET_a) has a direct relationship with dry-matter production if the growth factors, such as fertility, temperature, sunshine and soil are not limiting. Evidence from field experiment at several locations in India [4] indicates that yield was linearly related to seasonal evapotranspiration. Stewart *et al.* [5] proposed a linear relationship of the form:

$$\left(1 - \frac{Y_a}{Y_m}\right) = K_y\left(1 - \frac{ET_a}{ET_m}\right) \tag{2}$$

Where, ET_m is the potential evapotranspiration, mm; Y_a is the actual yield of crop, kg/ha; Y_m is the maximum (potential) yield of crop kg/ha and K_y is the crop yield response factor. The average amount of irrigation water requirement *(IR)* applied and used to meet water demands of plants has been calculated by combining equation (1) and (2), as

$$IR = \left[1 - \frac{1}{K_y}\left(1 - \frac{Y_a}{Y_m}\right)\right]ET_m - ER + W_n \tag{3}$$

The potential evapotranspiration consisted of the consumptive use of crops grown in the area and the monthly reference evapotranspiration was obtained by using Papadakis method [6]. Knowing the reference crop evapotranspiration, crop coefficient and crop growth days of each crop, and monthly potential evapotranspiration for crop water use was calculated as:

$$ET_O(k,j,l) = 5.625 \times \left(\frac{ea_{max}(j) - ea_{min-2}(j)}{D_m(l)}\right) \times CD(k,l) \tag{4}$$

$$ET_m(k, j, l) = K_c(k, l) \times ET_0(k, j, l) \tag{5}$$

Where, $ET_0\,(k,j,l)$ is the reference crop evapotranspiration for k^{th} crop in l^{th} month of j^{th} region; mm, $ET_m\,(k,j,l)$ is the maximum evapotranspiration for k^{th} crop in l^{th} month of j^{th} region; mm, $ea_{max}\,(j)$ is the saturated vapour pressure of j^{th} region in millibar at monthly maximum air temperature; °C, $ea_{min-2}(j)$ is the saturated vapour pressure of j^{th} region in millibar at monthly minimum air temperature minus 2 °C, $D_m(l)$ is the number of days in l^{th} month, $CD(k, l)$ is the crop growth days for k^{th} crop in l^{th} month, $K_c\,(k, l)$ is the crop coefficient for k^{th} crop in l^{th} month.

The efficiency of surface irrigation method normally is around 50%. Thus, actual water needs to be applied to satisfy the net irrigation requirement may be estimated after considering application efficiency. The other water losses include conveyance losses and application losses. Conveyance losses depend on length and type of conveyance system and are accounted after considering water conveyance efficiency (η_c). Application losses include evaporation, deep percolation and surface runoff. These losses occurring on irrigation fields are expressed as water application efficiency (η_a). Thus, the total amount of water drawn from the water source to irrigate area of 'A' ha becomes:

$$Q = \frac{IR \times A}{\eta_a \times \eta_c}$$

$$Q = \left(\frac{10 \times A}{\eta_a \times \eta_c}\right)\left[\left\{\left\{1 - \frac{1}{K_y}\left(1 - \frac{Y_a}{Y_m}\right)\right\}ET_m - ER\right\} + \eta_a W_n\right] \tag{6}$$

Where, Q is the amount of water drawn from the water source, ha-m; A is the area to irrigate through water drawn from the water source, ha; η_a is the application efficiency, percent and η_c is the conveyance efficiency, percent. Characteristics of soil relating to ability to absorb and capacity to store water in the root zone generally influenced the crop yield and depends on texture, structure and organic matter content of the soil. Thus, another factor introduced in the above equation to account for soil type by assuming that the effect of soil type is same on ET_m and ER. Thus, equation (6) can be rewritten to estimate irrigation water requirements for region, Q as

$$Q = \left(\frac{10 \times A}{\eta_a \times \eta_c}\right)\left[\left\{\left\{1 - \frac{1}{K_y}\left(1 - \frac{Y_a}{Y_m}\right)\right\}ET_m - ER\right\}S + \eta_a W_n\right] \tag{7}$$

