Studies on scope of energy conservation for groundwater pumping in Sonepat district of Haryana

By
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(2016AE05D)

A thesis submitted to Chaudhary Charan Singh Haryana Agricultural University, Hisar in the partial fulfillment of the requirements for the degree of

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(Soil and Water Engineering)

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CERTIFICATE - I

This is to certify that this thesis entitled **“Studies on scope of energy conservation for groundwater pumping in Sonepat district of Haryana”** submitted for the degree of **Doctor of Philosophy,** in the subject of **Agricultural Engineering (Soil and Water Engineering)** to the Chaudhary Charan Singh Haryana Agricultural University, Hisar is bonafide research work carried out by **Kuldeep Singh (Admn. No. 2016AE05D)** under my supervision and that no part of this dissertation has been submitted for any other degree.

The assistance and help received during the investigation have been fully acknowledged.

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CERTIFICATE - II

This is to certify that this thesis entitled **“Studies on scope of energy conservation for groundwater pumping in Sonepat district of Haryana”** submitted by **Kuldeep Singh (Admn. No. 2016AE05D)** to the Chaudhary Charan Singh Haryana Agricultural University, Hisar, in partial fulfillment of the requirements for the degree of **Doctor of Philosophy**, in the subject of **Agricultural Engineering** (**Soil and Water Engineering)** has been approved by the student’s Advisory Committee after an oral examination on the same, in collaboration with an External Examiner.

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MAJOR ADVISOR **PROFESSOR AND HEAD**

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Hisar

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ABBREVIATIONS AND SYMBOLS

et al.	:	And others
@	:	At the rate
ρ_b	:	Bulk density
BIS	:	Bureau of Indian Standards
CI	:	Cast iron
cm	:	Centimetre
CCS HAU	:	Chaudhary Charan Singh Haryana Agricultural University
^{o}	:	Degree
DSR	:	Direct seeded rice
EC	:	Electrical conductivity
η	:	Efficiency
η_{MHP}	:	Efficiency based on motor horse power
η_{PC}	:	Efficiency based on actual measured power consumption
η_{EXP}	:	Expected overall pumping efficiency
ET	:	Evapotranspiration
FYM	:	Farm yard manure
Fig.	:	Figure
e.g.	:	For example
GI	:	Galvanised iron
GW	:	Groundwater
H	:	Head
H_{stage}	:	Head per stage
ha	:	Hectare
HDPE	:	High density poly ethylene
HP	:	Horse power
h	:	Hour
IS	:	International standard
kg	:	Kilogram
km	:	Kilometre
kW	:	Kilowatt
kWh	:	Kilowatt per hour
KVK	:	Krishi Vigyan Kendra
LS	:	Loamy sand
l	:	Litre
$T_{max.}$	:	Maximum temperature
m	:	Meter
MJ	:	Megajoule
mWh	:	Megawatt per hour
mha	:	Million hectare

′ : Minute (for angle)
min : Minute
η_{min} : Minimum expected efficiency
$T_{\text{min.}}$: Minimum temperature
ml : Milliliter
mm : Millimeter
mt : Million tonnes
MHP : Motor horse power
N : Nitrogen
O.C : Organic carbon
^{o}C : Degree celsius
P : Phosphorous
% : Percentage
PVC : Polyvinylchloride
K : Potassium
η_{AP} : Pumping set efficiency based on actual electricity consumption
η_{MHP} : Pumping set efficiency based on motor horse power
RH : Relative humidity
SL : Sandy loam
″ : Second (for angle)
s : Second
sq. : Square
SS : Sunshine hours
t : Time
i.e. : That is
TW : Tube well
UGPL : Under ground pipe line
q : Quintal
V : Volts
Q : Volume of water flowing per unit time/ Discharge
WHP : Water horse power
WUE : Water use efficiency

CHAPTER-I

INTRODUCTION

1.1 General Background

Haryana is predominantly an agrarian state, located in north-western part of the country having only 1.3 percent of the country's geographical area and 2.5 percent of its cultivated area contributing about 6.9 percent in India's food production. Use of groundwater has played an important role in agriculture leading to overall economic development of the state in very limited period resulting in net irrigated area increase from 1.2 million ha in 1966-67 to 3.26 million ha in 2018-19 (Anonymous, 2020). The share of groundwater has increased from 0.60 million ha to 1.99 million ha, which is more than three times, whereas, area under surface irrigation is only increased from 0.90 million ha to 1.18 million ha during the same period. Subsequently, the number of tube wells has increased from 0.02 million in 1966 to 0.85 million in 2017-18 (Singh and Amrita, 2015; Anonymous, 2018). There has been rapid expansion of groundwater resources for fulfilling agriculture needs in the past few decades compelling farmers to shift to deeper tube wells (Bhalla, 2007; Hira 2009; Chawla *et al.*, 2010.) This practice not only disrupts ecological balance but also put major financial burden on farmers and also creates socio-economic inequality in its distribution (Sarkar, 2011).

In agriculture sector, irrigation has high energy requirement for pumping which is provided by diesel and electric systems (Ahmad, 2003). As groundwater level is declining with time, it is not possible to lift water using low lift centrifugal pumps. Therefore, these pumps are being replaced by submersible pumps, requiring more energy to lift the water (Haque *et al*., 2016). The pumping sets used in agriculture for irrigation purpose are having very low efficiency. Some of the factors affecting energy consumption during pumping are vertical lift (the depth of water source to the height of water application), operating pressure of irrigation system (*e.g.* high pressure for hydraulic gun sprinkler and low pressure for micro and surface irrigation), depth and frequency of irrigation and pumping system efficiency etc. Some of the factors responsible for low efficiency of irrigation pumping sets are: improper selection of pump and its prime mover, improper installation depth, poor hydraulic design of pump, poor maintenance, use of non standard parts during repair and quality of power supply. Performance of submersible pumps are highly affected by its impeller and diffuser. The diffuser provides main energy conversion in the submersible pump and also regulates its structure and performance to some extent (Shojaeefard *et al.*, 2012). The diffuser may account for 40-50 percent of total hydraulic loss by the pump (Zhao, 2002). Mismatching of diffuser and impeller not only affect the efficiency of pump but stability of pump performance is also affected to certain extent (Wei and Sun, 2017). In most submersible pumps used for groundwater extraction, an asynchronous motors (ASMs) is used as conventional drive technology produces relatively low global efficiency and resulting in high electrical energy consumption (Reeves *et al.*, 2003; Takacs, 2018). Different water suppliers summarized that average global efficiency of ASM pumps is about 48 percent, which is relatively low in comparison to centrifugal pumps (average value of 63%). Ninety-four percent of the 2500 pumps analysed in Germany was operating at efficiency of less than 60 percent, even small sized submersible pumps may operate with an efficiency of around only 20 percent (Plath and Wichmann, 2011; Staub *et al.*, 2012). In submersible pumps, 10-30 percent of energy consumed could be saved by changing the mode of operation and control system (Haque *et al.*, 2015). Well drawdown is also an important factor which plays vital role in variation of pump performance (Islam *et al.,* 2017).

The best options to redress the problem of declining water table at farm level are improvement of water use efficiency and farm productivity (Naresh *et al.*, 2014). These can only be achieved by selection of suitable irrigation method. The method of irrigation used at farm level is broadly classified as surface, subsurface, sprinkler and drip or trickle irrigation. Even after inclusion of some advanced irrigation methods in agriculture, surface method of irrigation is the most popular and commonly used. In this method, movement of water occurs by gravity flow in two dimensions from head to tail end of the field. Water is not uniformly distributed causing more percolation losses near the inlet of the plot due to more infiltration opportunity time (Rajurkar *et al.*, 2016). Poor farm design and uneven fields are accountable for nearly 30 percent of water losses (Gill, 1998). An annual irrigation saving of 10 to 12.5 cm was observed in zero tillage wheat sowing as a result of reduction in water evaporation and lower surface soil temperature by crop residue shading effects (Van Donk *et al.,* 2010).

High irrigation efficiency can be attained by using sprinkler irrigation in place of surface method of irrigation. Water saving of 14.48 and 16.89 percent with yield increasing by 4.45 and 6.95 percent in maize and wheat crop was observed by using sprinkler as compared to surface irrigation (Acharyna *et al.*, 1993). In an another study, when sprinkler and surface irrigated fields were compared to observe evaporation potential, it was found that sprinkler irrigated field had 3-11 percent lower evaporation potential (Liu and Kang, 2006a, 2006b).

Diminishing groundwater resources, high energy uses in groundwater pumping and low irrigation efficiency of commonly used irrigation methods are some major challenges for both agriculture and energy sector. Therefore, efficient utilization of water in irrigation and energy conservation in groundwater pumping are the issues that need special attention.

1.2 Most Relevant Review of Literature

Some most relevant review of literature on similar work done is given below:

Patel and Gupta (1979) revealed that main causes of excessive energy consumption and reduction in the pump sets efficiency in Gujrat State were improper selection of pumps, prime movers and their accessories along with improper fittings, installation under unfavourable operating condition and poor care and maintenance.

Hanson (1988) found that efficient pumps can become inefficient due to more wear and tear with time, changes in groundwater conditions and irrigation system.

Pandit *et al.* (1992) carried out a study on two submersible pumps, four vertical turbine pumps and one centrifugal pump located in Punjab Agricultural University Ludhiana. The overall efficiency was found in the range of 21 to 69 per cent. Submersible pumps sets had efficiency in the range of 42 to 52 per cent.

Khan and Saqib (1993) found lower motor efficiency mainly due to under loading and reduced power factors and further, worn pumping components and/or improper size of pumping unit were responsible for low pump efficiency.

Hanson (2002) suggested several options for improving over all pumping plant efficiency (OPPE) *viz.* repair or replacing worn pumps, replacement of mismatched pumps, adjusting impellers and converting to energy efficient electric motors.

Venkatesha (2002) reported that different pumps of the same size produce maximum efficiency at different total heads and discharge. Hence, operation ranges of different pumps require to be specified for proper selection.

Sud (2010) reported through field studies conducted in Punjab state that average efficiency of pump sets remained low in the range of 30-35% that offered significant scope of saving. It was suggested that up to 40% reduction in input power of 5 HP electric pumps was possible through use of efficient pumping and stable electricity.

1.3 Significance of Study

Water and energy conservation have become an important issue, particularly, in the water stressed and energy limited regions (Jiang *et al.*, 2013). Irrigated agriculture is the dominant user of fresh water resources and globally contributing to nearly 70% of consumptive use (Gleick, 2014). At world level about 40% requirement of irrigation water is fulfilled by groundwater and India is the world’s biggest user of groundwater (Aeschbach-Hertig and Gleeson, 2012). In India, groundwater irrigation covers more than half of the total irrigated area, accounting for 70% of the production and supports about 50% of the population (Anonymous, 1998; Shah, 2010 and Dhawan, 2017). However, it has now become clear that over exploitation of groundwater is resulting in depletion of aquifers and hence, water table is declining across the country (Devineni *et al.*, 2013; Russo *et al.*, 2013 and

Fishman *et al.,* 2015). In fact, the rates of depletion in India are probably the highest in the world (Aeschbach-Hertig and Gleeson, 2012).

In Haryana, a total number of 847750 tube wells have been reported in the year 2019 as against 27957 in 1966-67. During 2016-17, diesel and electric pump sets were 297616 and 550134, respectively, and share of net irrigated area under canals and tube wells was 11530 km^2 (38.80%) and 18210 km^2 (61.20%), respectively. The average decline in water table between June, 1974 to June, 2018 was 10.38 m and category wise distribution of blocks *i.e.* overexploited, critical, semi-critical and safe was 78, 3, 21 and 26, respectively, out of 128 blocks assessed during the year 2017. Earlier, the number of overexploited blocks were 64 in the year 2013 that increased by 14 in just four years (2013 to 2017), which showcase the alarming situation in Haryana (Anonymous, 2019).

The total share of electricity consumption for irrigation in Haryana is about 43.40 percent. Irrespective of electricity use, farmers pay Horse Power based (HP) flat rate in the state. This is the major reason for purchasing cheap but inefficient pumps (Singh, 2009). An average audit of electrical pump sets at four field study locations in Haryana found the pump set efficiency of only 21-24% (Anonymous, 2001). It was also concluded in the study that only 2% of the pumps had efficiency level above 40%.

Most of the wheat growers in the Indo-Gangetic Plains (IGP) of India apply surface irrigation either through border or check basin methods (Jat *et al.*, 2011). This is leading to mass mismanagement of energy and water resources. Irrigation efficiency of surface irrigation methods in India is only about 35% (Rosegrant, 1997) as 50% water losses occur due to leakage, seepage and through system inefficiencies (Hamdy *et al.*, 2003; Sivanappan, 1994; Wallace, 2000). Therefore, it is essential to efficiently utilize every drop of water in agriculture to obtain higher crop yield to boost economic status of resource poor farmers. This would only be possible either through adoption of sprinkler and micro irrigation system or proper design, layout, operation and management of surface irrigation methods. Improved irrigation system’s efficiency equally saves both water and energy. An optimized irrigation plan minimizes the irrigation water requirement. As the amount of irrigation water is reduced, the required energy to distribute the water will also be reduced. Utilization of high efficiency pumping plant is the most essential component of energy efficient irrigation. Careful selection and proper upkeep of the pumping system components is of paramount importance for efficient operation of irrigation system (Gellings, 2009).

Major cropping sequence of Sonepat district is paddy-wheat and the area under paddy and wheat crops was 0.90 and 1.42 lakh ha., respectively, during the year 2017-18 (Deptt. of Agriculture Sonepat, Govt. of Haryana). Paddy is grown by transplanting method while sowing of wheat crop is done by broadcasting of seed followed by cultivator, broadcasting of seed followed by rotavator, using zero tillage seed cum fertilizer drill and conventional seed cum fertilizer drill. The irrigation is mainly applied by surface border irrigation method. The border irrigation method is used without any design consideration leading to very low water use efficiency. Farmers' generally follow the practice of division of their fields (0.4 ha.) into 2 or 3 parts and on the other hand, some of the farmers make only one part of their field for irrigation. Generally, electricity is supplied during night hours and majority of farmers have fitted automatic switch on/off system on their tube wells. In many cases, fields are either over irrigated or some part left unirrigated and on the next day, this unirrigated part is irrigated through already irrigated area. In this way, there is a huge loss of water and energy during irrigation. Even most of the farmers do not level their fields prior to wheat sowing owing to the fact that precision land levelling machines are available which saves both water and energy. To meet the growing irrigation needs of high water requirement crops grown in the district, large number of new tube wells are being installed every year. In Sonepat district, number of electrified and diesel-based tube wells were 31,540 and 33,833, respectively, during 2016-17. With the fact that, the number and horse power of pumps are increasing with time, extracting more water and consuming more energy for irrigating the crops. Keeping this in view, there is an urgent need to quantify different losses in energy utilization and look for scope of energy conservation. In line to this, the present study entitled "Studies on scope of energy conservation for groundwater pumping in Sonepat district of Haryana" was undertaken with the following objectives:

1. Quantification of different mechanical and management factors responsible for energy losses
2. Identification of suitable remedial measures for energy conservation
3. Assessment of potential energy saving for groundwater pumping

CHAPTER-II

REVIEW OF LITERATURE

Over the years, irrigation has been increasingly shifting towards groundwater pumping, resulting in fast decline in groundwater levels. Due to successively increasing area under groundwater irrigation and declining groundwater levels, there is rising trend of using high horse power electric operated submersible pumps for lifting water from deeper depths. Energy used for groundwater pumping depends on a complexity of factors including water table depth, mechanical factors, cropping patterns, irrigation efficiency etc. A lot of literature is available on these aspects. However, a brief review of some of the most relevant and recent literature is presented in this chapter under following heads:

2.1 Effects of over extraction of groundwater on declining water table.

2.2 Mechanical factors affecting overall groundwater pumping efficiency

2.3 Influence of irrigation methods and agricultural practices on energy and water usage for groundwater irrigation

2.4 Influence of irrigation and management practices on crop yield and water use efficiency (WUE)

2.1 Effects of over extraction of groundwater on declining water table

Singh and Singh (2002) reported that water table was declining at the rate of 1-2 m per year in many parts of India due to overexploitation of groundwater and intensive irrigation in major canal commands. India was facing many water related problems *viz.* drying of aquifer resulting in depletion of water table, groundwater pollution, salinity, deterioration in groundwater quality and increased arsenic content in shallow aquifer in West Bengal. To overcome these problems, government of India had initiated several protective and legislative measures *i.e.* establishment of groundwater monitoring stations, artificial groundwater recharge and conjunctive use in canal commands *etc*.

Ambast *et al*. (2006) suggested the reversal of groundwater decline through artificial groundwater recharge and suitable land and water practices. Groundwater recharge was found practically feasible through vertical shafts directing water from the ground surface directly to aquifers, passed through a sand gravel filter. Through this system, the recharge rate was almost equal to a shallow cavity filter well yield (about 11 $l\ s^{-1}$). Further studies were conducted in the Kaithal and Karnal districts of Haryana for stabilizing water table within 6-7 m that permitted continuous use of shallow tube wells.

Jeevandas *et al*. (2008) assessed groundwater depletion and calculated irrigation efficiency at farm level in Amritsar and Faridkot districts of Punjab (India). They observed 77 and 33 cm per year decline in water table in Amritsar and Faridkot districts, respectively, due to cereal based cropping pattern predominated by paddy and wheat. They had also reported mean irrigation efficiency of 57 and 65% in paddy and 61 and 68% in wheat production in tube well irrigated and canal+tube well irrigated farms, respectively.

Aggarwal *et al.* (2009) found that deviation in cropping pattern has increased irrigation water requirement manifold and irrigated area increased from 71 to 95% in the state of Punjab. During last 35 years, number of tube wells increased from 0.192 to 1.65 million, while average rate of water table depletion in last few years was 55 cm year^{-1}. This resulted into more power consumption, adversely affected socio-economic condition of farmers, created ecological imbalances and hence badly affected sustainable agricultural production of the state. Shift of cropping pattern, delayed paddy transplantation, adoption of modern irrigation methods and rainwater harvesting techniques were some of the implications of the study suggested by the researchers.

Chatterjee and Purohit (2009) estimated dynamic groundwater resources of India by using groundwater resource estimation methodology-1997. They have reported that overall stage of groundwater development was 58% and out of 5723 observation units, 4078 were ‘safe’ and 839 were ‘over- exploited’ whereas, rest were found under ‘semi-critical’ and ‘critical’ category. They have further concluded that North western, Western and Peninsular regions of India were facing more over-exploitation.

Rodell *et al.* (2009) reported that groundwater depleted at a rate of 4.0±1.0 cm per year equivalent height of water (17.7±4.5 km^3 year^{-1}) in the States of Rajasthan, Haryana, Punjab and Delhi. It was observed during the study period of August 2002 to October 2008 that groundwater depleted equivalent to net loss of 109 km^3 of water, which was double the capacity of India’s largest surface water reservoir. The study proposed that there was an urgent need of sustainable groundwater usage to avoid reduction in agricultural output in the area.

Scott and Sharma (2009) examined trends of supply of electricity and groundwater development in Indo-Gangetic Basin (IGB) in Indian portion from 1980 to 1999. The principal findings of the study showed that in early 1980’s, a growing trend was observed in number of electric pumps in whole IGB region, whereas, in 1990’s, a stagnation was observed in eastern part of the basin. This trend was linked to electricity supply and pricing policies that varied from state to state. The eastern IGB led to increased reliance on diesel power due to inadequate electricity supply resulted in limited development of groundwater.

Goyal *et al.* (2010) analyzed water table depth variability *vis-a-vis* groundwater development and rainfall using ILWIS 3.6 GIS tools during 1987-2007 in Kaithal district of Haryana. The decline in water table ranged from 10-23 m in Guhla, Pundri and Kaithal blocks and in narrow range of 4-9 m in Kalayat and Rajaund blocks. They concluded that depletion was faster during 1997-2007 as compared to 1987-97. The groundwater decline might be due to indiscriminate abstraction of water for irrigation and decrease in rainfall since 1998.

Malik *et al*. (2010) observed groundwater decline and salinity in Gurgaon district of Haryana. They reported groundwater depletion at a rate of 0.77 m year^{-1} (Bilaspur) to 1.2 m year^{-1} (Hailymandi) blocks and net annual withdrawal was more than the net annual recharge. All the four blocks of the district had come in over exploited category with 209% groundwater development. Use of optimal groundwater conservation practices, rainwater harvesting and proper run off management were suggested measures of eradication of this problem.

Lashkaripour and Ghafoori (2011) examined that more increasing water demand and little recharge had exhausted groundwater resources in eastern part of Iran. This resulted in deterioration of groundwater quality and declined water table significantly during the 19 years study period. The major cause of excessive water table drop was attributed to higher pumping from wells than their natural recharge. The annual rate of decline was about 1.77 m during the years 1987 to 2006.

Singh (2013) observed that over exploitation of water resources threated sustainability of existing cropping system in Punjab and created critical second generation problem. He further recommended that potential cotton belt having brackish groundwater needs to be used in conjunction with canal water and paddy cultivation mainly responsible for fast receding water table should be strictly discouraged.

Patle *et al*. (2015) identified pre and post monsoon groundwater levels trends in Karnal district of Haryana by using Mann-Kendall test and Sen’s slope estimator and for time series modelling. They reported significant groundwater level decline during 1974-2010 with yearly average rates of water table decline 0.228 and 0.267 m during pre and post monsoon seasons, respectively, while rapid declines were observed between 2001 to 2010. The auto regressive integrated moving average (ARIMA) (0, 1, 2) was found suitable model for time series modelling and forecasting. The study also projected that pre and post monsoon groundwater levels in 2050 would decline by 12.97 m and 12.0 m over the observed water level in 2010, and touch to a level of 29.95m and 28.14m below ground surface.

Baweja *et al*. (2017) reported that free electricity and inappropriate agricultural practices had contributed to excessive groundwater pumping to meet the irrigation needs of high water requirement paddy and wheat crops extensively cultivated in Punjab state. The long term study results revealed that 41.6 cm per year groundwater decline was recorded. Efficient technologies/practices recommended to check declining water table were namely micro irrigation, bed planting, laser guided land levelling, zero tillage and crop diversification.

Singh and Amrita (2017) reported that over exploitation of groundwater resulted in declining water table situation in Haryana state. During last 38 years, the average water table decline was about 20 cm year^{-1} and 13 of its districts have been categorized as over exploited.

The over dependency on groundwater resources for irrigation has resulted in high power consumption, ecological imbalances and threats to sustainable agriculture. They suggested several technologies and practices to combat the declining water table problem *viz*. delayed paddy transplantation, crop diversification, zero tillage technology, laser guided land levelling, bio drainage and rainwater harvesting for artificial groundwater recharge.