Where, S is the soil factor. The amount of energy required to pump water for irrigation depends on net amount of irrigation water to be applied, total dynamic head, pump efficiency and efficiency of energy conversion of the power unit. The amount of energy required to lift given amount of water by tubewell is

$$E = \frac{27.25 \times Q \times H}{\eta_p \times \eta_m} \tag{8}$$

Where, E is the energy input, M kWh; Q is the volume of water pumped out, ha-m; H is the total dynamic head, m; η_p is the pump efficiency, fraction; η_m is the motor efficiency, fraction. The total dynamic pumping head required to estimate the energy requirements is a function of water table depth below ground surface, drawdown in the well, variation in water table depth between seasons, friction losses in pipes and fittings and delivery head. Combining equations (7) and (8), gives the final equation for estimation of energy requirements for irrigation operation as:

$$E(k,j,l)=\frac{272.5}{\eta_a\times\eta_c\times\eta_p\times\eta_m}\sum_{k=j=l=1}^{p,q,n}H(j)\times A(k,j)$$
$$\left[\left\{\left\{1-\frac{1}{K_y(k)}\left(1-\frac{Y_a(k,j)}{Y_m(k,j)}\right)\right\}ET_m(k,j,l)-ER(k,j,l)\right\}S(j)+\eta_a\sum_{i=1}^{3}Wi(k,l)\right] \quad (9)$$

Where, $E(k, j, l)$ is the total energy requirements for irrigation operation of k^{th} crop for j^{th} region in l^{th} month, kWh; $H(j)$ is the total head in j^{th} region, m; P is the number of crops, q is the number of sub- regions, n is the numbers of months, $K_y(k)$ is the crop response factor of k^{th} crop, $Y_a(k, j)$ is the actual yield of k^{th} crop in i^{th} region, $Y_m(k, j)$ is the maximum yield of k^{th} crop in j^{th} region, $ETm(k, j, l)$ is the crop evapotranspiration of k^{th} crop of j^{th} region in l^{th} month; mm, $ER(k, j, l)$ is the effective rainfall of k^{th} crop of j^{th} region in l^{th} month; mm, $S(j)$ is the soil factor of j^{th} region, $W_i(k, l)$ is the special water requirement for k^{th} crop in l^{th} month; mm.

The developed energy requirement model for irrigation operation was applied to electricity operated tubewells irrigated area in Punjab State. The data were obtained for the year 1995-96 for each district of the state. Information was collected on water table depth, rainfall, gross irrigated area, area irrigated by tubewells, number of electricity operated and diesel operated tubewells, irrigated area of a crop, actual crop yields, maximum possible crop yield in each district.

USDA-SCS [7] method was used for estimating effective rainfall *(ER)* for each crop. The values of application efficiency, conveyance efficiency, pump efficiency and motor efficiency have been assumed as 50%, 75%, 50% and 80% respectively. The amount of water required for growing seedlings in a nursery was assumed as 0.24 m per hectare and the nursery area was taken as one tenth of the field to be transplanted, the amount of water required for puddling and transplanting operation in paddy was taken as 0.30 m per hectare and in case of other crops, the water requirement for pre-sowing irrigation for land preparation was taken as 0.10 m per hectare. The deep percolation loss in paddy field was assumed to be 9 mm per day and irrigation application was cutoff at two weeks before harvesting of paddy.

Results and Discussion

Electricity requirement for irrigation operation

Month wise and district wise values of total electricity requirement for irrigation operation has been presented in Table 1 and comparison of actual and predicted values for the state has been shown in Fig.1. A perusal of the table reveals that the total electricity requirements of electricity operated tubewell irrigated area of Punjab state in 2017-18 was 3863 M kWh. The minimum value was 54.85 M kWh in Ropar district and maximum was 606.90 M kWh in Jalandhar district. The difference might be due to varying cropping pattern, depth to water table below ground surface, electricity operated tubewells irrigated area.

The season wise electricity requirement for irrigation was 2481 M kWh in *Kharif* and 1382 M kWh in *rabi* season. The electricity requirement during kharif was 64.2 percent of the annual requirement. Season wise variation in electricity requirement was due to higher ET demand of rice crop, which occupied about 67.4 percent of total irrigated area during *kharif*. Season wise electricity requirement for irrigation operation has been presented in Table 2. The maximum requirement of electricity 659.16 M kWh was in the month of July followed by 537.46 M kWh in June. This is due to high water demand of rice crop to meet its ET and deep percolation losses. Also electricity requirements for irrigation during June to October is as high as 53 percent of the total annual requirements.

Irrigation energy intensity

The energy required to apply one hectare meter of water was calculated in terms of kWh and has been given in Table 3. It was found that on the average, it takes about 1035 kWh to obtain and apply one ha-m of water in the Punjab state. The highest energy requirement, 1287 kWh to apply one ha-m of water was in district Hoshiarpur. The highest energy requirement is because of the deep water table depth and large season variation in water table. The spatial distribution of the irrigation energy intensity across the Punjab state (Fig. 2), clearly show the close relationship between water table depth, cropping pattern and the resulting energy requirements. The deep ground water in Hoshiarpur, Jalandhar and Sangrur is in sharp contrast to the shallow ground water and much large proportion of canal water in Ferozepur and Faridkot district.

Spatial analysis of electricity requirement for irrigation operation

The total electricity requirement was grouped into three sets of high, medium and low requirements. During *kharif* and *rabi* the low, medium and high range of electricity requirement were taken as less than 100 M kWh, 100 to 200 M kWh and greater than 200 M kWh respectively. On an annual basis, the lower, medium and high range of electricity requirements were taken as less than 200 M kWh, 200 to 400 M kWh and greater than 400 MkWh respectively. Spatial analysis of annual electricity requirement is shown in Fig.3. In low range electricity requirements, the districts were Hoshiarpur, Ropar, Bathinda and Faridkot. The medium range electricity requirements were in Ferozepur, Gurdaspur, Kapurthala and Sangrur districts. The high electricity requirements were in districts of Jalandhar, Ludhiana, Amritsar and Patiala. The main factors for this are variation in water table depth, effective rainfall, cropping pattern and area irrigated by electricity operated tubewells. The low –level electricity requiring districts during *kharif* were Hoshiarpur, Ropar, Faridkot and Bathinda (Table 2). Majority of these districts are in south-west Punjab where the exploitation of ground water is low due to its poor quality. In case of Hoshiarpur and Ropar district, the electricity requirements were low because of lesser area under tubewells irrigation. The medium energy requirement districts were Kapurthala and Sangrur. The region of high electricity requirement were in central plain covering the districts of Jalandhar, Ludhiana, Amritsar, Gurdaspur, Patiala and Ferozepur. The factors responsible for these variations were depth to water table, cropping pattern and electricity-operated tubewells irrigated area.

Table 1: Total energy requirements for electricity operated tubewells in Punjab during 2017-18 (M kWh)

Months	Hoshiarpur	Jalandhar	Ludhiana	Ferozepur	Amritsar	Gurdaspur	Kapurthala	Bathinda	Patiala	Sangrur	Ropar	Faridkot	Total
January	2.78	18.12	15.63	0.00	19.29	4.67	9.18	4.85	25.89	14.98	0.82	0.36	11.61
February	1.46	7.16	25.31	18.08	33.88	2.23	5.32	8.19	46.77	22.02	2.28	4.30	177.05
March	11.53	64.43	33.81	23.86	29.97	25.79	21.40	9.85	55.82	40.63	6.38	9.18	332.71

April	9.81	42.29	25.61	19.25	29.96	14.47	11.09	9.25	29.79	20.76	3.88	10.97	227.18
May	5.13	25.00	5.10	11.79	6.29	2.36	2.51	6.66	5.11	4.86	2.10	7.12	84.09
June	14.05	64.07	52.11	146.12	60.16	40.85	30.30	17.18	55.74	36.42	5.48	14.93	537.46
July	21.55	102.40	84.37	43.68	103.84	67.61	46.01	11.25	99.76	59.51	7.61	11.51	659.16
August	12.82	72.82	61.38	26.35	78.25	49.37	44.33	8.09	73.39	42.04	5.42	8.50	482.82
September	10.03	56.96	47.96	47.00	85.16	40.20	31.75	13.04	57.68	35.11	4.45	13.36	442.76
October	15.82	73.34	46.50	23.24	50.87	32.59	21.08	6.84	48.40	23.82	5.87	10.00	358.42
November	15.09	43.44	24.13	12.26	27.41	18.74	13.70	6.23	23.72	17.72	7.20	6.94	216.66
December	8.45	36.8	28.15	13.90	46.64	16.42	11.64	5.13	30.52	20.87	3.31	6.36	228.27
Total	128.56	606.90	450.10	385.57	571.77	315.36	248.38	106.66	552.65	338.81	54.85	103.58	3863.24