Singh and Kasana (2017) observed that number of tube wells had increased from 0.02 million (1966) to 0.73 million (2012) in Haryana that showed alarming signal of over-exploitation of groundwater. They investigated groundwater level variations from the groundwater level data of 893 observation wells during 2004-12, using geographical information system (GIS) and reported that groundwater levels were found to be in the range between 0.16 to 65.97 m and average annual decline was observed above 32 cm with sharp decline (108.9 cm year^{-1}) in Kurukshetra district.

Srivastava *et al*. (2017) identified the factors responsible for groundwater depletion in Punjab (India). The study revealed that small farmers were affected more due to falling groundwater level and incurs 2-3 times groundwater extraction cost than the large farmers. The withdrawal of energy subsidy expected to reduce net return of different crops. However, de-subsidization of energy can motivate farmers to improve groundwater use efficiency with the impact of 29-82% savings in existing groundwater use in different crops.

Jalota *et al*. (2018) suggested that water deficit was also responsible to water table decline/rise rather than groundwater withdrawal alone as the irrigation water requirement of wheat crop was less (300-400 mm) than rice (1500-2000 mm) yet the water deficit and water table decline was more in wheat than rice crop. In rice, evapotranspiration (ET) was almost equal to the rainfall, whereas, in wheat ET was 3.9 times than that of rainfall. So, in addition to rice, there was a need to reduce ET in wheat also, which could be attained through real water saving technologies like irrigation scheduling based on deficit irrigation, diversification of wheat to low ET crops *viz.* raya and chickpea, exhausting surface water supplies and reduction in evaporation during the fallow period.

Singla *et al*. (2018) observed that increased intensity of tube wells contributed to excessive use of groundwater for irrigation and hence resulted in declining groundwater level in good quality groundwater zones of Sirsa district in Haryana. They reported, very low *i.e*. 2 tube wells km^{-2} in Dabwali block and 5-10 tube wells km^{-2} in Sirsa, Rania, Bragudha and Elenabad blocks resulted in varying groundwater levels and groundwater development in the district. The study also concluded that most of the area in the district had more than 65% of groundwater exploitation.

Sivarajan *et al*. (2019) examined groundwater table depth variability during 1996-2016 in Ahmednagar district of Maharashtra using GIS modelling and found significant variability at confidence level 95% during the study period. It was reported that a significant decadal increase of about 0.7 m in groundwater decline and a remarkable decrease of about 0.61 cm year^{-1} in groundwater recharge in the study area.

2.2 Mechanical factors affecting overall groundwater pumping efficiency

Hooren (1989) calculated the fuel efficiency and fuel consumption cost of pumping power units in 15 farms at Ontario, Canada. The fuels used were petrol, diesel, electricity and natural gas. He observed that majority of the pumping plants were operating below the accepted standards. Fuel savings could be obtained by improving fuel efficiency or using cheaper fuels.

Reinemann *et al*. (1991) determined the mechanical energy efficiency of diesel and electric pumping sets in Pakistan to identify the factors of low efficiency. An average overall efficiency was found 54 and 48% for electric and diesel operated centrifugal pumps, respectively, in a study of 132 private pumping sets. Large scale retrofit programme was suggested to reduce the energy used for irrigation pumping in Pakistan.

Sadaphal (1991) found that features of agricultural pump sets used in India were outlined with respect to energy conservation and energy efficiency. It was estimated that 90% electrically operated irrigation pumping sets in India were operating inefficiently due to operational, technical, managerial, financial and social problems.

Koppad and Maurya (1994) conducted study in Belgaum district of northern Karnataka to determine the efficiency of diesel pump sets. The study showed that efficiency of these pump sets was observed in a very low range of 4.12 to 10%, which may be attributed to excessive pipe friction, inefficient foot valves and use of sharp bends. In addition, excessive diesel consumption also caused further drop in the efficiency.

Sant and Dixit (1996) evaluated different ways in which irrigation pump sets were made efficient and assessed the role of efficiency standards in achieving best utilization of electricity and reported that BIS norms for pump set efficiency need some improvement viz. increase in minimum efficiency level, upward revision of recommended pipe size, suitable flange size and accounting for changing pump efficiency with changing total suction head. They also reported that 326 million kw-h year^{-1} electricity could be saved through these recommendations and 61 MW per year on power expansion could be avoided.

Koppad and Maurya (1997) studied field performance of electric pumpsets in Belgaum district of Northern Karnataka and revealed that 88.40% of mono block and 90.70% of direct coupled pump sets were operating below 50% efficiency. The average head loss of 4.20 m was recorded in which maximum contributing component was due to pipe friction. The excessive pipe friction, sharp bends, inefficient foot valve, use of T-joints, and low pump speed were identified as important causes for low efficiency. In addition, poor maintenance and poor foundation also caused reduction in efficiency of pump sets.

Reddy *et al*. (2001) studied performance and problems of pump sets (3-7.5 hp) at farmers' field in different villages in six districts of Chhattisgarh state. The study revealed that 67 and 27% well water was being utilized by large and marginal farmers, respectively. They also found that operating efficiency of pump sets used by small and marginal farmers ranged from 6-37%, which was less than the large farmers, who adopted more efficient irrigation system. The pump set's improper installation and maintenance were the measure causes of low efficiency.

Ahmad (2003) concluded that majority of the farmers in Pakistan were using energy inefficient pumps mainly due to their lower cost. The efficiency of both electric/diesel prime movers varied between 25-50%. However, the high efficiency pumps were available but resource poor farmers were not capable to purchase these pumps. It was recommended that by management and manufacturing interventions the water and energy efficiency of locally manufactured pumps could be improved by at least 50%.

Scott and Shah (2004) found that India and Mexico were the largest users of groundwater in the world. They further stated that electrical energy supply and pricing were the main driving forces behind extensive groundwater pumping for irrigation in both the countries.

Calisir (2007) evaluated energy usage and material performance of submersible pumping plants in Turkey. The system efficiency (actual performance), flow rate, total dynamic head, performance rating and specific total energy consumption were 52 ± 1%, 41.1 ±1.0 l s^{-1}, 56.1±2.1 m, 78 ±% and 2.93 ± 0.10 MJ m^{-3}, respectively. The potential energy saving was determined as 22% in all the plants. Regression equations for specific total energy consumption, total dynamic head and flow rate were also developed.

Kaledhonkar *et al*. (2007) observed that water table in few blocks of Haryana and Punjab was declined at the rate of 1 m $year^{-1}$ in last decade due to the fact that a large number of centrifugal pumping units had been replaced by submersible pumps particularly in rice-wheat cropping area which contributed to overexploitation of groundwater.

Gellings (2009) found that installation of high efficiency pumping plant or improvement in the existing pumping sets minimized the unnecessary pumping losses. In addition, a well designed and properly managed irrigation system reduced its operating cost. Through careful planning and implementation of irrigation efficiency measures, both water and energy consumption could be minimized. In this study special emphasis was given on increasing electric pumping plant efficiency.

Manoharan *et al*. (2010) described the efficiency improvement in submersible motor by using a new slot design and Die-cast Copper Rotor (DCR) technology in place of Copper Fabricated Rotor (CFR) technology and were of the opinion that efficiency of submersible motor increased by 4-5% resulted in 1-1.5% increase in overall efficiency of submersible pump. Starting torque of DCR motor was also increased with new lamination. They further concluded that improvement in overall efficiency of pumping sets may be possible, if proper attention was given to limit the various losses *viz*. hydraulic, leakage, mechanical and disc friction.

Kaledhonkar *et al*. (2013) conducted study in Assandh block of Karnal district in Haryana. They concluded that declining water table had resulted in reduced discharge from shallow tube wells. The submersible pumps were replacing the centrifugal pumps. Less water productivity was reported under submersible than centrifugal pumps due to high water application in submersible pump system. Under both the pumping systems less than 40% pump efficiencies were observed, however, submersible pumps efficiencies were relatively higher than centrifugal pumps. Inappropriate size and its placement at inappropriate depth were few of the reasons of low efficiencies in submersible pumps besides rice-wheat cropping system which was identified major cause of water table decline in the area and suggested cultivation of low water requirement crops that would decrease rate of declining water table and reduce the replacement rate of centrifugal to submersible pumps.

Rahman and Salim (2015) compared performance of two, three phase motor-pump systems in relation to power consumption at lower than the rated voltage in the motor. The results showed that in low voltage conditions the system containing variable frequency drive (VFD) exhibits nearly constant efficiency over the entire voltage range, while the conventional system exhibits great reduction in efficiency at decreasing voltage. It was concluded that VFD had worked as efficient tool in preserving the efficiency of a motor-pump system in low voltage conditions.

Haque *et al*. (2016) studied the performance of three HP single phase submersible pump on the basis of well bore diameter and filter length. The maximum pump efficiency of 39 % was found for 0.10 m diameter well, with 0.9 m filter height at 57 m head and 83 l min^{-1} discharge. Optimum efficiency range of 36-39% was observer for well diameter 0.10 m to 0.15 m at discharge 85-125 l min^{-1}. It was concluded that reduction of well draw down could be achieved by increasing filter length and well diameter.

Sharma and Gupta (2016) while conducting a field survey to study the performance of agricultural pumping systems observed that 25% pumps were found in very high, 45% in excessive and 30% in indeterminate range of electricity consumption, whereas, only 15% pumps were operating at greater than 60% efficiency. Drastic improvement in performance of pumps was noticed by changing GI pipes by PVC and GI or CI foot valve by RPVC foot valve. Results of the study also showed reduction in energy index by 22 and 7% increase in system efficiency was recorded due to partial rectification measures in most of the pumping systems.

Islam *et al*. (2017) investigated effect of draw down, mainly influenced by well diameter and filter length on pump performance. In this study maximum draw down was 1.4 m for 0.10 m diameter well with 0.30 m filter length and pump efficiency was 10%. Similarly, maximum draw down was 0.18 m for 0.15 m well with 0.30 m filter length and 9% pump efficiency was observed. It was concluded in the study that optimum efficiency varied between 36-40% and discharge varied from 95 to 125 l min^{-1}. As per findings of the study better performance of submersible pumps could be achieved by increasing well diameter and filter length that reduce well draw down

Kasana and Singh (2017) indicated that the density of tube well per thousand ha and number had been increased by more than 250 and 300%, respectively from 1975 to 2013 in Haryana. Nearly 70% of tube wells owned by small farmers, but the benefit of electricity subsidy had gone to large farmers. It was concluded that the groundwater economy in the state is in growth phase and it is very important to clearly understand the dynamics of the state economy.

Wei and Sun (2017) designed and constructed a submersible pump model through the use of Auto CAD software with six diffuser inlet width. The performance curves of submersible pumps were obtained using computational fluid dynamics method. The study reveales that efficiency of submersible pump was found to be relatively high (75.9 to 83.7%), when the guide blade inlet width was approximately 40-55 mm.

Haque *et al*. (2017) investigated the performance of submersible pumps operating in different sites in Barind area of Bangladesh and compared with lab test results of new pumps. It was revealed that efficiency of the pumps reduced by 20-40% than lab test results. Main causes of lower efficiency were improper matching of pump standard conditions and operation/system requirements. It was also concluded in the study that energy consumption cost was dominated the life cycle cost of the pump.

Vedant and Vekariya (2018) evaluated the performance of mono block centrifugal and submersible pumps to develop characteristic curves and its operating conditions. The mono block pump was tested at suction lifts 0.5, 0.7, 1.6 and 2.5 m, the maximum efficiency was found 75% at 0.7 m suction lift and at 29.34 m head. The minimum efficiency of 47.94% was found at 0.7m suction lift. In case submersible pump maximum pump set, efficiency of 54.98% was found at working head 40.43 m, discharge 24.10 l s^{-1}, input HP 23.63 and WHP 12.99, it was the operating point of submersible pump. Above 50% efficiency could be achieved with discharge 24.10 to 17.89 l s^{-1}.

2.3 Influence of irrigation methods and agricultural practices on energy and water usage for groundwater irrigation

Tyagi *et al*. (1979) evaluated pumping, field application, conveyance, water use efficiency and crop production index per unit of water applied at CSSRI farm, Karnal. The pumping efficiency of electric centrifugal pumps was 52% as compared to 30% of diesel engine run pumps. The soil in the study area was alkali which resulted in low seepage (7%), therefore, the conveyance efficiency was observed as high as 93%. The total water requirement was higher and water use efficiency was lower for rice as compared to wheat while the overall system efficiency was higher in wheat (54%) as compared to rice (39%).

Harman *et al*. (1985) compared conventional tillage with no-till practices in an irrigated wheat/no-till feed grain/fallow crop rotation by applying a linear programme for ten years. The results showed that no-till practices increased water and energy use efficiency and also gave better returns in terms of land, management and risk.

Asif *et al*. (2003) compared laser land levelling with traditional land levelling and unlevelled land in wheat crop and found that laser land levelling significantly improved the grain yield (5.56 t ha^{-1}) than the unlevelled land (3.99 t ha^{-1}), but at par with traditional levelling. The results further showed a reduction in the total irrigation duration and applied water depth by 47 and 15 % as compared to unlevelled and traditional levelled fields, respectively. The highest water use efficiency (WUE) was recorded in laser levelled fields than the unlevelled and traditionally levelled fields.

Rana *et al*. (2006) evaluated different irrigation techniques *viz.* check basin, furrow and rain gun sprinkler at Faisalabad, Pakistan and observed that rain gun sprinkler irrigation increased water use efficiency by 30.8 and 28.3% and water application efficiency by 21.1 and 9.0% as compared to check basin and furrow irrigation system, respectively. Nitrogen leaching was lower in case of irrigation by rain gun sprinkler irrigation as compared to check basin and furrow system. Similar trend was also observed for sunflower yield.

Abdullaev *et al*. (2007) determined the impacts of laser land levelling on water use, productivity and crop yield in northern Tajikistan. The results showed that laser land levelling reduced the maximum water application rate by 593 m^3 ha^{-1}. It also reduced deep percolation losses (8%) and run off losses (24%) and increased net income (22%) and gross margin (92%) as compared to control.

Murthy and Raju (2009) studied the electrical energy requirements for irrigation in different cropping patterns in three districts of Northern Andhra Pradesh and observed significant differences in energy requirement and energy consumed. The estimated energy requirements were 11.03 million units whereas the actual consumption was 18.08 million units. They concluded that a number of factors were responsible for this large gap between requirement and consumption. One was the power supply pattern, which showed that most of the power supplied for agricultural needs during the night. Therefore, farmers tend to switch on the pump and leave it ‘on’ during whole night, which in turn results in overfilling of fields with water. The another reason was the lower water table resulting in increase in suction head of tube wells and further increases the energy requirement.

Khan *et al*. (2010) examined the energy consumption, benefit/cost ratio and energy input-output relationship of wheat, rice and barley crop production system and revealed that wheat, rice and barley consumed 3028, 6699, 2175 kW-h ha^{-1}, respectively. Similarly, wheat, rice and barley utilized 2852, 17754 and 856 m^3 ha^{-1} of water. They further observed that wheat was found to be the most energy efficient crop as compared to rice and barley, whereas barley crop was recorded with highest water productivity. The B:C ratio was highest in rice (3.33) followed by wheat (2.82) and barley (2.50).

Jat *et al*. (2011) conducted an experiment to evaluate the benefits of precision land levelling and crop establishment (furrow irrigated raised bed planting) technologies alone or in combination (layering precision conservation) in wheat. They reported that grain yield was 16.6% higher with nearly 50% less water consumption in precision laser land levelling and raised bed planting compared to traditional land levelling with flat planting. The agronomic and uptake efficiencies of N, P and K were also improved significantly under precision land levelling with raised bed planting technique.

Liu *et al*. (2013) estimated crop yield and water productivity of winter wheat (*Triticum aestivum* L.) under sprinkler and surface irrigation in the North China plain. Results showed that leaf parameters as well as above-ground biomass were higher in the sprinkler irrigated crop as compared to the surface irrigated crop. Similarly, the yield was also higher by 11.5-50.9% in sprinkler irrigated field. Water productivity was 18-57% higher and irrigation water productivity was higher by 21-81%, whereas, the seasonal crop evapotranspiration was lower by 4-23% in the sprinkler irrigated field.

Ansaridoust *et al*. (2014) evaluated effects of laser land levelling on water use efficiency, volume of water used, field capacity, fuel consumption, levelling cost, levelling index, and land uniformity coefficient using the software SPSS and Grade Plane. Significant differences were indicated between laser and conventional levelling techniques for all the field and water usage related parameters except the crop performance where no significant difference was observed between laser and conventional levelling.

Naresh *et al*. (2014) evaluated the effects of laser land levelling in comparison to traditional land leveling on water use productivity and crop yield of wheat, rice and sugarcane. Laser land levelling was found to be effective and saved 21% irrigation water, 31% energy and resulted in 6.6, 5.4 and 10.9% higher yields in rice, wheat and sugarcane. The total irrigation duration and applied water depth was also reduced in all the crops as compared to traditional levelled fields. Water use efficiency (WUE) was found to be 48, 47 and 49% higher in laser levelled field than control (unlevelled) while it was 22, 19 and 20% higher than traditionally levelled fields, respectively. The average annual net income from the laser levelled field was 14, 13.5 and 23.8% higher in rice, wheat and sugarcane from the traditional levelled field.

Darouich *et al*. (2017) adopted a multi-criteria analysis for the comparison of graded borders with and without precise land levelling and solid-set and semi-permanent sprinkler systems in wheat. SADREG and the PROASPER design models were used to develop alternative solutions for surface irrigation and for sprinkler systems. The higher water saving was observed in alternatives with precise land levelling mainly due to a controlled advance time and reduced percolation. Among surface and sprinkler systems, better utility was observed in case of semi-permanent systems due to higher water use and costs of land levelling in the case of graded borders. Overall, semi-permanent system was found better due to low investment cost.

Hashimi *et al*. (2018) assessed the effect of laser land levelling on infiltration by evaluating its relation to field size, water depth (WD), irrigation interval and cultivation age. The results showed a negative correlation between field size and irrigation interval, whereas, a positive association observed between WD and infiltration. They also observed that laser land levelling significantly reduced the water input and increased irrigation interval length. The cultivation age did not show any significant correlation with WD.

Razzaq *et al*. (2018) assessed the economics of high efficiency irrigation systems (HEIs) in Punjab province of Pakistan and observed that most of the farmers using HEIs were large farmers. The sprinkler and drip irrigation systems were installed in wheat crop and mango orchards, respectively. The high efficiency irrigation systems (sprinkler and drip irrigation) produced higher gross returns and water use efficiency than conventional farms.

Ali *et al*. (2019) analysed electricity and fuel consumption trends for crop production in India and Pakistan between the years 2002 and 2011 and observed that sown area and electricity consumption per hectare increased by 5.79 and 51.24% in Pakistan as compared to 0.59 and 53.83% in India.

Nasseri (2019) compared conventional tillage with surface irrigation ((T_1) and conservation tillage with sprinkler irrigation (T_2) in terms of energy indices and economics for two years in a semi-arid area of Iran and revealed that the total average energy consumed was higher for T_1 (16.36 GJ ha^{-1}) as compared to T_2 (14.07 GJ ha^{-1}). The net energy gain, energy use efficiency, energy productivity and energy profitability were found highest and specific energy was found lowest in case of T_2 as compared to T_1. The treatment T_2 also showed highest net return, benefit-cost ratio and productivity.

2.4 Influence of irrigation and management practices on crop yield and water use efficiency (WUE)

Wang *et al*. (2001) examined relationships between irrigation, evapotranspiration (ET), water use efficiency (WUE) and crop growth of a corn-wheat rotation system during a period of 12 years (1984-1996). They applied modelling strategy to analyse the measurements and to simulate the effect of different irrigation scenarios on crop growth parameters with the help of a process-based model (WAVES). They revealed that the ratio of Soil evaporation

(Es) to total ET was about 30 and 40% for corn and winter wheat, respectively. They also observed that mulching saved up to 80 mm of water during a wheat growth season through decreasing the soil evaporation by about 50%.

Kumar *et al*. (2013) evaluated five wheat establishment methods *viz*. conventional tillage, reduced tillage, raised bed planting, rotavator tillage and zero tillage for energy use and economic efficiency in sandy loam soil during 2005-2008 and observed that zero tillage improved energy use efficiency (13%), operational field capacity (81%) and specific energy (17%) as compared to conventional tillage. The net income was also higher in zero tillage (33%) followed by reduced tillage (20%) as compared to conventional tillage. They concluded that CA based crop establishment practices not only produced higher productivity and profitability, but also proved to be viable options in term of energy and time efficiency.

Rajkumar *et al*. (2018) compared laser guided land leveling technology with zero tillage along with crop residue retained treatments and Farmers' practice. Among eight treatments, yield of wheat was observed higher and quantum of irrigation water applied was less in case of laser guided land leveling with zero tillage with 100% previous crop residue retained treatment followed by laser land leveling with zero tillage with 50% previous crop residue retained treatment and was found more in case of farmers practice (control). The total water saving was to the extent of 27% in case of laser land leveling with zero tillage with 100% crop residue retained treatment over control treatment.

Sharma *et al*. (2018) compared sprinkler irrigation with surface irrigation method in wheat crop and observed that sprinkler irrigation resulted in saving of water (12.5%), grain yield (16.22%) and water productivity (30.76%) as compared to surface irrigation method.

Meena *et al*. (2019) evaluated water use efficiency, crop yield and water use of wheat crop variety HD-2967 from 2015-2016 to 2017-2018 in sandy loam soils and observed that full irrigation treatment (60 mm of water at all five critical crop growth stages) gave highest grain yield (5372.4 Kg ha^{-1}) but lower water use efficiency (1.88 kg m^{-1}). At 25% deficit irrigation *i.e*. 45 mm of water at all five critical crop growth stages contributed almost equal yield to that of 60 mm water treatment and significantly higher WUE (2.23 kg m^{-3}) resulted in saving of 25% water and electric power used for groundwater pumping.

Patent search

Since this research was based on the studies on scope of energy conservation for groundwater pumping in Sonepat district of Haryana, therefore the patent search is not applicable for this research work.

CHAPTER-III

MATERIALS AND METHODS

The present research work was undertaken to investigate the scope of energy conservation for groundwater pumping. The study consisted of surveying of important aspects of groundwater pumping carried out at the farmers' field for electric pumping sets, wherein different factors affecting energy consumption for pumping were assessed and other important statistics were obtained from Agriculture department, Haryana. The other part of the study was carried out in the experimental field area of KVK, Sonepat. Where, the role of different on-farm irrigation methods on energy utilization for pumping was assessed for wheat crop. The details of the materials used and methods followed during the course of this study are presented in this chapter.