Table 2: Season wise energy requirements for electricity operated tubewells in Punjab during 2017-18

***Kharif* season (M kWh)**													
Months	**Hoshiarpu**	**Jalandhar**	**Ludhiana**	**Ferozepur**	**Amritsar**	**Gurdaspur**	**Kapurthala**	**Bathinda**	**Patiala**	**Sangrur**	**Ropar**	**Faridkot**	**Total**
June	14.05	64.07	52.11	146.12	60.16	40.85	30.30	17.18	55.74	36.42	5.48	14.93	537.46
July	21.55	102.40	84.37	43.68	103.84	67.61	46.01	11.25	99.76	59.51	7.61	11.51	659.16
August	12.82	72.82	61.38	26.35	78.25	49.37	44.33	8.09	73.39	42.04	5.42	8.50	482.82
September	10.03	56.96	47.96	47.00	85.16	40.20	31.75	13.04	57.68	35.11	4.45	13.36	442.76
October	15.82	73.34	46.50	23.24	50.87	32.59	21.08	6.84	48.40	23.82	5.87	10.00	358.42
Total	74.28	369.62	292.33	266.40	378.29	230.65	173.50	56.42	334.98	196.93	28.86	58.42	2480.64
***Rabi* season (M kWh)**													
November	15.09	43.44	24.13	12.26	27.41	18.74	13.70	6.23	23.72	17.72	7.20	6.94	216.66
December	8.45	36.8	28.15	13.90	46.64	16.42	11.64	5.13	30.52	20.87	3.31	6.36	228.27
January	2.78	18.12	15.63	0.00	19.29	4.67	9.18	4.85	25.89	14.98	0.82	0.36	11.61
February	1.46	7.16	25.31	18.08	33.88	2.23	5.32	8.19	46.77	22.02	2.28	4.30	177.05
March	11.53	64.43	33.81	23.86	29.97	25.79	21.40	9.85	55.82	40.63	6.38	9.18	332.71
April	9.81	42.29	25.61	19.25	29.96	14.47	11.09	9.25	29.79	20.76	3.88	10.97	227.18
May	5.13	25.00	5.10	11.79	6.29	2.36	2.51	6.66	5.11	4.86	2.10	7.12	84.09
Total	54.27	237.27	157.77	99.16	193.47	84.70	74.88	50.23	217.66	141.87	25.99	45.25	1382.59

Table 3: Irrigation energy intensity for electricity-operated tubewells irrigated area in Punjab

Districts	**Ground water pumpage (ha-m)**	**Energy requirements (kWh)**	**Energy intensity (kWh/ha-m)**
Hoshiarpur	164765.9	212146400	1287.56
Jalandhar	591975.2	742847400	1254.86
Ludhiana	716922.8	766793800	1069.56
Ferozepur	1017387	785276500	771.85
Amritsar	689151	703287200	1020.51
Gurdaspur	390503	352756000	903.33
Kapurthala	352983.9	351327100	995.30
Bathinda	254979.4	255172200	1000.75
Patiala	887816.3	950634400	1070.75
Sangrur	541790.4	681718000	1258.26
Ropar	117567.7	107564900	914.91
Faridkot	260341.8	229678400	882.21
Average	1035.82		