3.1 General

3.1.1 Study area

The present study was carried out in Rai and Sonepat blocks of Sonepat district of Haryana. It lies between latitude of 28º 48′ 15″ to 29º 17′ 10″ and longitude of 76º 28′ 40″ to 77º 12′ 45″. Area under Sonepat district is 2260.53 sq km comprising of 5.11% of the state area. The average elevation of the area is 230 m above mean sea level. The district is surrounded by Panipat, Jind, Rohtak district and Delhi in North, West, North West and South, respectively. The area under Rai and Sonepat block is 280.49 and 397.89 sq km, respectively having sandy loam to loamy sand soil. The normal annual rainfall of the district is 567 mm. Based on long term records, about 76% of the annual rainfall was recorded during the South West monsoon in June-September months. The probability of occurrence of rainfall in the range 400-700 mm is 0.65. Irrigation in the district is done by using both surface and groundwater resources. The area irrigated by groundwater and surface water in the district is 42% and 58%, respectively. About 96% area with respect to net sown area in the district is irrigated area. The district has a high irrigation intensity of 159%. The area which is irrigated by surface water lies towards west where groundwater is mostly saline, while groundwater irrigation is maximum in the eastern parts adjoining the Yamuna river having fresh groundwater resources. The canal irrigation is mainly through Western Yamuna Canal. The groundwater level depth lies within 5-20 m below ground in most parts of the district. It rests between 2 to 25 m deep in the eastern side and 2-10 m in the north western parts of the district. Only small patches in the Rai and Sonepat blocks, where water table is deeper in the range of 20 to 40 m. The trend of decline of water table is 0.05 to 0.95 m year^{-1}. The tube wells installed in Sonepat, Rai and Ganaur blocks are comparatively at deeper depths. Groundwater is relatively of good quality in these blocks and found at deeper levels as compared to other areas in the district. Generally, Horse Power (H.P.) of pumps used mostly varies from 5 to 7.5 in different parts of the district. However, some are using higher capacity pumps up to 20 H.P. are for lifting groundwater in Sonepat and Rai block. These areas are more or less parallel to the Yamuna River in the eastern part of the district (Rana and Bhatia, 2013).

3.1.2 Cropping pattern

Both blocks under study have almost similar cropping pattern *i.e.* wheat is major crop grown in *rabi* and Paddy in *kharif*. Total cultivated area under different crops in Rai and Sonepat blocks during *kharif* 2018 was 14801 and 24970 ha, respectively. Likewise, cropping area in these blocks during *rabi* 2018-19 was 15071 and 29382 ha, respectively.

3.1.3 Status of pumping sets

The total number of Electric pumping sets in Rai and Sonepat blocks during the year 2018-19 were 5136 and 6897 as compared to 3456 and 4587 during the year 2011-12, respectively showing that the numbers of electric pumping sets in these blocks are continuously increasing due to declining water table which is also contributing to continuous increase in H.P. of submersible motors used for pumping resulting in high energy requirement for irrigation. The density (Number of electric submersible tube wells per square kilometer) in Rai and Sonepat blocks were recorded 18.31 & 17.33 respectively. Similarly, in 2018-19, the total number of pumping sets in whole Sonepat district were 62165 out of these 33057 pumps were operated by electrical power and 29108 were operated by diesel engine as compared to 25128 (electric power operated) and 33554 (diesel engine operated) in the year 2011-12 (Deptt. of Agriculture and Farmers' Welfare, Sonepat, Haryana). The submersible pumps operated by electrical power are replacing the centrifugal pumps operated by diesel engine because of declining water table depths in the district in the areas where groundwater is of good quality.

3.1.4 Groundwater levels data

The average water table depth of Rai and Sonepat blocks for the months of June (pre monsoon) and October (post monsoon) for the period of 1990 to 2020 were collected from the office of Hydrologist, Groundwater Cell, Rohtak (Deptt. of Agriculture and Farmers Welfare, Haryana) to examine the over all trend and behaviour of groundwater level rise or fall in the two blocks. Similarly, present water levels of each tube well selected for study were recorded at the time of observation along with other parameters of the tube wells with the help of electronic water level indicator. The water table readings were recorded when the tube wells were in operating condition.

3.2 Study at farmers' field

3.2.1 Selection of pumping sets

A total of 65 pumping sets (35 from Rai and 30 from Sonepat block) were selected for the study. All were equipped with submersible pumps and were being operated by electrical power. One each pumping set was selected from 61 village, whereas from 2 villages two pumping sets were selected for the study. In this way, total 63 villages were covered under this study. The selected pumping sets were operating at different water table depths using different H.P. motors and it was further ensured that groundwater was being pumped out from the selected tubewells at the time of different measurements. Hence, the present study is based on both primary data of farmers and actual parameters measured at electric submersible tube wells. The soil samples of upper layer (0-15 cm) from all the selected 65 farmers' field were also collected and analyzed.

3.2.2 Tube well discharge measurement

Coordinate method of pipe flow measurement (Fig. 3.1) was used to estimate the discharge of tube wells. A simple 'L' shape gauge was designed by using stainless-steel plates of 0.5 cm thickness and 4 cm width to measure x and y distances. Two pieces having horizontal length of 104 cm and vertical length of 19 cm were joined together at 90° angle. Similarly, two stainless steel metering scales with centimetre markings, having horizontal length of 100 cm, vertical length of 15 cm (fixed) and width 3.5 cm were welded on the stainless-steel plates exactly at 90° angle to measure x and y distances of falling water jet as shown in Fig 3.2.

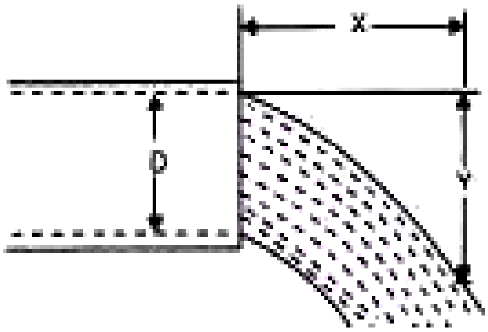


Fig. 3.1: Coordinate method of pipe flow measurement

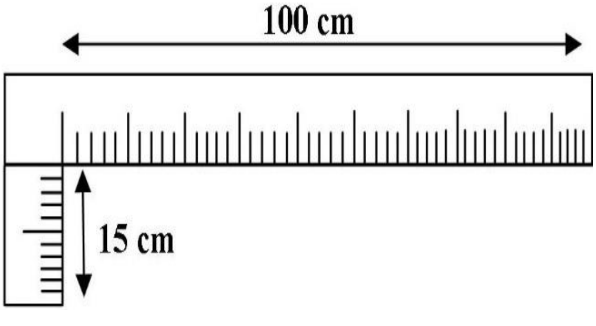


Fig. 3.2: L-shaped discharge measurement gauge

Design of gauge is based on following empirical formula: (Rama Mohan and Sreekumar, 2009)

$$\boldsymbol{Q}_{(l/s)} = \frac{\boldsymbol{D}^2 \times \boldsymbol{X}}{\mathbf{59} \times \boldsymbol{Y}^{1/2}} = \frac{\boldsymbol{D}^2 \times \boldsymbol{X}}{\mathbf{228.5}} \tag{3.1}$$

Where,

Q: Discharge from the tube well (litre/second)

D: Delivery pipe diameter (cm)

X: Horizontal distance (cm)

Y: Vertical distance (cm) (fixed as 15 cm)

For estimating water discharge from the tube well, the ‘L’ shaped gauge scale was placed on delivery pipe and moved slowly forward, when inner lower point of the inner face of the vertical 15 cm long plate (y-axis) just touched the upper surface of flowing water jet, the reading on the sliding scale (x-axis) placed on the delivery pipe was noted (Fig. 3.3a). The inside diameter (cm) of the delivery pipe was measured with the help of simple stainless-steel scale. The water discharge in l sec^{-1} from the tube well was calculated by using the equation 3.1.

3.2.3 Measurement of water table

An electronic water level indicator was used to measure water levels accurately in pumping wells. The instrument consists of a 15.8 mm outer diameter stainless steel weighted probe attached to a 10 mm wide polyethylene tape marked with meter scale in one side and foot scale on the other side. The probe is lowered in the gap that exists between casing pipe and delivery pipe of submersible tube well. As soon as the probe touches the water in the tube well, a beep sound rings. The measure of total length of the tape which is inserted into the bore is the depth of water table for a particular tube well (Fig. 3.3b). The water levels then were recorded when the pumping sets were in operating condition and hence it represented the pumping water level rather than static water level.

3.2.4 Measurement of electrical energy consumption

A calibrated energy meter was used to measure the actual energy consumption by submersible pumping system. For taking the observations, the running tube well was stopped and the energy meter was connected to the electricity supply. The tube well was restarted just after making proper connections with three phase energy meter. After a lapse of 15 minute, initial reading of energy meter and time were recorded. The tube well was kept running for at least one hour and final reading was again recorded. The tube well discharge was measured after 30 min. of tube well restart. In this way, electrical energy consumption of submersible tube well in kWh was finally measured (Fig. 3.3c). The data were collected and observations were recorded during the year 2018 and 2019 mainly during *kharif* season.

Fig. 3.3a. L - shaped gauge for discharge measurement

Fig. 3.3b. Electronic water level indicator

Fig. 3.3c. Actual energy consumption by Energy meter

Fig. 3.3d. Recording of tube well and field data

Fig. 3.3e. Measurement of electrical parameters

Fig. 3.3f. Different measurements of tube well

Fig. 3.3: An overview of different measurements at pumping sets to quantify different mechanical factors responsible for energy losses and information of respondent farmers

3.2.5 Pumping set data collection:

All the information related to pumping set, owner of the pumping set and their land holding were recorded. For this a questionnaire (Annexure-I) was prepared and used as research tool for data collection as per objectives of the study. A total of 65 respondents were interviewed in their native language in order to get accurate information (Fig. 3.3d).

3.3 Experimental procedure

3.3.1 Bernoulli's equation

Bernoulli's equation which basically describes the energy conservation law for in-viscid flow in a piping system is used to obtain the characteristic curve of a system.

3.3.2 Pressure loss

The pressure losses occur due to the friction of the liquid particles against each other (shear forces) and the pipe walls. Due to this friction, there would be a significant energy loss that could have been transferred to the useful work. In general, the pressure losses appear in two forms in a piping system *viz.* linear (in straight pipes) and local (in valves, bends, and other pipe fittings).

3.3.3 Empirical relation for calculating pressure loss

Among the numerous empirical relations suggested for calculating the pressure loss in the straight pipes, the most commonly used relation is Hazen-Williams relation.

$$\boldsymbol{H_L = 10.64\,\mathrm{L}\left(\frac{\mathrm{Q}}{\mathrm{C}}\right)^{1.85}\frac{1}{\mathrm{D}^{4.87}}} \qquad (3.2)$$

Where, Q is the flow rate in $m^3 s^{-1}$, L and D are the length and diameter of the pipe in m, H_L is the pressure loss in 1m length of the pipe and C is the Hazen-Williams constant which depends on the relative roughness of the pipe. The values for C for some pipe materials and pressure loss factor for different pipe roughness are given in Table 3.1 and 3.2.

Table 3.1: Values for C used in Hazen-Williams relation

Pipe Type	**Average value for C**	**Design value of C**
Very smooth pipes, like asbestos pipes	150	140
Smooth pipes like copper and brass pipes	140	130
Seamless steel pipes	140	110
Steel or commercial pipes	130	100
Cast iron pipes	130	100
Cement pipes	120	100
Rough iron pipes with many years in service	100	80

Table 3.2: Pressure loss factor for different pipe roughness

Pipe Type	**Multiple by**
For new steel pipes	0.80
For very rough pipes	1.70
For old and rusty steel pipes	1.25

3.3.4 Direct method

In this method the pressure loss in the piping system is obtained from the following relation. Once K and flow velocity are known, the pressure loss is calculated and added to the pressure loss for straight pipe. It is given by the following equation:

$$\mathbf{H_L = K\,\frac{V^2}{2g}} \tag{3.3}$$

Where, K is the resistance coefficients and its value for different fittings has been used (Nourbakhsh *et al*., 2008).

3.4 Different parameter measurements

The following parameters were measured to determine the overall pumping efficiency and to evaluate the performance of selected pumping systems.

3.4.1 Measurement of total head

The total head of a submersible pump was determined as under:

$$\mathbf{H = W_p + H_f + H_v + K_f\frac{V^2}{2g} + H_b + H_t} \tag{3.4}$$

Where,

W_p = Pumping water level, m

H_f = Head loss due to friction, m

H_v = Velocity head, m (*i.e.*$\frac{V^2}{2g}$)

$K_f\frac{V^2}{2g}$ = Head loss due to fittings of pipe, m

H_b = Head loss due to bend, m

H_t = Height of delivery pipe from the ground surface, m

3.4.2 Pumping water level (W_p)

The pumping water level was measured in running condition of the tube wells. It was measured with the help of electronic water level indicator.

3.4.3 Head loss due to friction (H_f)

The head loss due to friction was estimated by using Hazen-Williams Equation (3.4).

3.4.4 Velocity head (H_v)

The velocity head was estimated as under:

$$\mathbf{H_v = \frac{V^2}{2g}} \tag{3.5}$$

Where,

V: Velocity of water in the pipe during the pumping m s^{-1}

g: 9.81 m s^{-1}

3.4.5 Head loss due to fittings ($K_f\frac{V^2}{2g}$)

The head loss due to different type of fittings were calculated by using equation (3.3).

3.4.6 Head loss due to bend (H_b)

The head loss due to bend is calculated by referring table (Murty, 1982) which gives straight pipe length (meters) equivalent of resistance to flow in valves and fitting. The equivalent straight length of pipe for different types of bends and this length can be directly put in equation (3.4).

3.4.7 Height of delivery pipe from the ground surface (H_t)

It was measured with the help of measuring tape in (m).

3.4.8 Material of delivery pipe

The material of delivery pipe (GI/PVC) was also considered for calculating the head loss due to friction.

3.4.9 Age of delivery pipe

The age of G.I. pipes (new/old) was noted down and used in calculation of head loss due to friction. Table 3.2 gives pressure loss factor for different pipe roughness.

3.4.10 Measurement of discharge (Q)

The discharge ($l\ s^{-1}$) was measured using L-shaped gauge.

3.4.11 Measurement of electrical parameters

The electrical parameter voltage was measured with the help voltmeter.

3.4.12 Estimation of water horse power (WHP)

It is a theoretical horse power for pumping set. It is the head and capacity of the pump expressed in terms of the horse power.

$$\mathbf{WHP} = \frac{\mathbf{Q} \times H}{76} \tag{3.6}$$

Where,

Q: flow rate ($l\ s^{-1}$)

H: (net static head + velocity head at suction and discharge + friction losses due to fittings and length of pipe) (m)

3.4.13 Input horse power (IHP)

The horse power given to the pump by the power source. It is indicated on prime mover by the manufacturing company.

3.5 Estimation of different pumping efficiency

3.5.1 Over all pumping plant efficiency (%)

The overall pumping plant efficiency is the efficiency of the entire pumping unit. It takes into account all the losses in the pumping system. The overall efficiency of tube well was estimated based on motor horse power and actual power consumption. This is given by,

$$\eta_{MHP} = \frac{WHP}{Motor\ horse\ power} \tag{3.7}$$

$$\eta_{PC} = \frac{0.746 \times WHP}{Actual\ measured\ power\ consumption} \tag{3.8}$$

Where,

η_{MHP}: Efficiency based on motor horse power (%)

η_{PC}: Efficiency based on actual measured power consumption (%)

3.5.2 Expected minimum pumping efficiency based on performance chart of pump

Expected minimum efficiency was also determined based on BIS code IS 8034:2002. Knowing the number of stages for different pump sets (which was obtained from the farmers during survey), the head per stage was determined by dividing the total head with number of stages. Then, using the value of head per stage (m) and discharge (l s^{-1}) for pump sets minimum efficiency was determined from standard charts given in BIS code IS 8034:2002 and same is given in Fig. 3.4. When the point-based head and discharge lied in between the two efficiency lines, the higher value was taken as minimum efficiency as per the instructions in the standards. The efficiency in charts represents efficiency for three or more stages. For two stage pumps, efficiency was multiplied by a factor of 0.98 and 0.97 for single stage pump as per instructions. After that it was multiplied by the motor efficiency factor given in Table 3.3. The motors used for bore sizes more than 200 mm, motor efficiency factor was taken same as that for 200 mm as per instructions which suggests that it should be declared separately by the manufacturers and it shall not be less than the motor efficiency factor of motors of same rating for 200 mm bore size.

Overall minimum expected efficiency of the pump set as per BIS chart, was given by multiplying it by corresponding factor based on number of stages and the corresponding motor efficiency factor.

$$\eta_{min.} = \eta_{chart} \times f_n \times f_m \tag{3.9}$$

Where,

η_{min}: minimum expected efficiency (%)

η_{chart}: expected efficiency from chart based on head per stage and discharge

f_n: efficiency factor based on number of stages

f_m: motor efficiency factor

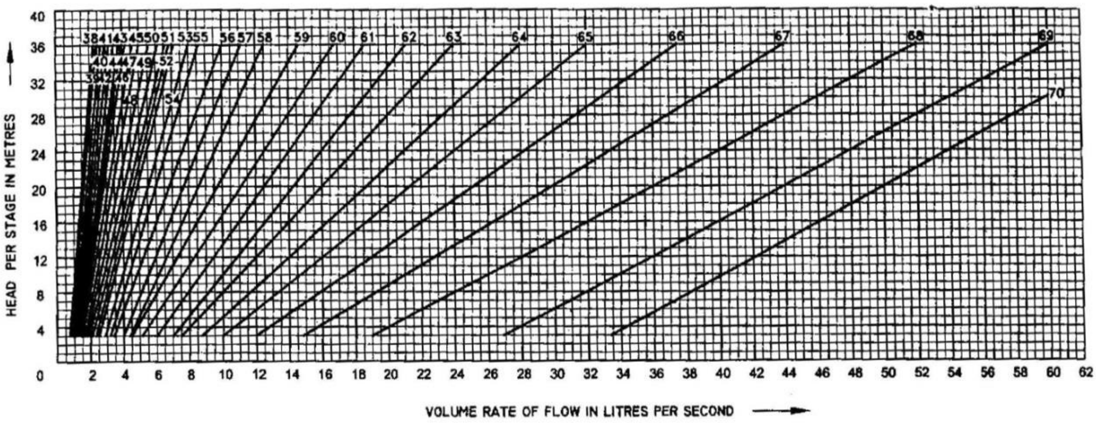


Fig. 3.4: Standard performance chart for minimum expected efficiency (%) for submersible pump sets

Table 3.3: Three phase motor efficiency factor

Motor rating, kW	Three phase motor efficiency factor		
	Nominal bore size, mm		
	100	150	200
1.1	56	57	-
1.5	60	66	-
2.2	63	67	69
3.0	63	67	69
3.7	64	68	70
4.5	-	70	72
5.5	-	73	75
7.5	-	74	76
9.3	-	75	77
11.0	-	76	78
13.0	-	77	79
15.0	-	78	80

3.5.3 Estimation of electrical energy consumption at farmers' field

Actual electrical energy consumption per hour was measured at individual farmer's tube well. Thus, total electricity consumption per ha was estimated by multiplying the total time of irrigation to per hour energy consumption.

3.5.4 Assessment of current status of energy utilization for groundwater pumping for major crops

Block wise data of both *kharif* and *rabi* crop season during 2018 and 2018-2019 were collected from Department of Agriculture, Sonepat. The energy utilization for major crops was assessed by using different observations such as electricity consumption (kWh), crop irrigation requirement, net and gross irrigation requirements, application efficiency, rainfall data, number of irrigations for different crops etc.

3.6 Field experiments at KVK, farm

A field experiment during *rabi* 2017-18 and 2018-19 was undertaken to examine the effect of different irrigation practices on water and energy consumption in wheat crop at research farm of CCS HAU KVK Sonepat by conducting field experiments. The different irrigation methods (Check basin, border flood and micro sprinkler irrigation) and agricultural practices (zero tillage, conventional tillage and laser guided land levelling) were evaluated in terms of water use and electrical energy consumption. The soil of KVK research farm was loamy sand in texture having marginally alkali under groundwater (Soil and water testing laboratory, CCSHAU, Hisar) and source of irrigation was only groundwater. The average groundwater table depth at the farm during *rabi* 2017-18 and 2018-19 was 17.68 m.

3.6.1 Experimental Details

Comparative performance of different treatments in terms of volume of water pumped and energy utilized was evaluated in wheat crop. The irrigation water was applied by electric submersible tube well installed at KVK, farm. The five treatments were selected as given in Table 3.4 having further details as given below:

- In treatment T_1, pre-sowing irrigation was applied after harvesting of paddy crop without any tillage operation and the slope of this field was zero.
- In treatment T_2, field was prepared with the help of conventional tillage implements (Fig 3.7a).
- In treatment T_3, the field was levelled with the help of laser guided land leveller and a longitudinal slope of 0.3% was given with the help of laser eye and cross staff of laser guided land leveller (Fig 3.7b & c) as per the recommended slope, which in sandy soil is 0.2 to 0.4% as per package of practices of CCS HAU, Hisar. The land slope of 0.3% was given, as per design criteria of loamy sand soil at experimental site.
- In treatment T_4, micro-sprinkler irrigation having line to line spacing of 8 m and spacing between two sprinklers sets was also 8 m. The average nozzle discharge of 8.33 l min^{-1} with average operating pressure of 1.5 Kg cm^{-2} and distribution efficiency of 95.08 and 94.36% was recorded at the time of 1st irrigation during the year 2017-18 & 2018-19, respectively at wind speed ranging between 1.1-1.8 m s^{-1}. The sprinklers mounted on outermost lateral lines were operated in part circle mode (180^0) to avoid flow of irrigation water outside the intended area. Further, a buffer zone of 6 m was maintained between treatment T_4 and other treatments.
- In treatment T_5, field was kept as per general practices adopted by farmers on their fields. *i.e*. without any slope or land levelling.

Similar tillage and land preparation operations were performed in all the four treatments except T_1 where no tillage operation was performed. Field plots of 10 m × 40 m size for border and micro sprinkler irrigation were selected.

In farmers’ practice, the plot size was 0.133 ha (20.12 m × 67.06 m), which was selected on the basis of general practice adopted by the farmers of Rai and Sonepat blocks for border irrigation, using groundwater pumping system, operated by electricity. Generally, farmers’ land holdings and field boundaries are divided into acres with each field being approximately of one acre (0.4 ha) and majority of the farmers in these blocks do not divide their one-acre field into parts for border irrigation, although some farmers divide it in two parts. None of the farmers divide their field in four or more than four parts. So, one third part of 0.4 ha (1 Acre = 0.4 ha) area was considered as the standard plot size of farmer's practice in this study.

The layout of experiment consisted of five treatments with three replications (Fig. 3.5) as per Randomized complete block design for statistical analysis. The plot codes are assigned to different plots as given in Table 3.4.

Table 3.4 Plot code and plot size for different methods of irrigation in wheat crop

Plot No.	Plot description	Plot code	Plot size (m^2) W(m) ×L(m)
1.	Check basin irrigation with zero tillage having zero slope	T_1	10 × 40
2.	Border irrigation with conventional tillage	T_2	10 × 40
3.	Border irrigation with laser guided land leveling having 0.3% slope	T_3	10 × 40
4.	Micro sprinkler irrigation	T_4	10 × 40
5.	Farmer's practice	T_5	20.12 × 67.06

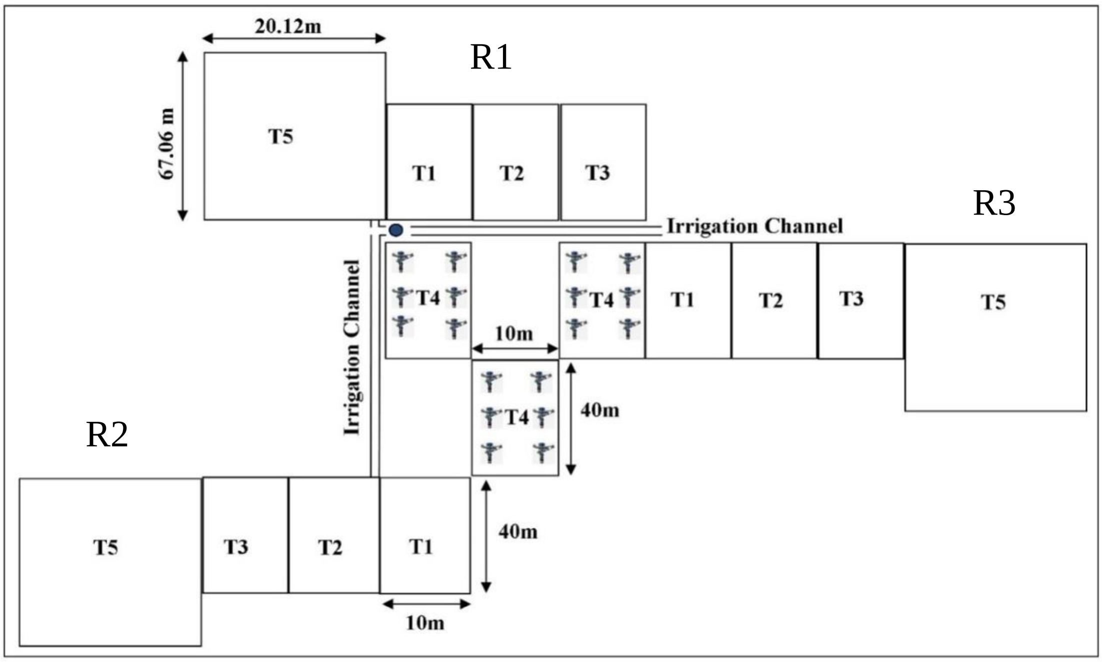


Fig. 3.5: Layout of field experiment

3.6.2 Measurement of advance and recession time

Water advance and recession time (Fig. 3.9c, d, e & f) for check basin, border irrigation and farmer's practice treatment (T_1, T_2, T_3 and T_5) was measured by inserting wooden stakes at regular interval of 10 m along the length of different plots. Layout and placement of wooden stakes for measuring water advance and recession time in field is shown in Fig. 3.6. The time taken by the water to reach to different stakes since turning on the inflow stream into the border strip was recorded. Similarly, the time at which water receded from different stakes was also noted down. The difference between the time when the water front reached a particular point along the plot and the time at which the water receded from the same point was taken as the infiltration opportunity time.

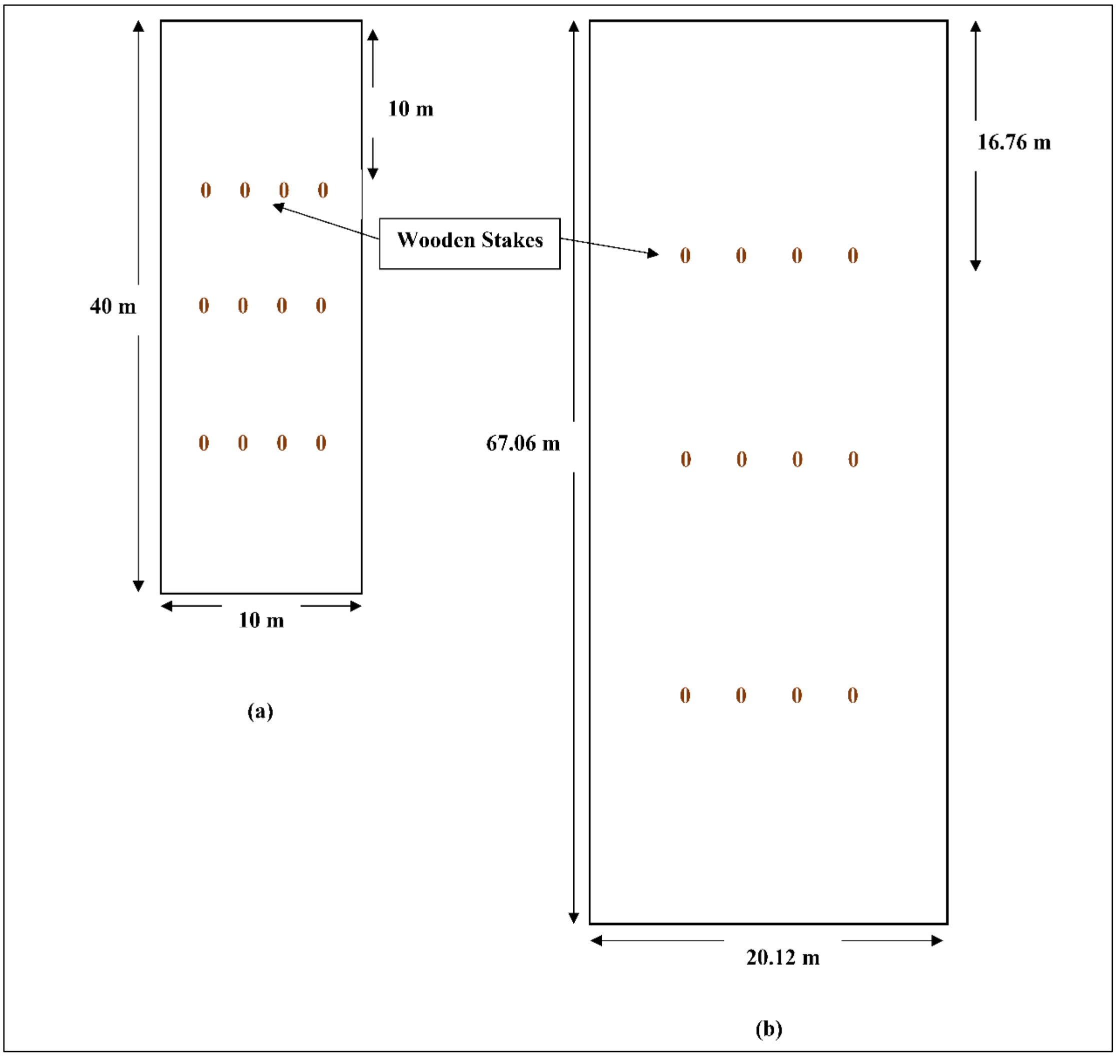


Fig. 3.6: Layout and placement of wooden stakes for measuring water advance and recession in treatments (a) T_1, T_2 and T_3 and (b) T_5

3.7 Standard package of practice

3.7.1 Sowing of crop

Wheat variety HD-2967 was selected for sowing. T_1 was sown with the help of zero tillage seed cum Fertilizer drill (Fig. 3.7d) and T_2 to T_4 were sown by using seed cum fertilizer drill (Fig. 3.7e). T_5 was sown by broadcasting of seed followed by cultivator and planking (Fig. 3.7f)

Fig. 3.7a. Conventional land levelling equipment

Fig. 3.7b. Procedure for formation of land slope

Fig. 3.7c. Laser guided land levelling

Fig. 3.7d. Wheat sowing by zero tillage

Fig. 3.7e. Wheat sowing by seed cum fertilizer drill

Fig. 3.7f. Wheat sowing by broadcasting followed by cultivator and planking

Fig. 3.7: An overview of agricultural practices to quantify different management factors responsible for energy losses

3.7.2 Irrigation schedule

The appropriate schedule for irrigating wheat crop was followed as per recommendations of package of practices of CCS HAU, Hisar (Table 3.5). During the crop growth period, six irrigations were applied including pre-sowing irrigation in different treatments.

Table 3.5: Irrigation schedule of different irrigation events in 2017-18 and 2018-19

Irrigation event	**Experimental year**	
	2017-18	**2018-19**
Pre sowing irrigation	10-12 November	06-08 November
Ist irrigation	15-17 December	12-14 December
IInd irrigation	11-13 January	04-06 January
IIIrd irrigation	03-05 February	30 January-01 February
IVth irrigation	23-25 February	22-24 February
Vth irrigation	15-17 March	16-18 March

3.7.3 Agronomic practices

All the agronomic practices *i.e.* applications of chemical fertilizer, weedicide and other inputs were kept same in all the treatments. Selected meteorological observation during the experimental period were taken from metrological observatory and is depicted in Fig. 3.8.

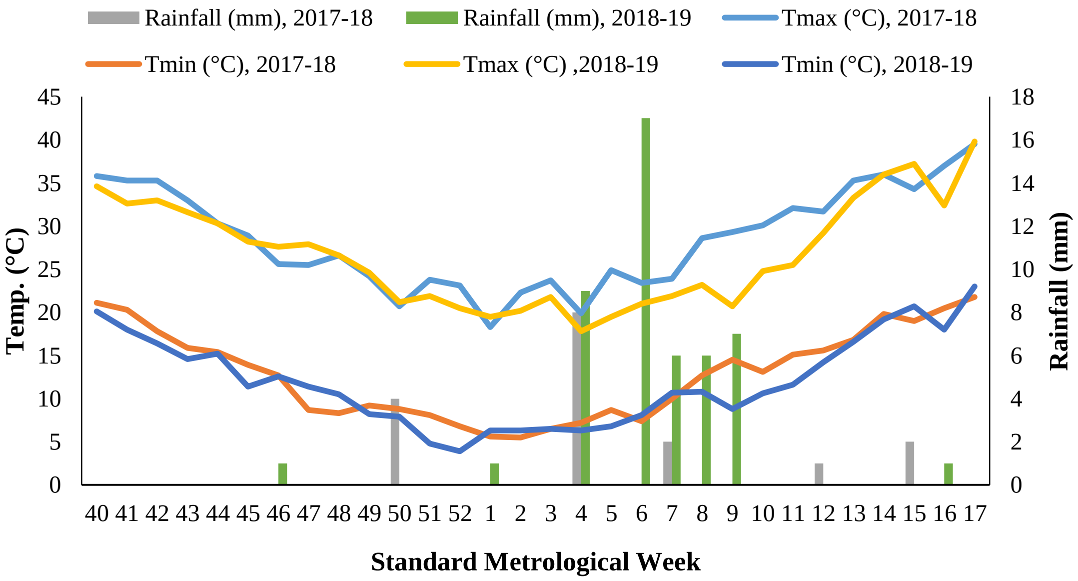


Fig. 3.8: Meteorological data during *rabi* 2017-18 and 2018-19

3.7.4 Yield

At harvest random samples (1m length × 1m width plot area) were taken from three locations of each plot to determine yield which were then converted to per ha values. Both straw and grain yields were recorded separately.

3.8 Field observations / measurements

3.8.1 Field capacity

Five undisturbed soil samples up to the depth of 120 cm (0-15, 15-30, 30-60, 60-90, 90-120 cm) were collected with the help of metal core. These samples were tested to determine field capacity by pressure plate membrane apparatus in laboratory of Dept. of Soil Science, CCSHAU, Hisar, as per standard procedure.

3.8.2 Soil and water parameters

Soil texture was determined by using international pipette method up to the soil depth of 120 cm. The soil types of the experimental site were loamy sand for depths 0-15, 15-30, and 30-60 cm and sand for depths 60-90 and 90-120 cm. The quality of water was found to be marginally alkali having pH 8.10. Soil samples from surface (0-15 cm) of all the 65 farmers' field selected for study of electric submersible tube wells in Rai and Sonepat blocks were also collected and analysed for soil textural classification using the same method for upper soil layer (0-15 cm).

3.8.3 Soil moisture

Soil samples were taken before and after each irrigation at soil depth of 0-15, 15-30, 30-60, 60-90 and 90-120 cm from each plot with the help of auger (Fig. 3.9a). The wet samples were weighted in the field. Soil samples were then dried in oven for 24 hours at 105ºC. The moisture content on dry weight basis was calculated as under

$$\boldsymbol{\theta} = \frac{\mathbf{W_W - W_D}}{\mathbf{W_D}} \times \mathbf{100} \tag{3.10}$$

Where,

θ: Soil moisture content on dry weight basis.

W_W: Wet weight of soil sample (g)

W_D: Dry weight of soil sample (g)

3.8.4 Infiltration rate

Infiltration measurements were made till reaching constant infiltration rate with the help of a single cylinder infiltrometer. During first hour, the readings were recorded after 2 min, 5 min, 10 min, 20 min, 30 min and after 1 hour. Then, hourly readings were recorded up to constant infiltration rate before each irrigation event (Fig 3.9 b). Measured infiltration data then were fitted to the Kostiakov Infiltration equation (Michael, 2008)

$$\mathbf{I = k\,t^{n}} \tag{3.11}$$

Where,

I: Cumulative depth of water infiltrated (cm)

k: Constant of Kostiakov equation

t: Cumulative time (min.)

n: Exponent of Kostiakov equation

Fig. 3.9a. Soil sampling for moisture content

Fig. 3.9b. Infiltration measurements in wheat field

Fig. 3.9c. Water advance measurement in zero tillage field

Fig. 3.9d. Water advance measurement in laser levelled field

Fig. 3.9e. Water advance measurement in conventional tillage field

Fig. 3.9f. Water recession measurement in laser levelled field

Fig. 3.9: An overview of measurements during performance evaluation of different irrigation methods

3.8.5 Inflow stream discharge

The discharge of tube well was measured with the help of water meter fitted at the pumping set of KVK, Sonepat, farm.

3.8.6 Bulk density

Bulk density was determined using mass volume relationship of the soil up to depth 120 cm (0-15, 15-30, 30-60, 60-90, 90-120 cm). Metal core of volume 1013 cm^3 was used for carefully collecting undisturbed soil samples and dried in oven for 24 hours at 105^0C to determine the dry weight of soil. Bulk density was calculated as under:

$$\mathbf{P_b = \frac{W_D}{V}} \tag{3.12}$$

Where,

P_b: Bulk density (g cm^{-3})

W_D: Dry weight of soil sample (g)

V: Volume of soil sample (cm^3)

3.8.7 Required net depth of the irrigation

Required net depth of the irrigation was estimated by following formula:

$$\mathbf{d_n = \frac{(\theta_{fc} - \theta_{bi}) \times P_b \times R.D}{100}} \tag{3.13}$$

Stored net depth of the irrigation was estimated by following formula:

$$\mathbf{d_s = \frac{(\theta_{ai} - \theta_{bi}) \times P_b \times R.D}{100}} \tag{3.14}$$

Where,

d_n: required net depth of the irrigation (cm)

d_s: stored net depth of the irrigation (cm)

θ_{fc}: moisture content at field capacity (%)

$\theta_{bi:}$ average moisture content before irrigation (%)

$\theta_{ai:}$ average moisture content after irrigation (%), taken 48 hours after irrigation

P_b: bulk density (g cm^{-3})

RD: root zone depth (cm), *RD for wheat was taken as 90 cm

3.8.8 Applied depth of the irrigation

Applied depth of the irrigation was calculated using Kostiakov equation. Exponent and constant of Kostiakov equation calculated from infiltration rate of the plot observed just before respective irrigation event and corresponding infiltration opportunity time of the respective plots were used to compute the applied depth of irrigation.

3.8.9 Depth of water delivered to the plot

Depth of water delivered to the plot was estimated as volume of water delivered (discharge × cut off time of plot) to the plot divided by the area (length × width) of the plot.

3.8.10 Electrical energy consumption

The time spent to irrigate the plot was noted down (time at which stream inflow closed -time at which stream inflow opened) in minutes and corresponding kWh consumed by the energy meter installed at pumping set were measured. Similarly, electrical energy utilized for each plot was calculated.

3.8.11 Micro sprinkler irrigation

In micro sprinkler applied depth was fixed at 6 cm for all the irrigations and schedule of irrigation was kept similar to other treatments.

3.8.12 Measurements of micro sprinkler parameters

Nozzle discharge, operating pressure and uniformity coefficient of micro sprinkler system were measured during the irrigation event.

3.8.13 Water use efficiency

Irrigation water use efficiency for grains ($\mathrm{WUE_{Grain}}$)was calculated by dividing the respective yield by the total irrigation depth applied in the treatment. It is given by,

$$\mathbf{WUE_{Grain}} = \frac{\mathbf{Yield\ (q)}}{\boldsymbol{Total\ irrigation\ depth\ applied\ (ha\text{−}cm)}} \tag{3.15}$$

3.9 Performance evaluation parameters

The performance of the border irrigation system was evaluated by estimating the water application and distribution efficiency. The performance of micro sprinkler was also evaluated by estimating uniformity coefficient of the system.

3.9.1 Water application efficiency (E_a)

It was estimated as the ratio of water stored in the root zone to the water delivered to the field (Michael, 2008),

$$\mathbf{E_a} = \frac{\mathbf{W_S}}{\mathbf{W_f}} \times \mathbf{100} \tag{3.16}$$

Where,

W_s: water stored in the root zone (cm)

W_f: water delivered to the field (cm)

3.9.2 Water distribution efficiency (E_d)

The water distribution efficiency (Ed) denotes the degree of uniformity in the amount of water infiltrated into the soil. It was estimated by following formula:

$$\mathbf{E_d} = \mathbf{100}\ [\mathbf{1} - \frac{Y}{\mathbf{D}}] \tag{3.17}$$

Where,

Y: average absolute numerical deviation in depth of water stored from average depth stored during the irrigation (cm)

D: average depth of water stored during irrigation (cm)

The status of crop growth under different treatments at the time of selected irrigation events is shown in Fig. 3.10, 3.11 and 3.12.

Fig. 3.10: Photograph of crop growth in different field plots (Treatment T_1 to T_5) at the time of I^{st} irrigation

Fig. 3.11: Photograph of crop growth in different field plots (Treatment T_1 to T_5) at the time of IIIrd irrigation

Fig. 3.12: Photograph of crop growth in different field plots (Treatment T_1 to T_5) at the time of V^{th} irrigation

3.9.3 Soil moisture of selected farmer's field:

Soil samples from the fields of 10 selected farmers, (five from each block) were collected twice during the period of wheat crop. First, before and after first irrigation and similarly, at fourth irrigation. The wet samples were weighted at the farmers field and then dried in oven for 24 hours at 105^0C to determine the dry weight of soil at Soil testing laboratory of KVK, Sonepat.

3.9.4 Estimation of application efficiency for selected irrigation events at farmers' field

Discharge of tube well, net depth of irrigation required, actual depth of irrigation applied and time of operation of submersible Tube well were measured at each selected farmer's field. This was used to determine the application efficiency at farmer's field.

3.9.5 Assessment of potential energy saving

After quantification of different mechanical and management factors responsible for energy losses, suitable remedial measures for energy conservation were identified. By application of these measures actual energy requirement for a unit area is calculated. The difference of present energy utilized and actual energy required per unit area is termed as energy saving. Therefore, potential energy saving of a particular area under specific crop can be assessed by multiplying the energy saving per unit area to the total area under that crop (Jhorar and Guru Prem, 2008). Energy requirement for different crops was estimated by the given formula:

$$\mathbf{E} = \frac{\mathbf{27.27 \times H}}{\mathbf{Pumping\ Eficiency}} \times \text{ Water pumped (ha} - \text{m)} \qquad (3.18)$$

Where,

E: Energy (kWh)

H: Head (m)

3.10 Statistical analysis

The data were analysed by using Randomized complete block design (Panse and Sukhatme, 1985). The treatment differences were tested by using 'F' test of significance on the basis of null hypothesis. The standard error of mean (SEm±) was calculated in each case and the critical difference (CD) at 5% level of significance was determined for significant results. Critical difference (CD) is given by:

$$\mathbf{C.D. = S.E._d \times 't'} \qquad (3.19)$$

Where,

$S.E._d$ = Standard error of the difference of treatment means

't' = Tabulated 't' value at error degree of freedom at 5% level of significance

CHAPTER-IV

RESULTS

The key results obtained from the present research work on scope of energy conservation for groundwater pumping are given in this chapter. The results thus obtained are presented with the help of appropriate tables and suitable illustrations under the following heads:

4.1 Field measurements of different parameters of existing tube wells with respect to energy utilization

4.2 Quantification of management factors responsible for energy losses

4.3 Estimation of energy consumption and potential energy saving for groundwater pumping in the study area

4.1 Field measurements of different parameters of existing tube wells with respect to energy utilization

Current status of energy utilization for groundwater pumping for irrigating major crops was assessed by recording relevant information/observation at farmers' field. A total of 65 submersible electricity powered pump sets (30 from Sonepat and 35 from Rai blocks) covering 63 villages were selected. Main data collected for evaluating efficiency of submersible pumps consisted of primary data of pump sets, pumping water level, tube well discharge, supply voltage and electrical power consumption.

4.1.1 Primary data of pumping sets

Primary data related to the 65 sampled submersible pump sets (*i.e.* tube well number 1 to 30 from Sonepat and 31 to 65 from Rai blocks) was collected by means of survey and direct measurements at selected farmers' field. Data like name of owner of field, name of village, length, height, diameter and material of delivery pipe were recorded/measured. The bore diameter, column pipes diameter, column pipe material and type of well were also recorded. Primary information of different tube wells is given in Table 4.1 and 4.2 for Sonepat and Rai block, respectively.

4.1.2 Pumping water level and tube well discharge

Each tube well was operated for about one hour before making every measurement. The measured value of depth of pumping water level & estimated value of tube well discharge based on coordinate method is given in Table 4.3 and Table 4.4 for Sonepat and Rai block, respectively.