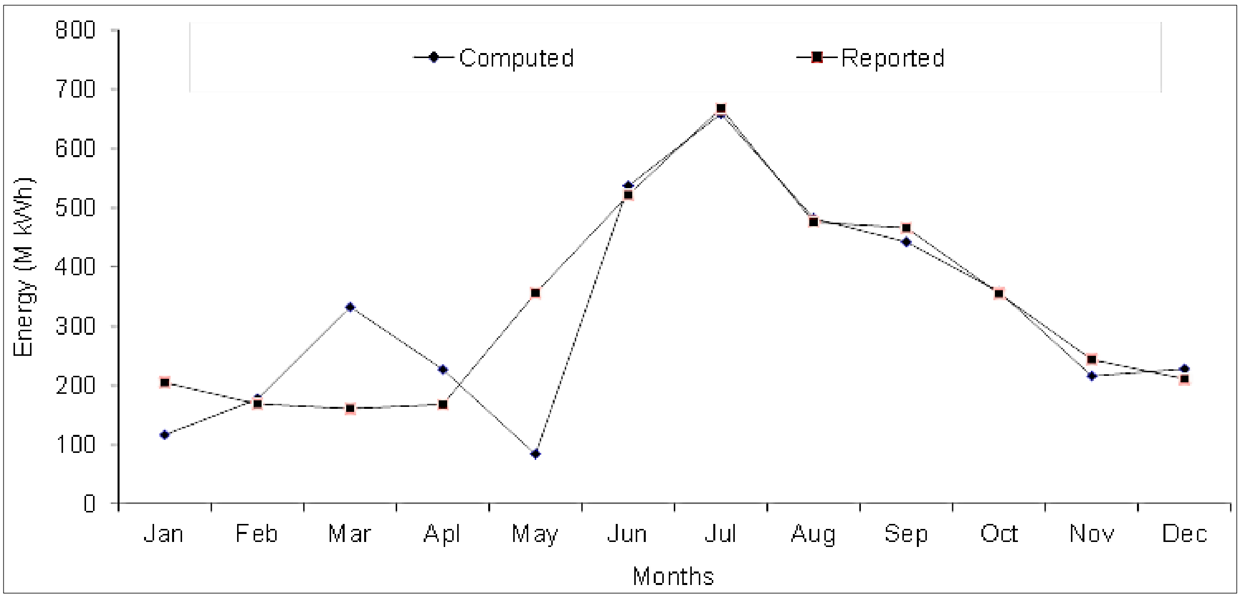

Fig 1: Comparison of actual and predicted electricity requirements for irrigation operation in Punjab during 2017-18