Table 4.1: Details of pipe diameter and material used in different tube wells of Sonepat block

Tube well No.	Name of farmer	Village	Bore dia., cm	Delivery pipe				Column pipe			*Type of tube well
				Material	Dia., cm	Height, m	Total length, m	Material	Dia., cm	Length, m	
1	Rohtash	Jahri	22.5	G.I.	7.5	0.7	2.2	G.I.	7.5	51.83	C
2	Narender	Tharu	22.5	G.I.	7.5	0.7	6.0	PVC	7.5	38.11	C+F
3	Rajbir	Sahajadpur	22.5	G.I.	7.5	1.0	2.6	G.I.	7.5	33.54	C+F
4	Neeraj	Kilorad	22.5	G.I.	7.5	0.5	2.3	G.I.	7.5	35.06	C+F
5	Krishan	Uldepur	22.5	G.I.	7.5	0.8	2.2	G.I.	7.5	39.63	C+F
6	Rohtash	Tharya	17.5	G.I.	7.5	0.9	4.1	HDPE	7.5	42.68	C+F
7	Dharam	Sandal Kalan	22.5	G.I.	7.5	0.7	2.2	PVC+G.I	7.5	51.83	C+F
8	Ravinder	Sandal Kalan Nawada	22.5	G.I.	7.5	0.8	4.8	PVC	7.5	51.83	C+F
9	Rajender	Sandal Khurrd	22.5	G.I.	7.5	0.6	2.5	HDPE	7.5	39.63	C+F
10	Naresh	Bhadana	22.5	G.I.	10.0	0.5	3.6	HDPE	7.5	21.34	C
11	Ravinder	Kakroi	22.5	G.I	10.0	0.8	2.4	HDPE	7.5	19.82	C
12	Ishwar	Mehlana	22.5	G.I	10.0	0.9	4.4	HDPE	10	21.34	C
13	Ramkawar	Tihar Kalan	22.5	G.I	7.5	0.4	2.1	HDPE	7.5	19.82	C
14	Jitender	Tihar Khurd	22.5	G.I	7.5	0.4	2.0	G.I	7.5	76.22	C+F
15	Naresh	BhatgaonMalyan	22.5	G.I	7.5	0.9	2.8	HDPE	10	18.29	C
16	Angrej	SalimsarMajra	22.5	G.I	10.0	1.1	2.4	HDPE	7.5	18.29	C
17	Jagbir	Mahipur	22.5	G.I	7.5	0.9	5.2	HDPE	7.5	19.82	C
18	Paramjeet	BhatgaonDungran	22.5	G.I	7.5	0.7	2.4	HDPE	7.5	16.77	C
19	Virender	Rattangarh	22.5	G.I	7.5	1.1	2.4	HDPE	7.5	15.24	C
20	Jitender	BhatanaJafrabad	22.5	PVC	10.0	0.7	1.7	HDPE	10	33.54	C+F
21	Ajit	Chitana	22.5	G.I	10.0	0.6	2.5	HDPE	7.5	33.54	F
22	Narender	Juan-1	22.5	G.I	10.0	0.4	1.8	HDPE	7.5	24.39	C
23	Ved Singh	Juan-2	22.5	PVC	10.0	0.8	1.8	HDPE	10	30.49	C
24	Meena	SalimpurTrauli	22.5	G.I	7.5	0.5	1.5	HDPE	7.5	15.24	C
25	Jitender	Hullaheri	15.0	G.I	7.5	1.2	2.9	G.I	7.5	15.24	C
26	Jitender	Barwasni	22.5	PVC	10.0	0.9	3.2	HDPE	10	16.77	C+F
27	Balwan	Chatiya -Oliya	22.5	G.I.	7.5	0.6	2.5	G.I.	7.5	39.63	C+F
28	Samsher	Krewari	22.5	G.I.	10.0	0.8	2.2	HDPE	7.5	21.34	C
29	Sukhbir	Machari	22.5	G.I	7.5	0.5	3.6	HDPE	7.5	19.82	C
30	Satyawan	Mahra	22.5	PVC	10.0	0.9	2.8	HDPE	10	30.49	C+F

*C: Cavity tube well F: Filter tube well C+F: Both cavity & filter

Table 4.2: Details of pipe diameter and material used in different tube wells of Rai block

Tube well No.	Name of farmer	Village	Bore dia., Cm	Delivery pipe				Column pipe			*Type of tube well
				Material	**Dia., cm**	**Height, m**	**Total length, m**	**Material**	**Dia., cm**	**Length, m**	
31	Satpal	Jagdishpur	22.5	G.I.	12.5	0.6	4.6	HDPE	7.5	19.8	F
32	Rajender	Harsana	15.0	G.I.	10.0	1.0	2.9	G.I.	7.5	18.3	C
33	Surender	Bhovapur	22.5	G.I.	10.0	0.6	8.2	HDPE	10	24.4	F
34	Anil	Aterna-1	22.5	G.I.	10.0	0.7	2.0	HDPE	7.5	27.4	F
35	Arun	Manoli	22.5	G.I.	7.5	0.8	2.6	HDPE	7.5	30.5	F
36	Rajesh	BhairaBakipur	22.5	G.I.	7.5	0.7	4.0	HDPE	7.5	24.4	F
37	Bhagirath	Pubsera-1	22.5	G.I.	10.0	0.9	2.6	HDPE	7.5	24.4	F
38	Satpal	Aurangabad	22.5	G.I.	7.5	1.0	2.6	G.I	7.5	35.1	F
39	Braham	Dahisara	22.5	G.I	10.0	1.0	2.9	HDPE	10	25.9	F
40	Suresh	Jakholi	22.5	G.I.	10.0	0.7	2.3	HDPE	7.5	32.0	F
41	Rajesh	Jatheri	17.5	G.I.	7.5	0.9	2.1	G.I	7.5	33.5	C
42	Anil	Khatkar	22.5	G.I.	10.0	0.4	5.0	HDPE	7.5	24.4	C
43	Jaiveer	Toki	22.5	G.I	10.0	0.5	4.4	HDPE	10	24.4	F
44	Sudesh	Rathdhana	17.5	G.I	10.0	1.0	3.1	HDPE	7.5	35.1	F
45	Chotu Ram	Nangal Kalan	20.0	G.I	7.5	0.9	4.3	HDPE	7.5	38.1	F
46	Surender	Patla	22.5	G.I	7.5	0.9	9.2	G.I	7.5	30.5	F
47	Amit	Liwan	22.5	G.I	10.0	0.7	3.5	HDPE	10	35.1	C+F
48	Rajesh	Saboli	22.5	G.I	7.5	0.5	4.3	HDPE	7.5	30.5	C+F
49	jagbir	Bindrauli	22.5	G.I	10.0	0.6	3.8	HDPE	10	24.4	C
50	Narender	Ladpur	22.5	G.I	10.0	0.9	2.3	HDPE	10	21.3	C
51	Mahender	Safiyabad	17.5	G.I	10.0	0.5	2.0	HDPE	7.5	24.4	C+F
52	Dharam	Garhibala	22.5	G.I	7.5	0.6	1.6	HDPE	7.5	19.8	C
53	Karambir	Nasirpur	22.5	G.I	10.0	0.8	2.4	HDPE	10	24.4	C
54	Baldev	Barauta	22.5	G.I	7.5	0.8	3.9	HDPE	7.5	21.3	C
55	Prem Parkash	Jajal	22.5	G.I	10.0	0.7	2.4	HDPE	10	38.1	C
56	Rajender	Chhathera	17.5	G.I	7.5	0.9	3.4	HDPE	7.5	27.4	C+F
57	Vinod	Munirpur	22.5	G.I	10.0	1.0	3.4	HDPE	7.5	24.4	C+F
58	Hawa Singh	Jhundpur	17.5	G.I	7.5	0.4	1.5	G.I	7.5	29.0	C
59	Prem	Jagdishpur- Tanada	22.5	G.I	10.0	0.7	2.4	HDPE	7.5	24.4	F
60	Dilbag	Tanda	22.5	pvc	10.0	0.5	3.5	HDPE	7.5	33.5	F
61	Omkawar	Khewra	22.5	G.I	7.5	0.7	3.3	G.I	7.5	38.1	C+F
62	Sube Singh	Aterna-2	22.5	G.I	10.0	0.7	2.9	HDPE	7.5	27.4	F
63	Med Singh	Pubsera-2	22.5	G.I	7.5	0.7	4.9	HDPE	7.5	33.5	F
64	Deepak	Deepalpur	22.5	G.I	7.5	0.8	3.5	G.I	7.5	36.6	F
65	Sanjay	Mukimpur	17.5	G.I	7.5	0.9	3.1	G.I	7.5	36.6	F

*C: Cavity tube well F: Filter tube well C+F: Both cavity &filter

Table 4.3: Horizontal distance of water jet (x coordinate) corresponding to 15 cm vertical drop of water jet estimated discharge & pumping water level for selected tube wells of Sonepat block

Tube well No.	Value of x- coordinate, cm	Pumping water level depth below ground surface, m	Discharge, l s^{-1}
1	48.0	44.21	11.82
2	32.9	34.51	8.10
3	39.0	27.44	9.60
4	32.8	30.18	8.07
5	42.6	32.20	10.49
6	26.1	39.02	6.43
7	27.2	47.56	6.70
8	23.6	46.95	5.81
9	21.1	32.99	5.19
10	36.0	12.44	15.75
11	39.5	11.98	17.29
12	19.5	13.11	8.53
13	36.0	15.00	8.86
14	26.5	22.62	6.52
15	66.9	14.91	16.47
16	27.2	5.79	11.90
17	90.1	15.09	22.18
18	65.2	12.10	16.05
19	61.2	5.79	15.07
20	41.2	16.71	18.03
21	41.6	22.10	18.21
22	47.2	18.41	20.66
23	53.5	21.01	23.41
24	56.8	9.00	13.98
25	58.5	9.80	14.40
26	53.8	11.49	23.54
27	43.6	31.89	10.73
28	38.9	12.96	17.02
29	68.8	15.21	16.94
30	43.4	17.32	18.99

Table 4.4: Horizontal distance of water jet (x coordinate) corresponding to 15 cm vertical drop of water jet estimated discharge & pumping water level for selected tube wells of Rai block

Tube well No.	Value of x- coordinate, cm	Pumping water level depth below ground surface, m	Discharge, l s^{-1}
31	27.2	15.85	18.60
32	19.8	11.89	8.67
33	36.0	9.35	15.75
34	35.4	21.40	15.49
35	36.6	18.35	9.01
36	70.0	15.50	17.23
37	36.4	20.10	15.93
38	63.1	30.80	15.53
39	35.9	21.75	15.71
40	30.5	26.35	13.35
41	46.9	26.50	11.55
42	43.8	18.35	19.17
43	54.2	14.25	23.72
44	29.8	30.45	13.04
45	59.1	24.40	14.55
46	46.5	26.05	11.45
47	44.0	27.70	19.26
48	78.5	26.10	19.32
49	47.2	14.65	20.66
50	46.8	16.70	20.48
51	38.0	13.70	16.63
52	72.4	14.70	17.82
53	64.2	18.40	28.10
54	67.2	15.00	16.54
55	40.0	31.10	17.51
56	53.2	22.45	13.10
57	32.1	12.30	14.05
58	50.4	24.80	12.41
59	27.2	20.70	11.90
60	37.2	17.35	16.28
61	69.0	32.80	16.99
62	41.2	21.20	18.03
63	62.1	21.50	15.29
64	45.9	32.35	11.30
65	30.7	30.10	7.56

4.1.3 Motor HP, supply voltage & electrical power consumption

Different electrical parameters *viz.* supply voltage reading and actual energy consumption by pumping sets were measured by voltmeter and energy meter, respectively. During measurement of energy consumption, standard procedure was adopted *i.e.*, energy meter readings were recorded after one hour from connecting the energy meter to the submersible pumping set to eliminate the chances of error. Motor horse power was noted down through personal interview with the concerned farmer. Measured value of supply voltage, electrical power consumption and motor HP is given in Table 4.5 and 4.6 for Sonepat and Rai blocks, respectively.

Table 4.5: Motor HP, supply voltage & electrical power consumption for selected pumps of Sonepat block

Tube well No.	Supply voltage, volts	Energy meter reading, kWh	Motor horse power, HP
1	365	18.8	20.0
2	290	12.6	12.5
3	272	15.0	12.5
4	315	13.8	10.0
5	-	14.4	12.5
6	355	9.60	10.0
7	330	13.8	15.0
8	295	11.0	15.0
9	300	9.6	12.5
10	370	8.6	7.5
11	380	9.6	7.5
12	402	10.8	7.5
13	380	6.4	7.5
14	380	16.4	20.0
15	370	10.0	7.5
16	410	8.4	7.5
17	380	9.8	7.5
18	360	10.4	7.5
19	380	7.8	7.5
20	355	13.4	12.5
21	-	15.6	12.5
22	290	15.8	12.5
23	290	16.6	12.5
24	310	8.6	7.5
25	370	9.0	7.5
26	-	11.2	10.0
27	-	13.8	12.5
28	365	8.8	7.5
29	380	10.8	7.5
30	365	14.2	12.5

Table 4.6: Motor HP, supply voltage & electrical power consumption for selected pumps of Rai block

Tube well No.	Supply voltage, volts	Energy meter Reading, kWh	Motor horse power, HP
31	220	13.0	12.5
32	400	6.8	7.5
33	232	11.6	12.5
34	330	10.4	10.0
35	-	7.2	7.5
36	310	10.8	10.0
37	325	11.6	12.5
38	350	13.2	12.5
39	340	10.2	10.0
40	370	13.8	12.5
41	360	11.2	12.5
42	330	10.6	12.5
43	260	10.8	12.5
44	280	11.4	10.0
45	309	13.2	15.0
46	270	15.2	15.0
47	315	16.4	15.0
48	370	12.6	10.0
49	370	14	12.5
50	397	15.2	10.0
51	390	9.0	7.5
52	350	10.0	7.5
53	360	13.6	12.5
54	380	9.6	10.0
55	392	16.8	15.0
56	370	14.4	12.5
57	380	10.6	7.5
58	272	13.2	12.5
59	250	12.0	12.5
60	245	12.0	10.0
61	380	18.2	12.5
62	292	15.6	12.5
63	318	12.4	10.0
64	360	14.1	15.0
65	360	10.2	10.0

4.1.4 Head loss due to friction & velocity head

Tube wells used in the study area were found to deliver the discharge into open channels for further flow into the fields by gravity. Hence, the total working head consisted of total lift (pumping water level depth + height of delivery pipe above ground surface) using equation 3.4 and head loss due to friction in pipes & fittings was calculated by using equation 3.2 & 3.3 & velocity head was estimated using equation 3.5. The estimated /measured value of these components is given in Table 4.7 and 4.8 for Sonepat and Rai blocks respectively.

Table 4.7: Details of different head losses of pipes & velocity head in tube wells of Sonepat block

Tube well No.	Head loss due to friction, m			Total head loss due to friction, m	Velocity head, m
	Column pipe	Delivery pipe	Accessories (bends and valves etc.)		
1	5.43	0.23	0.26	5.93	0.36
2	1.52	0.31	0.10	1.94	0.17
3	2.99	0.23	0.18	3.40	0.24
4	1.82	0.12	0.13	2.07	0.17
5	4.16	0.23	0.21	4.61	0.29
6	1.11	0.14	0.06	1.32	0.11
7	1.82	0.10	0.07	1.99	0.12
8	1.12	0.13	0.05	1.31	0.09
9	0.70	0.06	0.04	0.80	0.07
10	2.92	0.16	0.46	3.54	0.21
11	3.23	0.13	0.57	3.93	0.25
12	0.23	0.06	0.15	0.45	0.06
13	0.94	0.13	0.12	1.18	0.21
14	2.66	0.07	0.10	2.83	0.11
15	0.67	0.54	0.09	1.30	0.71
16	1.49	0.06	0.96	2.51	0.12
17	5.12	1.76	1.34	8.22	1.29
18	2.38	0.44	0.35	3.17	0.67
19	1.92	0.28	0.31	2.52	0.59
20	0.49	0.07	0.05	0.61	0.27
21	6.01	0.11	1.23	7.35	0.27
22	5.52	0.13	0.76	6.41	0.35
23	2.14	0.11	0.24	2.49	0.45
24	1.67	0.42	1.01	3.11	0.51
25	2.31	0.48	0.37	3.16	0.54
26	1.19	0.18	0.24	1.61	0.46
27	3.48	0.21	0.22	3.90	0.30
28	3.38	0.18	0.53	4.09	0.24
29	3.11	0.60	0.39	4.09	0.75
30	1.46	0.08	0.16	1.69	0.30

Table 4.8: Details of different head losses of pipes & velocity head in tube wells of Rai block

Tube well No.	**Head loss due to friction, m**			**Total head loss due to friction, m**	**Velocity head, m**
	Column pipe	**Delivery pipe**	**Accessories (bends and valves etc.)**		
31	3.69	0.09	0.79	4.58	0.12
32	1.08	0.04	0.20	1.32	0.06
33	0.82	0.36	0.11	1.30	0.21
34	3.65	0.08	0.45	4.18	0.20
35	1.48	0.17	0.12	1.77	0.21
36	3.95	0.85	0.40	5.19	0.78
37	3.41	0.12	0.94	4.47	0.21
38	6.10	0.45	0.43	6.98	0.63
39	0.87	0.13	0.25	1.25	0.20
40	3.23	0.07	0.34	3.64	0.15
41	4.21	0.27	0.25	4.73	0.35
42	4.81	0.31	1.32	6.44	0.30
43	1.76	0.41	0.24	2.41	0.47
44	3.39	0.10	0.65	4.13	0.14
45	4.51	0.67	0.29	5.46	0.55
46	3.77	1.14	0.15	5.06	0.34
47	1.72	0.22	0.16	2.10	0.31
48	6.10	1.13	0.31	7.54	0.98
49	1.36	0.28	0.19	1.82	0.35
50	1.17	0.17	0.18	1.52	0.35
51	3.69	0.10	0.51	4.30	0.23
52	3.41	0.36	0.89	4.66	0.83
53	2.40	0.31	0.33	3.05	0.65
54	3.20	0.76	0.37	4.33	0.72
55	1.56	0.13	0.14	1.83	0.25
56	2.67	0.43	0.24	3.34	0.45
57	2.70	0.12	0.37	3.20	0.16
58	3.32	0.17	0.59	4.09	0.40
59	1.99	0.06	0.27	2.33	0.12
60	4.88	0.13	0.49	5.50	0.22
61	9.78	0.83	0.51	11.12	0.75
62	4.83	0.17	0.59	5.58	0.27
63	4.35	0.83	0.32	5.50	0.61
64	4.41	0.42	0.24	5.07	0.33
65	2.10	0.18	0.11	2.39	0.15

4.1.5 Estimation of pump set efficiency for groundwater pumping

a) Water horse power & expected minimum efficiency

The theoretical power imparted to the delivered water by the pump was estimated by substituting the measured value of pump discharge & total working head for different tube wells in equation 3.6. Knowing the number of stages in different pump sets as obtained from the farmers, the expected minimum efficiency was also determined as per BIS code IS 8034:2002 following the procedure described in chapter-III and is given in Table 4.9 and 4.10 for Sonepat and Rai blocks, respectively.

Table 4.9: WHP & expected minimum efficiency of selected tube wells for Sonepat block

Tube well No.	Discharge, $l\ s^{-1}$	Total Head, m	WHP, HP	Number of stages	Head per Stage, m	Expected minimum efficiency, %
1	11.82	51.19	7.96	4	12.80	50.40
2	8.10	37.33	3.98	3	12.44	46.97
3	9.60	32.07	4.05	3	10.69	48.51
4	8.07	32.93	3.50	3	10.98	46.36
5	10.49	37.93	5.23	3	12.64	48.51
6	6.43	41.39	3.50	3	13.80	42.92
7	6.70	50.35	4.44	3	16.78	44.46
8	5.81	49.16	3.76	3	16.39	43.68
9	5.19	34.41	2.35	3	11.47	43.89
10	15.75	16.67	3.46	3	5.56	50.25
11	17.29	16.97	3.86	3	5.66	50.25
12	8.53	14.53	1.63	4	3.63	48.00
13	8.86	16.74	1.95	4	4.19	48.75
14	6.52	25.99	2.23	4	6.50	48.80
15	16.47	17.86	3.87	2	8.93	48.51
16	11.90	9.56	1.50	2	4.78	48.51
17	22.18	25.46	7.43	2	12.73	49.25
18	16.05	16.65	3.52	2	8.33	48.51
19	15.07	10.05	1.99	4	2.51	51.00
20	18.03	18.30	4.34	2	9.15	50.56
21	18.21	30.28	7.25	3	10.09	51.59
22	20.66	25.59	6.95	2	12.79	50.56
23	23.41	24.73	7.62	2	12.37	50.56
24	13.98	13.15	2.42	2	6.58	48.51
25	14.40	14.67	2.78	2	7.34	47.22
26	23.54	14.50	4.49	2	7.25	50.65
27	10.73	36.65	5.18	2	18.33	46.03
28	17.02	18.12	4.06	2	9.06	49.25
29	16.94	20.54	4.58	2	10.27	48.51
30	18.99	20.25	5.06	3	6.75	52.36

Table 4.10: WHP & expected minimum efficiency of selected tube wells for Rai block

Tube well No.	Discharge, $l\ s^{-1}$	Total Head, m	WHP, HP	Number of stages	Head per Stage, m	Expected minimum efficiency, %
31	18.60	21.16	5.18	2	10.58	50.56
32	8.67	14.24	1.62	4	3.56	47.45
33	15.75	11.46	2.38	3	3.82	52.36
34	15.49	26.51	5.40	3	8.84	50.16
35	9.01	21.11	2.50	3	7.04	47.25
36	17.23	22.14	5.02	3	7.38	50.92
37	15.93	25.64	5.37	3	8.55	50.82
38	15.53	39.45	8.06	3	13.15	50.05
39	15.71	24.15	4.99	2	12.08	48.41
40	13.35	30.87	5.42	3	10.29	49.28
41	11.55	32.49	4.94	3	10.83	48.00
42	19.17	25.48	6.43	3	8.49	51.59
43	23.72	17.60	5.49	2	8.80	51.31
44	13.04	35.69	6.12	3	11.90	47.36
45	14.55	31.33	6.00	3	10.44	50.70
46	11.45	32.37	4.88	3	10.79	49.92
47	19.26	30.79	7.80	3	10.26	52.26
48	19.32	35.07	8.92	3	11.69	50.16
49	20.66	17.39	4.73	2	8.69	50.56
50	20.48	19.43	5.24	3	6.48	51.68
51	16.63	18.76	4.10	2	9.38	47.22
52	17.82	20.80	4.88	2	10.40	48.51
53	28.10	22.91	8.47	2	11.46	51.31
54	16.54	20.89	4.55	4	5.22	50.92
55	17.51	33.92	7.81	2	16.96	49.69
56	13.10	27.10	4.67	3	9.03	48.75
57	14.05	16.70	3.09	2	8.35	47.78
58	12.41	29.65	4.84	3	9.88	48.00
59	11.90	23.83	3.73	3	7.94	50.05
60	16.28	23.53	5.04	3	7.84	50.92
61	16.99	45.36	10.14	3	15.12	50.05
62	18.03	27.76	6.59	3	9.25	51.59
63	15.29	28.35	5.70	3	9.45	50.16
64	11.30	38.54	5.73	4	9.64	49.92
65	7.56	33.58	3.34	3	11.19	45.14

b) Estimated value of overall efficiency of tube wells based on motor HP & actual power consumption

The overall efficiency of tube well is often estimated based on the ratio of WHP to motor HP. In this study additional information on actual power consumption was collected & the same was also used to estimate the overall efficiency based on the ratio of estimated power consumption to meet WHP & the actual power consumption by the different tube wells is given in Table 4.11 and 4.12 for Sonepat and Rai blocks, respectively.

Table 4.11: Overall efficiency of selected tube wells based on MHP & actual power consumption for Sonepat block

Tube well No.	**WHP**		**MHP**	**Measured power consumption, kW**	**Overall efficiency based on**	
	HP	**kW**			**MHP (η_{MHP})**	**Power consumption (η_{PC})**
1	7.96	5.94	20.0	18.8	39.8	31.6
2	3.98	2.97	12.5	12.6	31.8	23.6
3	4.05	3.02	12.5	15.0	32.4	20.2
4	3.50	2.61	10.0	13.8	35.0	18.9
5	5.23	3.90	12.5	14.4	41.9	27.1
6	3.50	2.61	10.0	9.6	35.0	27.2
7	4.44	3.31	15.0	13.8	29.6	24.0
8	3.76	2.80	15.0	11.0	25.1	25.5
9	2.35	1.75	12.5	9.6	18.8	18.3
10	3.46	2.58	7.5	8.6	46.1	30.0
11	3.86	2.88	7.5	9.6	51.5	30.0
12	1.63	1.22	7.5	10.8	21.8	11.3
13	1.95	1.46	7.5	6.4	26.0	22.8
14	2.23	1.66	20.0	16.4	11.2	10.1
15	3.87	2.89	7.5	10.0	51.6	28.9
16	1.50	1.12	7.5	8.4	20.0	13.3
17	7.43	5.54	7.5	9.8	99.1	56.6
18	3.52	2.62	7.5	10.4	46.9	25.2
19	1.99	1.49	7.5	7.8	26.6	19.0
20	4.34	3.24	12.5	13.4	34.7	24.2
21	7.25	5.41	12.5	15.6	58.0	34.7
22	6.95	5.19	12.5	15.8	55.6	32.8
23	7.62	5.68	12.5	16.6	61.0	34.2
24	2.42	1.81	7.5	8.6	32.3	21.0
25	2.78	2.07	7.5	9.0	37.1	23.0
26	4.49	3.35	10.0	11.2	44.9	29.9
27	5.18	3.86	12.5	13.8	41.4	28.0
28	4.06	3.03	7.5	8.8	54.1	34.4
29	4.58	3.41	7.5	10.8	61.0	31.6
30	5.06	3.77	12.5	14.2	40.5	26.6

Table 4.12: Overall efficiency of selected tube wells based on MHP & actual power consumption for Rai block

Tube well No.	WHP		MHP	Measured power consumption, kW	Overall efficiency based on	
	HP	kW			MHP (η_{MHP})	Power consumption (η_{PC})
31	5.18	3.86	12.5	13.0	41.4	29.7
32	1.62	1.21	7.5	6.8	21.6	17.8
33	2.38	1.77	12.5	11.6	19.0	15.3
34	5.40	4.03	10.0	10.4	54.0	38.8
35	2.50	1.87	7.5	7.2	33.4	25.9
36	5.02	3.75	10.0	10.8	50.2	34.7
37	5.37	4.01	12.5	11.6	43.0	34.6
38	8.06	6.02	12.5	13.2	64.5	45.6
39	4.99	3.72	10.0	10.2	49.9	36.5
40	5.42	4.05	12.5	13.8	43.4	29.3
41	4.94	3.68	12.5	11.2	39.5	32.9
42	6.43	4.79	12.5	10.6	51.4	45.2
43	5.49	4.10	12.5	10.8	43.9	37.9
44	6.12	4.57	10.0	11.4	61.2	40.1
45	6.00	4.47	15.0	13.2	40.0	33.9
46	4.88	3.64	15.0	15.2	32.5	23.9
47	7.80	5.82	15.0	16.4	52.0	35.5
48	8.92	6.65	10.0	12.6	89.2	52.8
49	4.73	3.53	12.5	14.0	37.8	25.2
50	5.24	3.91	10.0	15.2	52.4	25.7
51	4.10	3.06	7.5	9.0	54.7	34.0
52	4.88	3.64	7.5	10.0	65.1	36.4
53	8.47	6.32	12.5	13.6	67.8	46.5
54	4.55	3.39	10.0	9.6	45.5	35.3
55	7.81	5.83	15.0	16.8	52.1	34.7
56	4.67	3.48	12.5	14.4	37.4	24.2
57	3.09	2.30	7.5	10.6	41.2	21.7
58	4.84	3.61	12.5	13.2	38.7	27.4
59	3.73	2.78	12.5	12.0	29.9	23.2
60	5.04	3.76	10.0	12.0	50.4	31.3
61	10.14	7.56	12.5	18.2	81.1	41.6
62	6.59	4.91	12.5	15.6	52.7	31.5
63	5.70	4.25	10.0	12.4	57.0	34.3
64	5.73	4.27	15.0	14.1	38.2	30.3
65	3.34	2.49	10.0	10.2	33.4	24.4

4.2 Quantification of management factors responsible for energy losses

Comparative evaluation of different irrigation methods and agricultural practices were examined at farm of KVK, Sonepat to estimate the volume of water pumped and energy utilized under different practises by conducting field experiment for wheat crop. The irrigation water was applied through electrical submersible tube well installed at KVK, farm. Results of field evaluations carried out during different irrigation events for the year 2017-18 & 2018-19 are described in subsequent sections.

4.2.1 Required net depth of irrigation

For estimating required net depth of irrigation, information on field capacity, bulk density, moisture content before each irrigation event and root zone depth were measured. Field capacity, soil texture for different layers of soil and bulk density for experimental area of farm at KVK, Sonepat was determined as outlined in section 3.8.1, 3.8.2 and 3.8.6, respectively. The estimated values of field capacity. Soil texture and bulk density for depth up to 120 cm for wheat field are given in Table 4.13. The surface layer showed slightly higher value of field capacity, which may be due to addition of FYM and incorporation of crop residues in the farm area.

The texture of field was loamy sand in upper layer and shifted towards sand as moving downwards. The bulk density was minimum in upper layer (1.44 g cm^{-3}) and increased towards lower depths and found maximum (1.56 g cm^{-3}) in 90-120 cm depth mainly due to presence of sand. The average required net depth of irrigation estimated during different years of study is given in Table 4.14.

Table 4.13: Soil texture, field capacity and bulk density of experimental site

Soil depth (cm)	Wheat field		
	Soil texture	Field capacity (%)	Bulk density (g cm^{-3})
0-15	Loamy sand	17.02	1.44
15-30	Loamy sand	16.83	1.46
30-60	Loamy sand	16.68	1.50
60-90	Sand	10.04	1.54
90-120	Sand	9.96	1.56

Table 4.14: Average required net depth of irrigation during different irrigation events in 2017-18 and 2018-19

Year	Average required net depth of irrigation (cm)						
	Pre sowing irrigation	Ist irrigation	IInd irrigation	IIIrd irrigation	IVth irrigation	Vth irrigation	Mean
2017-18	6.25	6.01	5.54	5.51	5.87	6.04	5.87
2018-19	6.32	6.05	5.71	5.59	5.94	5.98	5.93

4.2.2 Applied depth of irrigation

Applied depth of irrigation was calculated based on Infiltration opportunity time (which is difference of water advance and recession time) and cumulative infiltration depth and time relationship. Advance time is the time taken by the water front, from the time when the inflow stream is introduced into the field, to advance to predefined distance and recession time is the time when water receded from the same distance. The applied depth of irrigation was estimated separately for different treatments as well as for different irrigation events during different years of study and is given in Table 4.15.

Table 4.15: Applied depth of irrigation on the basis of infiltration rate & time of irrigation for different treatments during different irrigation events in 2017-18 and 2018-19

Treatment	**Applied depth of irrigation (cm)**						
	Pre sowing irrigation	**Ist irrigation**	**IInd irrigation**	**IIIrd irrigation**	**IVth irrigation**	**Vth irrigation**	**Mean**
2017-18							
T_1	7.98	7.78	7.37	7.33	7.41	7.78	**7.61**
T_2	8.30	7.93	7.63	7.60	7.69	8.05	**7.87**
T_3	7.08	6.79	6.47	6.43	6.46	6.75	**6.66**
T_4*	6.00						**-**
T_5	9.04	8.66	8.22	8.24	8.30	8.69	**8.53**
2018-19							
T_1	8.27	8.06	7.63	7.59	7.68	8.06	**7.88**
T_2	8.46	8.09	7.79	7.76	7.85	8.21	**8.02**
T_3	7.27	6.96	6.64	6.60	6.61	6.93	**6.83**
T_4	6.00						**-**
T_5	9.90	9.48	9.00	9.05	9.09	9.51	**9.34**

*****Depth of irrigation for micro irrigation treatment is based on volume of water delivered over known area.

4.2.3 Stored depth of irrigation

Stored depth of irrigation was estimated from information on field capacity, bulk density, root zone depth and moisture content after each irrigation event. The Stored depth of irrigation was estimated separately for different treatments as well as for different irrigation events during different years of study and is given in Table 4.16.

Table 4.16: Stored depth of irrigation for different treatments during different irrigation events in 2017-18 and 2018-19

Treatment	**Stored depth of irrigation (cm)**						
	Pre sowing irrigation	**Ist irrigation**	**IInd irrigation**	**IIIrd irrigation**	**IVth irrigation**	**Vth irrigation**	**Mean**
2017-18							
T_1	6.28	6.08	5.82	5.55	6.06	5.98	5.96
T_2	6.36	6.18	5.65	5.73	5.91	6.24	6.01
T_3	6.11	5.94	5.91	5.47	5.92	5.83	5.86
T_4	5.87	5.83	5.27	5.29	5.75	5.86	5.65
T_5	6.41	5.99	5.63	5.87	6.24	6.21	6.06
2018-19							
T_1	6.34	5.94	5.67	5.80	6.17	6.17	6.02
T_2	6.51	6.19	5.78	5.77	6.11	6.16	6.09
T_3	6.28	6.08	5.64	5.60	6.02	5.87	5.91
T_4	5.84	5.80	5.51	5.36	5.78	5.85	5.69
T_5	6.49	6.14	5.82	6.01	6.07	6.11	6.11

4.2.4 Applied depth of irrigation based on stream discharge

Applied depth of irrigation was calculated from discharge of tube well used for irrigation and time of irrigation (cut-off time). Applied depth of irrigation for different treatments as well as for different irrigation events during different years of study is presented in Table 4.17.

Table 4.17: Applied depth of irrigation on the basis of stream discharge for different treatments during different irrigation events in 2017-18 and 2018-19

Treatment	Applied irrigation depth based on stream discharge (cm)						
	Pre sowing irrigation	Ist irrigation	IInd irrigation	IIIrd irrigation	IVth irrigation	Vth irrigation	Mean
2017-18							
T_1	8.30	8.09	7.67	7.63	7.72	8.09	7.92
T_2	8.68	8.30	7.99	7.96	8.05	8.41	8.23
T_3	7.32	7.02	6.67	6.64	6.67	6.97	6.88
T_4	6.00						-
T_5	9.50	9.09	8.64	8.66	8.74	9.15	8.96
2018-19							
T_1	8.60	8.38	7.94	7.90	7.99	8.38	8.20
T_2	8.86	8.47	8.15	8.12	8.21	8.58	8.40
T_3	7.51	7.19	6.85	6.81	6.82	7.15	7.06
T_4	6.00						-
T_5	10.41	9.96	9.46	9.51	9.57	10.02	9.82

4.2.5 Water application efficiency

Water application efficiency was calculated by dividing average required depth of irrigation by applied depth of irrigation for treatment T_1, T_2, T_3 and T_5. For, treatment T_4 (micro irrigation), it was calculated based on the stored depth of irrigation computed based on moisture observations. Moisture measurements for surface irrigation methods was taken at 20 m distance from the head end of the field. While, the applied depth as calculated from the infiltration opportunity time showed that the applied depth of irrigation was larger than required depth of irrigation at all points in the field. Therefore, it was assumed that whole required net depth of irrigation was stored in the root zone, hence accordingly water application efficiency for these treatments was calculated based on the required depth of irrigation. For treatment T_4 (micro irrigation), the stored depth of irrigation as computed based on moisture observation was used for estimating the water application efficiency. Noting that certain amount of moisture content might have been lost due to evapotranspiration during the period from the day of irrigation to the day of moisture observation, it is expected that actual water application efficiency under treatment T_4 would be slightly higher than the reported values.

Water application efficiency for different treatments as well as for different irrigation events during different years of study is given in Table 4.18.

Table 4.18: Water application efficiency for different treatments during different irrigation events in 2017-18 and 2018-19

Treatment	**Water application efficiency (%)**						
	Pre sowing irrigation	**Ist irrigation**	**IInd irrigation**	**IIIrd irrigation**	**IVth irrigation**	**Vth irrigation**	**Mean**
2017-18							
T_1	78.3	77.2	75.2	75.3	79.2	77.7	77.1
T_2	75.3	75.8	72.6	72.5	76.2	75.1	74.6
T_3	88.2	88.5	85.7	85.7	90.8	89.6	88.1
T_4	97.9	97.2	87.9	88.2	95.9	97.6	94.1
T_5	69.1	69.4	67.4	66.9	70.7	69.6	68.8
2018-19							
T_1	76.5	75.1	74.9	73.6	77.4	74.3	75.3
T_2	74.7	74.8	73.4	72.0	75.6	72.9	73.9
T_3	87.0	87.0	86.1	84.7	89.9	86.4	86.8
T_4	97.4	96.6	91.9	89.4	96.4	97.6	94.9
T_5	63.8	63.8	63.5	61.7	65.3	62.9	63.5

4.2.6 Water distribution efficiency

Water distribution efficiency was calculated by dividing average mean deviation of applied depth at 0, 10, 20, 30 & 40 m by mean applied depth of irrigation infiltrated in the field. In treatment T_4 water distribution efficiency was estimated by calculating uniformity coefficient of micro irrigation system. Water distribution efficiency for different treatments as well as for different irrigation events during different years of study is given in Table 4.19.

4.2.7 Total electrical energy consumption for irrigation pumping under different irrigation/cultural practice

Total energy consumption for each irrigation event was computed by multiplying cut off time of irrigation stream required to irrigate each treatment's area and energy consumed by tube well (kWh), which was summed to determine the total energy consumption per hectare for each treatment during all the irrigations. The total energy consumption values under various treatments for the year 2017-18 & 2018-19 are given in Table 4.20.

Table 4.19: Water distribution efficiency for different treatments during different irrigation events in 2017-18 and 2018-19

Treatment	Water distribution efficiency (%)						
	Pre sowing irrigation	I^{st} irrigation	II^{nd} irrigation	III^{rd} irrigation	IV^{th} irrigation	V^{th} irrigation	Mean
2017-18							
T_1	89.5	89.0	89.0	89.6	88.2	88.8	89.0
T_2	89.0	88.8	87.0	89.3	88.6	88.3	88.5
T_3	91.9	91.1	91.5	91.9	91.5	91.3	91.5
T_4	-	95.08	-	-	-	-	-
T_5	84.2	86.3	86.0	86.0	85.2	86.8	85.7
2018-19							
T_1	90.1	89.6	89.9	90.2	88.7	89.6	89.7
T_2	89.3	89.0	87.3	89.6	87.7	88.8	88.6
T_3	92.3	91.1	92.1	92.0	91.9	92.6	92.0
T_4	-	94.36	-	-	-	-	-
T_5	83.6	86.6	86.1	86.5	85.3	86.2	85.7

Table 4.20: Energy consumption and volume of irrigation water applied in different treatments

Treatment	Energy consumption, kWh ha^{-1}			Volume of irrigation water applied (m^3 ha^{-1})		
	2017-18	2018-19	Mean	2017-18	2018-19	Mean
T1	1150.3	1191.3	1170.8	4750.2	4919.3	4834.8
T2	1196.2	1220.4	1208.3	4939.5	5039.4	4989.4
T3	1000.1	1025.2	1012.6	4129.7	4233.3	4181.5
T4	1399.2	1399.2	1399.2	3600.0	3600.0	3600.0
T5	1302.5	1427.3	1364.9	5378.2	5893.4	5635.8

4.2.8 Yield and irrigation water use efficiency (WUE)

Yield in terms of grain and straw was recorded for different treatments. Irrigation water use efficiency (WUE) for grain was calculated by dividing the respective yield by the total irrigation depth applied. Yield, Irrigation water use efficiency (WUE) of grain for different treatments as well as for different irrigation events during different years of study is given in Table 4.21.

Table 4.21: Yield and water use efficiency (WUE_{Grain}) as affected by various treatments during 2017-18 and 2018-19

Treatment	Grain yield (q ha^{-1})		Straw yield (qha^{-1})		WUE_{Grain} (q $ha^{-1}cm^{-1}$)	
	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
T1	40.71	41.52	50.08	53.15	0.86	0.84
T2	41.45	42.36	51.82	55.07	0.84	0.84
T3	43.21	44.19	54.01	57.45	1.05	1.04
T4	45.04	46.07	56.76	60.35	1.25	1.28
T5	37.64	38.05	47.06	49.46	0.70	0.65
CD (p= 0.05)	0.72	0.66	0.89	0.86	0.15	0.14

4.3 Estimation of energy consumption and potential energy saving for groundwater pumping in the study area

4.3.1 Groundwater level

The water table depth in the study area was being monitored by the Groundwater Cell of Agriculture Department, Govt. of Haryana through a network of observation wells twice in a year *i.e.*, in the month of June (pre-monsoon depth) and October (post monsoon depth). Groundwater level during June and October months of each year during 1990-2020 & its mean values in Rai and Sonepat blocks is presented in Table 4.22.

Table 4.22: Groundwater level (m) in Rai and Sonepat blocks from 1990 to 2020

Year	**Rai**			**Sonepat**		
	June	**October**	**Mean**	**June**	**October**	**Mean**
1990	6.80	6.17	6.49	8.09	7.15	7.62
1991	7.08	7.45	7.27	7.31	7.11	7.21
1992	8.26	7.98	8.12	7.71	8.78	8.25
1993	8.67	7.85	8.26	9.75	7.81	8.78
1994	8.78	7.9	8.34	9.15	7.76	8.46
1995	8.88	6.89	7.89	8.53	6.65	7.59
1996	7.83	6.62	7.23	7.36	6.06	6.71
1997	7.45	7.86	7.66	7.56	6.54	7.05
1998	7.03	6.8	6.92	7.15	6.28	6.72
1999	7.88	8.8	8.34	7.25	7.71	7.48
2000	9.35	8.6	8.98	8.22	8.03	8.13
2001	9.12	9.95	9.54	8.67	9.63	9.15
2002	10.47	9.9	10.19	10.25	9.67	9.96
2003	10.91	11.64	11.28	10.98	10.53	10.76
2004	12.48	12.84	12.66	10.5	10.44	10.47
2005	11.92	11.87	11.9	11.31	10.84	11.08
2006	11.69	11.65	11.67	11.51	10.17	10.84
2007	9.54	12.78	11.16	13.01	8.45	10.73
2008	9.63	12.13	10.88	14.02	9.47	11.75
2009	9.37	11.9	10.64	13.02	8.29	10.65
2010	9.96	11.46	10.71	16.05	8.31	12.18
2011	8.3	12.35	10.32	15.69	7.35	11.52
2012	10.36	12.52	11.44	16.72	9.42	13.07
2013	10.15	12.45	11.3	16.62	9.41	13.02
2014	12.84	12.88	12.86	9.28	9.20	9.24
2015	13.48	13.78	13.63	9.73	9.46	9.59
2016	14.73	14.7	14.72	10.32	10.18	10.25
2017	14.15	14.47	14.31	7.23	5.60	6.42
2018	15.06	15.27	15.17	6.2	5.12	5.66
2019	16.32	16.70	16.51	8.33	7.87	8.10
2020	16.44	15.5	15.97	8.99	8.15	8.57

4.3.2 Area under different crops

Area under different crops and sources of irrigation in Rai and Sonepat blocks for the year 2018-19 was obtained from Agriculture Department, Sonepat, Haryana and presented in tables 4.23 to 4.26. For the Rai block wheat in *rabi* & paddy in *kharif* season occupied more than 80% of the cropped area. Likewise, in the Sonepat block wheat covered more than 80% and paddy covered 77.69% of the cropped area in their respective seasons. Other major crops in these blocks which were considered for estimation of electrical energy consumption were sugarcane & cotton which individually occupying more than 5% of the total cropped area.

Table 4.23: Area under different crops in Rai block during the year 2018-19

Rai block					
***kharif* season**			***rabi* season**		
Crop	**Cropped area (ha)**	**Percentage of total cropped area**	**Crops**	**Cropped Area, ha**	**Percentage of total cropped area**
Paddy	12260	82.83	Wheat	12910	85.66
Sugarcane	715	4.83	Mustard	210	1.39
Cotton	72	0.49	Sugarcane	715	4.75
Fodder	720	4.86	Gram	4	0.03
Bajra	46	0.31	Fodder	240	1.59
kharif pulse	28	0.19	Barley	12	0.08
Maize	475	3.21	Others	980	6.5
Others	485	3.28	-	-	-
Total area	**14801**	**-**	**Total area**	**15071**	**-**

Table 4.24: Cropped area (ha) under tube well and canal irrigation systems in Rai block during the year 2018-19

Rai block							
***kharif* season**				***rabi* season**			
Crop	**Total area**	**Tube well irrigated**	**Canal irrigated**	**Crop**	**Total area**	**Tube well irrigated**	**Canal irrigated**
Paddy	12260	11239	1021	Wheat	12910	10587	2323
Sugarcane	715	603	112	Mustard	210	210	-
Cotton	72	70	2	Sugarcane	715	603	112
Fodder	720	706	14	Gram	4	4	-
Bajra	46	46	-	Fodder	240	224	16
kharif pulse	28	28	-	Barley	12	12	-
Maize	475	470	5	Others	980	972	8
Others	485	485	-	-	-	-	-
Total	**14801**	**13647**	**1154**	**Total**	**15071**	**12612**	**2459**

Table 4.25: Area under different crops in Sonepat block during the year 2018-19

Sonepat block					
***kharif* season**			***rabi* season**		
Crop	**Cropped Area (ha)**	**Percentage of total cropped area**	**Crops**	**Cropped Area, ha**	**Percentage of total cropped area**
Paddy	19400	77.69	Wheat	25220	85.84
Sugarcane	2810	11.26	Mustard	415	1.41
Cotton	1288	5.16	Sugarcane	2810	9.56
Fodder	320	1.28	Gram	5	0.02
Bajra	250	1	Fodder	500	1.7
kharif pulse	62	0.25	Barley	10	0.03
Maize	200	0.8	*rabi* pulses	2	0.01
Others	640	2.56	Others	420	1.43
Total area	**24970**	**-**	**Total area**	**29382**	**-**

Table 4.26: Cropped area (ha) under tube well and canal irrigation systems in Sonepat block during the year 2018-19

Sonepat block							
***kharif* crops**				***rabi* crops**			
Crop	**Total area**	**Tube well irrigated**	**Canal irrigated**	**Crop**	**Total area**	**Tube well irrigated**	**Canal irrigated**
Paddy	19400	14938	4462	Wheat	25220	18840	6380
Sugarcane	2810	1967	843	Mustard	415	415	-
Cotton	1288	1211	77	Sugarcane	2810	1967	843
Fodder	320	296	24	Gram	5	5	-
Bajra	250	250	-	Fodder	500	470	30
kharif pulse	62	62	-	Barley	10	10	-
Maize	200	180	20	*rabi* pulses	2	2	-
Others	640	628	12	Others	420	412	8
Total	**24970**	**19532**	**5438**	**Total**	**29382**	**22121**	**7261**

4.3.3 Irrigation practices of selected farmers

Applied depth of irrigation was calculated on the basis of time of irrigation and discharge of tube wells for two irrigation events *viz*. Ist and IVth for ten selected farmers (five in each block). Required depth was determined from soil moisture measured before irrigation at each selected farmers' field. The values of field capacity and bulk density of experimental farm (Table 4.13) were used to calculate the required depth of irrigation being more or less similar texture of soils at ten selected farmers' field. Application efficiency was calculated as the ratio of required and applied irrigation depth for respective irrigations. Data pertaining to irrigation practices at ten selected farmer fields is given in Table 4.27.