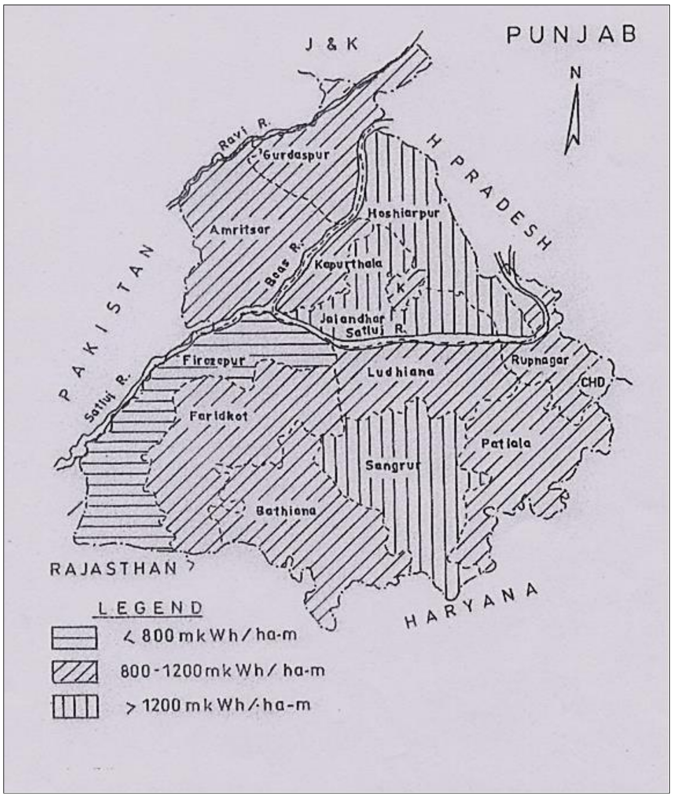

Fig 2: Irrigation energy intensity for electricity operated tubewells in Punjab

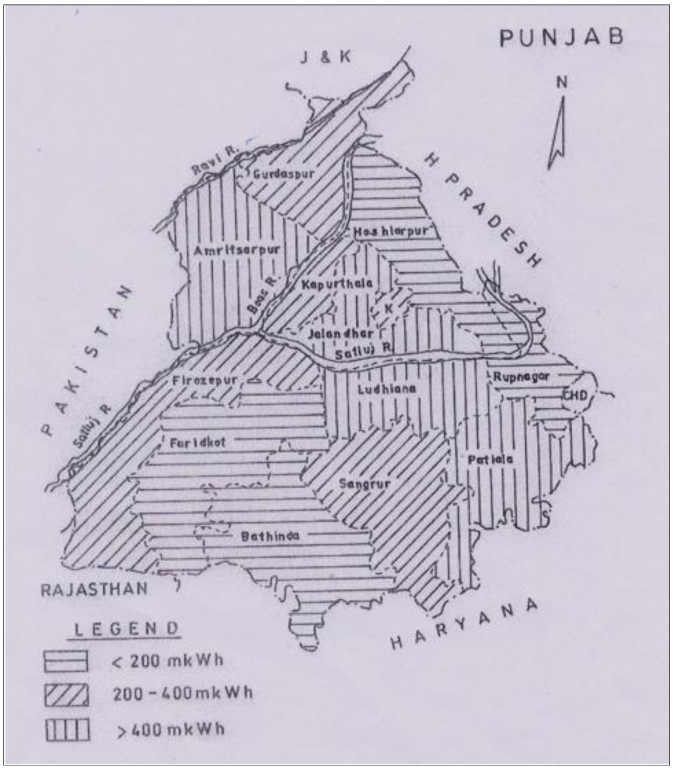

Fig 3: Annual energy requirement for electricity operated tubewells in Punjab

Conclusions

ENIRMOD (ENergy IRRigation MODel) can be used to predict energy requirements for irrigation. The model was validated by comparing month wise, results predicted by developed model for electricity operated tubewells for irrigation operation in Punjab state with actual energy consumed by electricity operated tubewells. The predicted consumption of electricity for the Punjab was 3863 M kWh against 4598 MkWh of actual consumption. The actual consumption is 16 percent higher than the predicted consumption. It may be due to excessive transmission losses and supply of free electricity to tubewells in the state. The electricity requirements during kharif is 64.2 percent of the annual requirements. The electricity requirements for irrigation during the growing period (June to October) is 53 percent of the total annual requirements. The electricity requirements of electricity-operated tubewells is high (>400 M kWh) in Jalandhar, Amritsar, Patiala and Ludhiana districts. Thus these districts should be targeted for energy and water conservation measure. The average electricity requirements to apply one hectare meter of water in the Punjab state is 1035 kWh/ha-m.

References

1. Panesar BS. Future Contribution of Energy in Production. Agriculture Agril Engg Today. 2000; 24(5):29-61.
2. Sandhu SS, Jain HM, Kang PS. Energy Conservation in Agriculture Sector. Proc. National Conference on Energy in Production Agriculture and Food processing. PAU, Ludhiana, 1987, 296-301.
3. Svehlik ZJ. Estimation of Irrigation Water Requirement. In: Rydzewski J R (ed). Irrigation Development Planning. John Wileysons- Inc, NY, 1987, 115-143.
4. Prihar SS, Sandhu BS. Irrigation of Field Crops-Principle and Practices. ICAR, New Delhi, 1987, 142.
5. Stewart JI, Hajan RM, Pruitt WO. Function to Predict for Optimal Irrigation Programms. J Irrig & Drain Div, ASCE. 1974; 100(IR-2):179-203.
6. Narda NK, Kausal MP. Water Resource Utilization, Cropping Pattern and Irrigation Needs of Punjab. J Res Punjab Agric Univ. 1983; 20(4):493-502.
7. USDA-SCS Irrigation Water Requirement. Tech. Release No. 21. SCS, Engg. US Govt. Printing office, USA, 1970, 88.