Table 4. 27: Irrigation practices at farmer's field of ten selected farmers

Tube well No.	**Discharge of tube well (l s^{-1})**	**Texture**	**Time of irrigation for one acre field (h)**		**Required depth of irrigation (cm)**		**Applied depth of irrigation (cm)**		**Application efficiency (%)**	
			Ist	**IVth**	**Ist**	**IVth**	**Ist**	**IVth**	**Ist**	**IVth**
31	18.6	SL	6.3	6.1	6.21	6.11	10.42	10.09	59.59	60.55
48	19.32	LS	5.7	5.4	6.28	6.14	9.79	9.28	64.14	66.16
47	19.26	LS	6.1	5.6	6.39	6.26	10.45	9.59	61.14	65.27
38	15.53	SL	6.8	6.7	5.97	5.78	9.39	9.25	63.57	62.48
46	11.45	SL	8.5	8.4	5.94	5.84	8.65	8.55	68.67	68.30
20	18.03	SL	6.1	5.8	6.11	5.92	9.78	9.30	62.47	63.65
15	16.47	SL	6.6	6.4	5.96	5.76	9.66	9.37	61.69	61.47
11	17.29	SL	6.4	6.3	6.21	6.03	9.84	9.68	63.10	62.29
19	15.07	SL	7.7	7.6	6.27	6.20	10.32	10.18	60.75	60.90
26	23.54	SL	5.2	5.1	6.31	6.13	10.88	10.67	57.99	57.45
Mean	**17.46**	-	**6.54**	**6.34**	**6.17**	**6.02**	**9.92**	**9.60**	**62.31**	**62.85**

SL: Sandy loam
LS: Loamy sand

4.3.4 Electrical energy consumption and potential energy saving at selected farmers' field

Average irrigation depth applied at farmers' field was computed based on estimated depth of irrigation during the two irrigations (*i.e.* I^{st} and IV^{th}). Knowing the average depth of irrigation per event, total number of irrigations & measured energy consumption (kW) per hour at the farmers' field, the energy requirement per hectare was estimated. Similarly, the possible energy requirement at the farmers' field was also estimated if the farmer adopt the laser levelled field with recommended slope & size of the field for surface irrigation (based on treatment T_3) Estimated energy requirement for conventional practice at farmers' field and suggested practice (T_3) was computed. Similarly, potential energy saving if farmer adopts the treatment T_3 was also calculated and is given in Table 4.28.

Table 4.28: Estimated energy requirement and potential energy saving (%) for conventional and recommended practices at farmers' field

Tube well No.	**Energy consumption (kWh)**	**Energy requirement, kWh ha^{-1}**		**Potential energy saving (%)**
		Farmers' practice	**Laser levelled graded field (T_3)**	**Laser levelled graded field (T_3)**
31	13.00	1194.49	818.80	31.45
48	12.60	1036.36	771.08	25.59
47	16.40	1421.83	1023.17	28.03
38	13.20	1320.46	948.77	28.14
46	15.20	1903.48	1486.74	21.89
20	13.40	1181.59	849.92	28.06
15	10.00	963.30	677.27	29.69
11	9.60	903.42	645.85	28.51
19	7.80	884.30	613.69	30.60
26	11.20	854.81	562.56	34.18
Mean	**12.24**	**1166.40**	**839.79**	**28.61**

*Energy consumption per hour was measured during I^{st} irrigation only and assuming six irrigations including pre-sowing irrigation

4.3.5 Cropped area and irrigation requirements for major crops

Cropped area under major crops *i.e.* crops occupying more than 5% of the cropped area under tube well irrigation for the two selected blocks is given in Table 4.24 & 4.26. Crop water requirement & net irrigation requirement for different crops were adopted as per the recommendations of Dhindwal *et al.* (2008). The gross irrigation requirement was estimated using the average application efficiency during the irrigation events measured at selected farmers' field which was found to be 62.58% (Table 4.27). The values of cropped area and irrigation requirements for major crops are given in Table 4.29.

Table: 4.29: Cropped area and irrigation requirements for major crops in Sonepat & Rai blocks

Crop	**Cropped area under tube well irrigation**		**Water requirement (cm)**	**Net irrigation requirement* (cm)**	**Average net irrigation depth (cm)**	**Gross irrigation depth (cm)**
	Sonepat	Rai				
Wheat	18840	10587	40-50	30-35	32.5	51.8
Sugarcane	1967	603	90-110	55-70	62.5	99.7
Cotton	1211	70	55-65	30-45	37.5	59.8
Paddy	14938	11239	140-160	85-110	97.5	155.5

*Considering effective rainfall during crop period

4.3.6 Energy requirement for groundwater pumping in major crops

Electrical energy requirements for irrigation in major crops grown in Sonepat & Rai blocks were computed using equation 3.18 given under chapter III. This was based on cropped area irrigated by tube well, gross irrigation depth, (Table 4.29), average water table depth (mean of water table depth in June & October, 2020) collected from Hydrologist, Department of Agriculture, Govt. of Haryana (Table 4.22), assumed drawdown (4m) & average friction losses, based on average friction losses for the respective blocks, (Tables 4.7 & 4.8). Average groundwater table depth for the months of June & October for the year 2020 and friction losses for Rai block were 15.97 & 4.06 m and for Sonepat block were 8.57 & 3.0 m, respectively which add to become total head of 24.03 & 15.62 m for Rai and Sonepat blocks, respectively. Using this data, electrical energy requirements for groundwater pumping in major crops grown in Sonepat & Rai blocks were computed at existing level of average pumping efficiency and expected energy consumption under assumed improvement levels based on average and maximum overall efficiency of tube wells from the data given in Tables 4.11& 4.12. Estimated energy consumption (mWh) at current and expected efficiency levels for major crops in Sonepat & Rai blocks is given in Table 4.30 and 4.31, respectively.

Table 4.30: Estimated energy consumption (mWh) at current and expected efficiency levels for major crops in Sonepat block

Crop	**Existing efficiency level (%)**	**Expected overall efficiency level (%)**					
	26.10	**30**	**35**	**40**	**45**	**50**	**55**
Wheat	15938.6	13866.6	11885.6	10399.9	9244.4	8319.9	7563.6
Sugarcane	3200.1	2784.1	2386.4	2088.1	1856.1	1670.5	1518.6
Cotton	1182.1	1028.4	881.5	771.3	685.6	617.1	561.0
Paddy	37912.5	32983.9	28271.9	24737.9	21989.3	19790.4	17991.2

Table 4.31: Estimated energy consumption (mWh) at current and expected efficiency levels for major crops in Rai block

Crop	Existing efficiency level (%)	Expected overall efficiency level (%)				
	32.52	**35**	**40**	**45**	**50**	**55**
Wheat	11059.1	10275.5	8991.0	7992.0	7192.8	6538.9
Sugarcane	1211.3	1125.5	984.8	875.4	787.8	716.2
Cotton	84.4	78.4	68.6	61.0	54.9	49.9
Paddy	35220.4	32724.8	28634.2	25452.6	22907.4	20824.9

CHAPTER-V

DISCUSSION

Results obtained during the study conducted for the present research work on scope of energy conservation for groundwater pumping are discussed in this chapter.

5.1 Quantification of different factors responsible for energy consumption for groundwater pumping

General information related to selected submersible pumping sets is given in Table 4.1 and 4.2 for Sonepat and Rai blocks, respectively. Different factors responsible for energy consumption for groundwater pumping were studied which included pumping water level, friction losses in the associated pipes & fittings, height of delivery pipe above ground surface, overall pumping efficiency (motor & pump efficiency), water requirement of crops, total area under irrigation and water application efficiency etc.

5.1.1 Energy consumption attributed to different components of total head

The energy required for groundwater pumping is directly proportional to the total head against which water is being pumped. The total head in the study area consisted of pumping water level, friction losses, velocity head and height of delivery pipe above ground surface. Knowing different components of the total head, it is possible to quantify the power consumption attributed to different components of total head as under:

$$P_i = \frac{H_i}{H} \times P_a$$

Where,

Pi: Power consumption attributed due to a particular component of head, kW

Hi: Head due to particular component, m (*e g*. Pumping water level, head due to friction losses etc.)

H: Total head, m

Pa: Actual power consumption, kW

Power consumption for groundwater pumping as attributed to the different components of total head is given in Tables 5.1 & 5.2 for Sonepat & Rai block, respectively.

5.1.2 Pumping water level

The pumping water level, as measured during operation of selected tube wells showed that it varied from 5.8 to 47.6 m below ground surface in the Sonepat and 9.35 to 32.80 m in Rai block. The pumping water level accounted for 57.71 to 95.90% of the total power consumption for groundwater pumping in Sonepat block with an average value of 80.68%, whereas, in Rai block, the corresponding values were 70.01 to 91.69% and 80.25%.

It is expected that deeper is the pumping water level, higher would be the percent of power consumption attributed to pumping water level.

In general, the percentage of power consumption attributed to pumping water level increased with increasing depth of the pumping water level in both Sonepat & Rai blocks as shown in Fig. 5.1 (a and b). However, it can be seen that for some of the tube well, the percentage of power consumption as attributed to pumping water level was lower than the general trend for the selected tube wells, which suggest that other factors such as friction losses, delivery pipe height etc. may have contributed for relatively higher fraction of total power consumption for such tube wells.

For instance, TW-13 and TW-17 were having 15.00 and 15.10 m pumping water levels respectively, while the percentage of total power consumption attributed to pumping water level were estimated as 89.61 and 59.31%, respectively for TW-13 & TW-17. It was further observed that in spite of having almost similar pumping water level, TW-17 had relatively less percent share of power consumption due to pumping water level.

A further analysis of the pumping system at TW-13 & TW-17 revealed that following factors contributed to relatively higher friction head loss in TW-17 (= 8.22 m) as compared to TW-13 (= 1.18 m):

i) Use of 90^0 bend in TW-17, contributed to head loss of 1.34 m instead of long radius bend used in TW-13 (=0.12 m)
ii) Higher velocity head in TW-17 (= 1.29 m) as compared to TW-13 (0.21 m), this contributed to higher friction losses in the pipes
iii) Maximum head loss attributed in TW-17 (5.12 m) as compared to TW-13 (0.94 m) was due to comparatively high discharge
iv) Relatively longer length (= 4.37 m) & higher height (0.86 m) of delivery pipe in TW-17 as compared TW-13 (length = 1.73 m, height = 0.36 m) .

Similarly, the pumping level in TW-35 & 42 was equal to 18.35 m, however, the percentage of power consumption attributed to pumping water level was 86.93 & 72.02% for TW- 35 & 42, respectively. Considering the depth of placement of pump which was 30.5 m in TW-35 & 24.4 m in TW-42 (see length of column pipe in Table 4.2), none would have expected relatively higher head loss due to friction in TW-42 as compared to TW-35. However, contrary to the above expectation, relatively higher head loss due to friction in TW-42 as a result of higher discharge & use of 90^0 bend was obtained. On the other hand, for TW-53, where the pumping water level was 18.40 m, the contribution of pumping water level was 80.31 % despite the fact that the discharge of the pump was 28.10 l s^{-1} as compared to 19.17 l s^{-1} for TW-42. This was due to use of higher column pipe dia. (10 cm) in TW-53 as compared to. Column pipe dia. of TW-42 (7.5 cm) cm dia. Therefore, it may be concluded that selection of suitable size of column pipe dia. is important to reduce the power consumption due to friction losses.

5.1.3 Total friction losses

The total friction losses as measured during operation of studied tube wells showed that it ranged from 0.45 to 8.22 m in the Sonepat block, while this loss in selected tube wells of Rai block varied from 1.25 to 11.12 m. The total friction losses accounted for 2.32 to 32.27% of the total power consumption for groundwater pumping in Sonepat block with an average value of 13.79%. The percentage of total power consumption attributed to total friction losses in Rai block observed from 5.16 to 25.28% with a mean value of 15.26%. Total head losses included head loss due to friction in column pipe, delivery pipe and accessories (bends, valves *etc*.). It was noticed that maximum share of head loss was recorded due to column pipe, which depends upon pump discharge, material of pipe, total length & diameter of column pipe used. As the length of column pipe increased, head loss increased, while increase in diameter of column pipe, head loss decreased. Head loss due to friction in delivery pipe and accessories varied as per the total length and material used in delivery pipe. Similarly, head loss in accessories was dependent upon different type of accessories used. In some tube wells, friction head loss due to delivery pipe was recorded as high while, in other tube wells, friction head loss due to accessories was measured to be high. The data related to variation of power consumption (%) attributed to total friction losses for Sonepat and Rai blocks is given in Fig. 5.2 (a and b).

In Sonepat block, lowest % of total power consumption attributed to total friction losses was recorded 2.32 % in TW-9. This was due to use of standard elbow and relatively low value of velocity head (= 0.07m). This tube well also had minimum discharge and very smooth pipes. Highest value of percentage of total power consumption attributed to total friction losses in Sonepat block was recorded 32.27% in TW-17. This was due to use of 90^0 bend, use of longer total length of delivery pipe (5.23 m) and relatively high value of velocity head (= 1.29 m).

Similarly, in Rai block lowest % of total power consumption attributed to total friction losses was recorded 5.16% in TW-39. This was due to very less head loss in column pipe because of using higher diameter (10 cm) column pipe. Highest value of percentage of total power consumption attributed to total friction losses in Rai block was 25.28% in tube well No. 42. The reason behind this was using 90^0 bend in delivery pipe, higher head loss in column pipe and longer total length of delivery pipe that has contributed 1.32 m, 4.81 m and 0.31 m head losses, respectively. Higher head loss in delivery pipe was due to use of 90^0 bend of 10 cm size and pipes used in column were having 7.5 cm dia. that has contributed higher head losses.

5.1.4 Height of delivery pipe

Height of delivery pipe as measured in selected tube wells of Sonepat and Rai blocks during the study varied from 0.36 to 1.17 m and 0.36 to 1.04 m, respectively. Height of delivery pipe accounted for 1.34 to 11.96% of percentage of total power consumption for groundwater pumping in Sonepat block with an average value of 3.77% while in Rai block corresponding values were 1.20 to 6.78% and 3.03%. Variation of power consumption (percent) attributed to height of delivery pipe for Sonepat and Rai blocks is depicted in Fig. 5.3 (a and b).

It was revealed that the percentage of total power consumption due to height of delivery pipe above ground surface was highest (11.96%) in TW-16 having total height of 1.14 m whereas maximum total height (1.17m) was observed in TW-25 consuming 7.96% of total power consumption. This difference is attributed to variation in total head measured in these tube wells, which were recorded 9.56 and 14.67 m in TW-16 & TW- 25, respectively, in Sonepat block. Delivery pipe height contributed lowest percentage (1.34%) of total power consumption in TW-1 having total height of delivery pipe (0.69 m), but TW-13 having minimum delivery pipe height (0.36m) accounted for (2.12%) of total power consumption. This difference is due to variation in head in these two tube wells. Total head in TW-1 &13 was recorded 51.19 and 16.74 m, respectively.

5.1.5 Velocity head loss

Velocity head loss as recorded during operation of selected tube wells varied from 0.06 to 1.29 m in Sonepat block while in Rai block, it varied from 0.06 to 0.98 m. The velocity head loss accounted for 0.18 to 5.90% of the percentage of total power consumption for groundwater pumping in Sonepat block with an average value of 1.75%. In Rai block, it varied from 0.39 to 3.99% with an average value of 1.46%. Variation of power consumption (%) attributed to velocity head loss for Sonepat and Rai blocks is depicted in Fig. 5.4 (a and b).

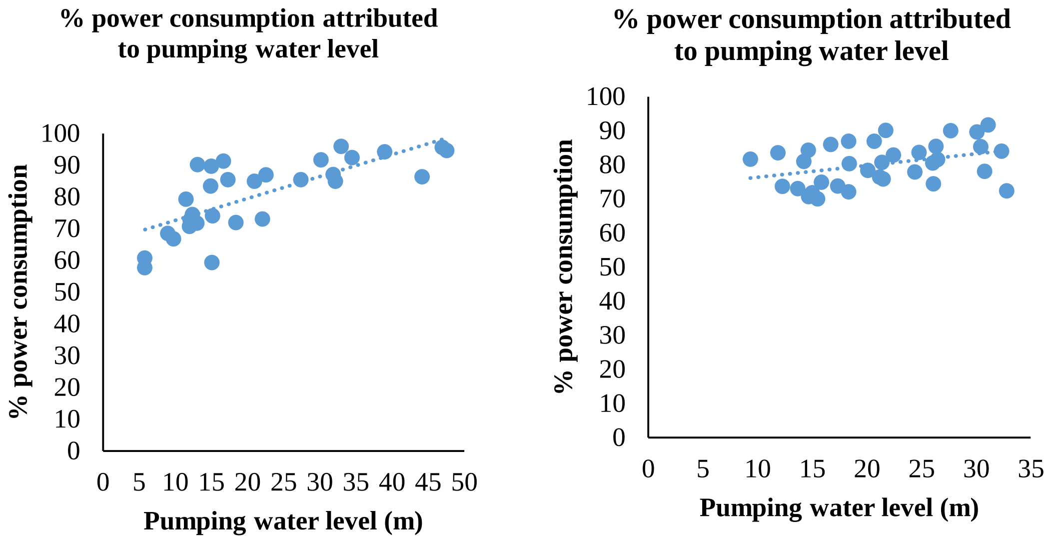
Minimum percentage of total power consumption attributed to velocity head loss was measured 0.18% that was having velocity head loss of (0.09 m) in TW-8 whereas, minimum velocity head loss (0.06 m) having percentage of total power consumption (0.41%) was observed in TW-12. The difference in percentage of total power consumption for velocity head loss is due to variation in total head of these tube wells which were recorded 49.16 and 14.53 m for TW-8 & 12, respectively in Sonepat block. Highest percentage of total power consumption attributed to velocity head was recorded (5.90%) having velocity head loss of (0.59 m) in TW-19. However, highest velocity head loss (1.29 m) having percentage of total power consumption (5.05%) was recorded in TW-17. This difference accounted to variation in total head of TW-19 and TW-17, which was recorded 10.05 and 25.46 m, respectively in Sonepat block. Similarly, minimum percent of total power consumption attributed to velocity head loss (0.39%) having total velocity head (0.14 m) in TW-44, whereas, lowest value of velocity head loss (0.06 m) having percentage of total power consumption (0.44%) was measured in TW-32. This difference is due to variation in total head of TW-32 and TW-44, which were having 14.24 and 35.69 m total head, respectively. The maximum percentage of total power consumption attributed to velocity head loss (3.99%) having total velocity head (0.83 m) in TW-52, whereas, highest value of velocity head (0.98 m) contributed to percentage of total power consumption (2.78%) in TW-48. This difference is due to variation in total head of TW-52 & 48 which were recorded 20.80 m and 35.07 m, respectively. Variation of power consumption (%) attributed to total friction loss with velocity head loss for Sonepat and Rai blocks is depicted in Fig. 5.5 (a to b).

Table 5.1: Measured power consumption and power consumption attributed to different components of total head in Sonepat block

Tube well no.	Pumping water level, m	Total friction losses, m	Height of delivery pipe above GS, m	Velocity head loss, m	Total head, m	Measured power consumption, kWh	Power consumption (kWh) attributed to				Percentage (%) of total power consumption attributed to			
							Pumping water level	Total friction losses	Height of delivery pipe above GS	Velocity head loss	Pumping water level	Total friction losses	Height of delivery pipe above GS	Velocity head loss
1	44.20	5.93	0.69	0.36	51.19	18.80	16.23	2.18	0.25	0.13	86.34	11.58	1.34	0.71
2	34.50	1.94	0.71	0.17	37.33	12.60	11.64	0.65	0.24	0.06	92.42	5.18	1.91	0.46
3	27.40	3.40	0.99	0.24	32.07	15.00	12.82	1.59	0.46	0.11	85.44	10.61	3.09	0.75
4	30.20	2.07	0.51	0.17	32.93	13.80	12.66	0.87	0.21	0.07	91.71	6.27	1.54	0.52
5	32.20	4.61	0.84	0.29	37.93	14.40	12.22	1.75	0.32	0.11	84.89	12.15	2.21	0.76
6	39.00	1.32	0.94	0.11	41.39	9.60	9.05	0.31	0.22	0.03	94.23	3.18	2.27	0.26
7	47.60	1.99	0.69	0.12	50.35	13.80	13.05	0.55	0.19	0.03	94.54	3.95	1.36	0.23
8	47.00	1.31	0.81	0.09	49.16	11.00	10.52	0.29	0.18	0.02	95.61	2.66	1.65	0.18
9	33.00	0.80	0.56	0.07	34.41	9.60	9.21	0.22	0.16	0.02	95.90	2.32	1.62	0.20
10	12.40	3.54	0.48	0.21	16.67	8.60	6.40	1.83	0.25	0.11	74.39	21.24	2.90	1.23
11	12.00	3.93	0.81	0.25	16.97	9.60	6.79	2.22	0.46	0.14	70.71	23.14	4.79	1.46
12	13.10	0.45	0.91	0.06	14.53	10.80	9.74	0.33	0.68	0.04	90.16	3.07	6.29	0.41
13	15.00	1.18	0.36	0.21	16.74	6.40	5.73	0.45	0.14	0.08	89.61	7.05	2.12	1.23
14	22.60	2.83	0.43	0.11	25.99	16.40	14.26	1.79	0.27	0.07	86.96	10.89	1.66	0.43
15	14.90	1.30	0.94	0.71	17.86	10.00	8.34	0.73	0.53	0.40	83.43	7.27	5.26	3.97
16	5.80	2.51	1.14	0.12	9.56	8.40	5.10	2.21	1.00	0.10	60.67	26.28	11.96	1.23
17	15.10	8.22	0.86	1.29	25.46	9.80	5.81	3.16	0.33	0.50	59.31	32.27	3.39	5.05
18	12.10	3.17	0.71	0.67	16.65	10.40	7.56	1.98	0.44	0.42	72.67	19.01	4.27	4.04
19	5.80	2.52	1.14	0.59	10.05	7.80	4.50	1.95	0.89	0.46	57.71	25.06	11.37	5.90
20	16.70	0.61	0.71	0.27	18.30	13.40	12.23	0.45	0.52	0.20	91.26	3.34	3.89	1.47
21	22.10	7.35	0.56	0.27	30.28	15.60	11.39	3.79	0.29	0.14	72.99	24.27	1.85	0.91
22	18.40	6.41	0.41	0.35	25.59	15.80	11.36	3.96	0.25	0.22	71.90	25.05	1.59	1.38
23	21.00	2.49	0.79	0.45	24.73	16.60	14.10	1.67	0.53	0.30	84.92	10.06	3.18	1.83
24	9.00	3.11	0.53	0.51	13.15	8.60	5.89	2.03	0.35	0.33	68.44	23.65	4.06	3.89
25	9.80	3.16	1.17	0.54	14.67	9.00	6.01	1.94	0.72	0.33	66.80	21.56	7.96	3.70
26	11.50	1.61	0.94	0.46	14.50	11.20	8.88	1.24	0.73	0.35	79.31	11.10	6.48	3.16
27	31.90	3.90	0.56	0.30	36.65	13.80	12.01	1.47	0.21	0.11	87.04	10.65	1.52	0.82
28	13.00	4.09	0.84	0.24	18.12	8.80	6.31	1.98	0.41	0.12	71.74	22.55	4.63	1.32
29	15.20	4.09	0.48	0.75	20.54	10.80	7.99	2.15	0.25	0.39	74.00	19.91	2.35	3.65
30	17.30	1.69	0.94	0.30	20.25	14.20	12.13	1.19	0.66	0.21	85.43	8.36	4.64	1.47

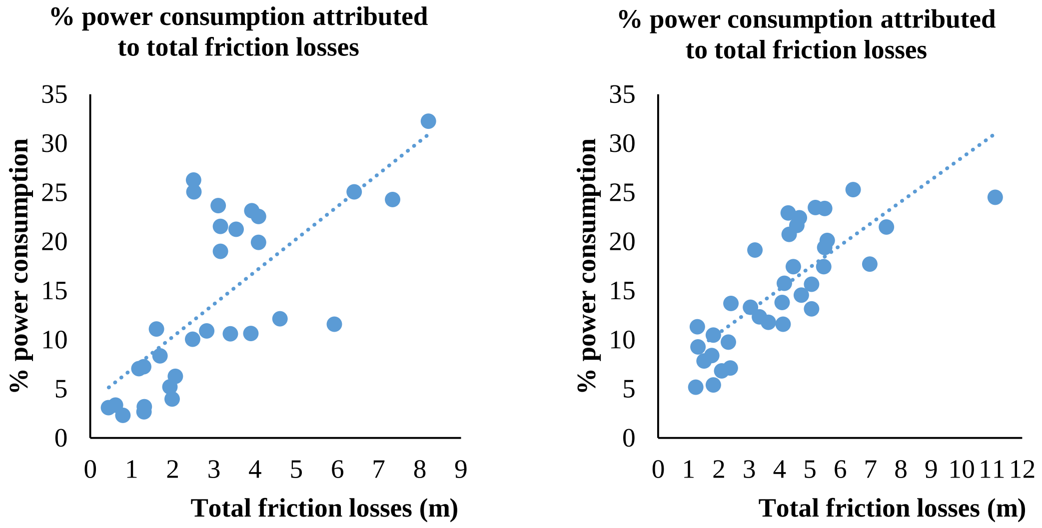
Table 5.2: Measured power consumption and power consumption attributed to different components of total head in Rai block

Tube well no.	Pumping water level, m	Total friction losses, m	Height of delivery pipe above GS, m	Velocity head loss, m	Total head, m	Measured power consumption, kWh	Power consumption (kWh) attributed to				Percentage (%) of total power consumption attributed to			
							Pumping water level	Total friction losses	Height of delivery pipe above GS	Velocity head loss	Pumping water level	Total friction losses	Height of delivery pipe above GS	Velocity head loss
31	15.85	4.58	0.61	0.12	21.16	13.00	9.74	2.81	0.37	0.07	74.91	21.65	2.88	0.55
32	11.89	1.32	0.97	0.06	14.24	6.80	5.68	0.63	0.46	0.03	83.50	9.27	6.78	0.44
33	9.35	1.30	0.61	0.21	11.46	11.60	9.46	1.31	0.62	0.21	81.59	11.33	5.32	1.79
34	21.40	4.18	0.74	0.20	26.51	10.40	8.40	1.64	0.29	0.08	80.72	15.75	2.78	0.75
35	18.35	1.77	0.77	0.21	21.11	7.20	6.26	0.60	0.26	0.07	86.93	8.40	3.67	1.01
36	15.50	5.19	0.67	0.78	22.14	10.80	7.56	2.53	0.33	0.38	70.01	23.46	3.04	3.51
37	20.10	4.47	0.86	0.21	25.64	11.60	9.09	2.02	0.39	0.09	78.39	17.43	3.37	0.82
38	30.80	6.98	1.04	0.63	39.45	13.20	10.31	2.34	0.35	0.21	78.07	17.70	2.64	1.60
39	21.75	1.25	0.95	0.20	24.15	10.20	9.19	0.53	0.40	0.09	90.06	5.16	3.94	0.85
40	26.35	3.64	0.74	0.15	30.87	13.80	11.78	1.63	0.33	0.07	85.36	11.79	2.39	0.48
41	26.50	4.73	0.91	0.35	32.49	11.20	9.14	1.63	0.32	0.12	81.56	14.55	2.81	1.07
42	18.35	6.44	0.38	0.30	25.48	10.60	7.63	2.68	0.16	0.13	72.02	25.28	1.50	1.19
43	14.25	2.41	0.47	0.47	17.60	10.80	8.74	1.48	0.29	0.29	80.97	13.71	2.67	2.64
44	30.45	4.13	0.97	0.14	35.69	11.40	9.73	1.32	0.31	0.04	85.32	11.57	2.70	0.39
45	24.40	5.46	0.91	0.55	31.33	13.20	10.28	2.30	0.39	0.23	77.88	17.44	2.92	1.77
46	26.05	5.06	0.91	0.34	32.37	15.20	12.23	2.38	0.43	0.16	80.48	15.64	2.82	1.06
47	27.70	2.10	0.69	0.31	30.79	16.40	14.75	1.12	0.37	0.16	89.96	6.82	2.23	1.00
48	26.10	7.54	0.46	0.98	35.07	12.60	9.38	2.71	0.16	0.35	74.42	21.49	1.30	2.78
49	14.65	1.82	0.56	0.35	17.39	14.00	11.79	1.47	0.45	0.28	84.24	10.49	3.21	2.03
50	16.70	1.52	0.86	0.35	19.43	15.20	13.06	1.19	0.68	0.27	85.95	7.83	4.44	1.79
51	13.70	4.30	0.53	0.23	18.76	9.00	6.57	2.06	0.26	0.11	73.03	22.91	2.84	1.22
52	14.70	4.66	0.61	0.83	20.80	10.00	7.07	2.24	0.29	0.40	70.67	22.43	2.93	3.99
53	18.40	3.05	0.81	0.65	22.91	13.60	10.92	1.81	0.48	0.39	80.31	13.30	3.55	2.85
54	15.00	4.33	0.84	0.72	20.89	9.60	6.89	1.99	0.39	0.33	71.80	20.74	4.01	3.42
55	31.10	1.83	0.74	0.25	33.92	16.80	15.40	0.91	0.36	0.13	91.69	5.39	2.17	0.75
56	22.45	3.34	0.86	0.45	27.10	14.40	11.93	1.78	0.46	0.24	82.84	12.34	3.19	1.65
57	12.30	3.20	1.04	0.16	16.70	10.60	7.81	2.03	0.66	0.10	73.65	19.14	6.24	0.98
58	24.80	4.09	0.36	0.40	29.65	13.20	11.04	1.82	0.16	0.18	83.64	13.81	1.20	1.36
59	20.70	2.33	0.69	0.12	23.83	12.00	10.42	1.17	0.35	0.06	86.87	9.76	2.88	0.49
60	17.35	5.50	0.46	0.22	23.53	12.00	8.85	2.80	0.23	0.11	73.74	23.37	1.94	0.93
61	32.80	11.12	0.69	0.75	45.36	18.20	13.16	4.46	0.28	0.30	72.31	24.52	1.51	1.66
62	21.20	5.58	0.71	0.27	27.76	15.60	11.91	3.14	0.40	0.15	76.37	20.12	2.56	0.97
63	21.50	5.50	0.74	0.61	28.35	12.40	9.40	2.41	0.32	0.27	75.84	19.40	2.60	2.15
64	32.35	5.07	0.79	0.33	38.54	14.10	11.84	1.85	0.29	0.12	83.94	13.15	2.04	0.87
65	30.10	2.39	0.94	0.15	33.58	10.20	9.14	0.73	0.29	0.05	89.64	7.12	2.80	0.44



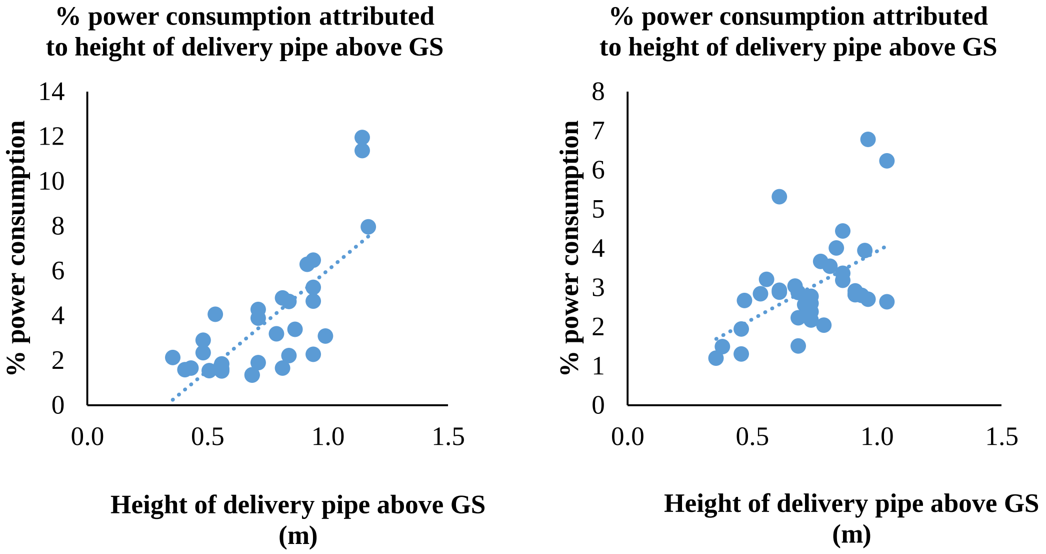
(a) (b)

Fig. 5.1: Variation of % power consumption as attributed to pumping water level for (a) Sonepat and (b) Rai block



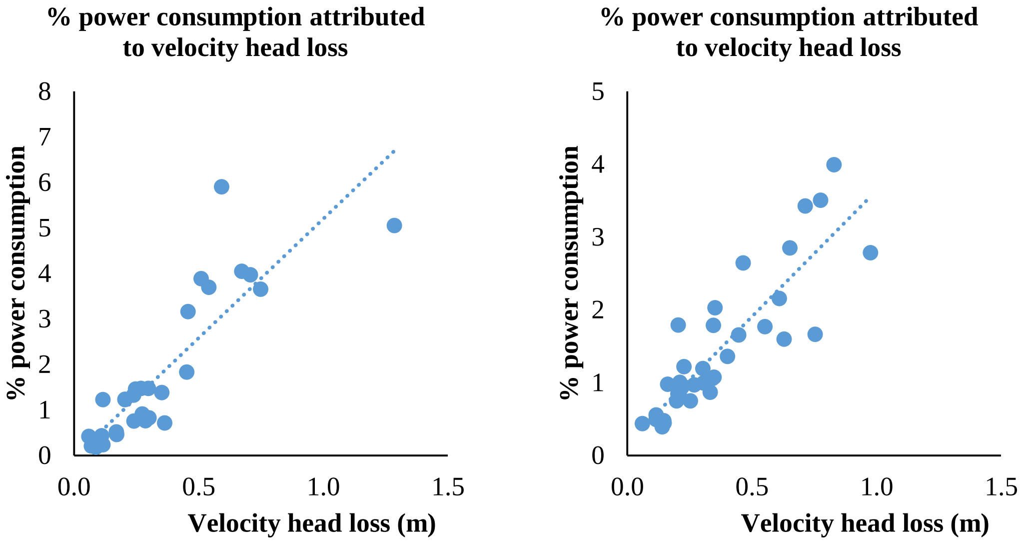
(a) (b)

Fig. 5.2: Variation of % power consumption as attributed to total friction losses for (a) Sonepat and (b) Rai block



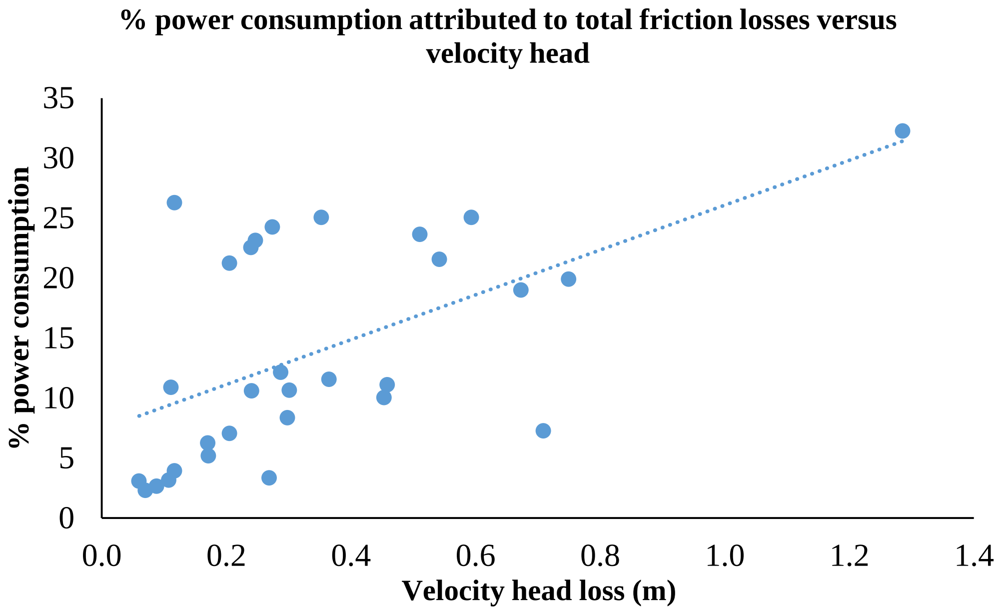
(a) (b)

Fig. 5.3: Variation of % power consumption as attributed to height of delivery pipe above GS for (a) Sonepat and (b) Rai block

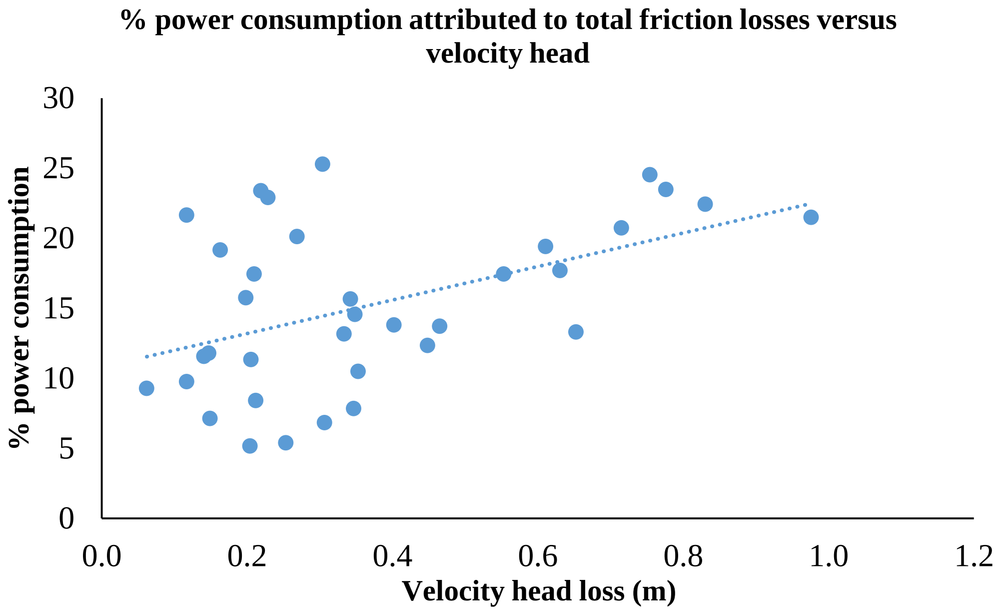


(a) (b)

Fig. 5.4: Variation of % power consumption as attributed to velocity head loss for (a) Sonepat and (b) Rai block



(a)



(b)

Fig. 5.5: Variation of % power consumption as attributed to total friction loss to velocity head loss for (a) Sonepat and (b) Rai block

5.2 Efficiency of selected tube wells

As already stated in section 3.5.1 & 3.5.2 of chapter III, three type of overall pumping efficiencies were computed for the selected tube wells of the studied area *i.e.* i) expected minimum efficiency (η_{EXP}) as per the BIS code IS 8034:2002 depending on tube well discharge & head at the site ii) pumping set efficiency based on the ratio of WHP to MHP (η_{MHP}) and iii) pumping set efficiency based on the ratio of electricity required to meet WHP to the actual electricity consumed (η_{AP}) by the tube well as measured by an energy meter.

5.2.1 Expected overall pumping efficiency (η_{EXP})

The computed value of minimum expected efficiency for different tube wells is given in Tables 4.9 & 4.10 for Sonepat & Rai block, respectively. The minimum expected overall pumping efficiency, as per BIS code depends on three factors i) discharge of tube well ii) head per stage and iii) motor horse power. Higher is the discharge of tube well, for a given value of head per stage & MHP, higher is the value of minimum expected overall efficiency. Higher is the head per stage, for a given value of discharge & MHP, lower is the value of minimum expected overall efficiency. Larger is the motor HP, for a given value of discharge & head per stage, higher is the value of minimum expected efficiency. A perusal of data (Table 5.3) indicated that the minimum expected overall efficiency varied from 42.92 to 52.36% in Sonepat block and 45.14 to 52.36% in Rai block. Tube wells having maximum & minimum value of individual factor affecting expected efficiency and those having maximum & minimum value of expected overall pumping efficiency are summarised in Table 5.3.

Table 5.3: Minimum expected overall pumping efficiency for some of the selected tube well in Sonepat & Rai blocks

Tube well no.	Discharge (Q), $l\ s^{-1}$	Head per stage (H_{stage}), m	MHP (Motor efficiency factor) *	Pump efficiency	Minimum expected overall pumping efficiency, %
53	28.10[1]	11.46	12.5 (0.77)	68.0	51.31
55	17.51	16.96[1]	15.0 (0.78)	65.0	49.69
1	11.82	12.80	20.0[1](0.80)	63.0	50.40
14	6.52	6.50	20.0[1](0.80)	61.0	48.80
6	6.43	13.80	10.0 (0.74)	58.0	42.92[2]
33	15.75	3.82	12.5 (0.77)	68.0	52.36[1]
9	5.19[2]	11.47	12.5 (0.77)	57.0	43.89
19	15.07	2.51[2]	7.5[2] (0.75)	68.0	51.00

Note: 1: Maximum value observed in the study area; 2: Minimum value observed in the study area.

* Three phase motor efficiency factor as per BIS code IS 8034:2002, which is to be multiplied to pumping efficiency to obtain the overall efficiency of pump set/tube well.

It was further observed that the expected overall efficiency for TW-53 having maximum discharge among the selected tube well was noted as 51.31%. Likewise, expected overall pumping efficiency for TW-9 having minimum discharge among the selected tube wells was noted as 43.89%. Maximum value of head per stage was observed for TW-55 with expected overall pumping efficiency of 49.69%. Minimum value of head per stage was obtained for TW-19 with expected overall pumping efficiency of 51%.

The lowest value of expected overall efficiency (42.92%) was noted for TW-6 located in the Sonepat block. This was due to relatively low value of tube well discharge (6.43 $l\ s^{-1}$) and relatively high value of head per stage (13.80 m/stage). The highest value of minimum expected overall efficiency (52.36%) was noted for TW-33 located in the Rai block. This was due to relatively low value of head per stage (3.82 m per stage) & relatively high value of tube well discharge (15.75 $l\ s^{-1}$).

The TW-24 & TW-57 having equal MHP of 7.5 HP were giving almost equal discharge of 13.98 & 14.05 $l\ s^{-1}$, respectively (Table 4.9 & 4.10). However, minimum expected overall pumping efficiency at TW-24 (48.51%) was noted higher than TW-57 (47.78%) due to lower head per stage at TW-24 (6.58 m $stage^{-1}$) than TW-57 (8.35 m per stage).

Based upon foregoing discussion, it may be suggested that in the selection of pumps for tube wells, priority must be given to high discharge pumps with minimum head per stage to obtain higher efficiency and the time of operation may be adjusted as per the required volume of water to be pumped.

A relationship was also fitted in the following form through regression:

$$\eta_{EXP} = 43.89 - 0.34 \times H_{stage} + 0.325 \text{ X } Q + 0.335 \times MHP \qquad [\ R^2 = 0.825]$$

Where,

η_{EXP}: Expected minimum efficiency, %

H_{stage}: Head per stage, m

Q: Discharge, $l\ s^{-1}$

MHP: Motor horse power, HP

Knowing the head per stage (m), tube well discharge ($l\ s^{-1}$) & MHP, the minimum expected overall efficiency can also be predicted from the above relationship. However, it may be noted that this relationship is valid only for i) three or more stages pump sets ii) motor rating 1.1 kW to 15 kW iii) bore size up to 200 mm.

5.2.2 Efficiency of tube wells based on motor horse power (η_{MHP})

As stated in section 3.5.1, the efficiency of tube well based on MHP was estimated as the ratio of WHP to MHP. Since all the tube wells were fitted with submersible motor, the information on MHP as informed by the concerned farmer was used to estimate the efficiency of tube well based on MHP. The electricity charges for tube wells in the study area were based on flat rate *i.e.* fixed monthly charges depending on the MHP. It might be possible that some of the farmers might not have given the correct information related to HP for obvious reasons. For instance, the TW-17, 48 & 61, the overall efficiency based on MHP was computed as 99.1, 89.2 & 81.1%, respectively (Table 4.11 & 4.12), which seems to be unpredictable. Anticipating this type of problem, the actual power consumption by the tube well in the study area was measured to compute the overall efficiency of tube wells. Further, the efficiency of tube well based on MHP is only useful when the tube well is being operated at the duty point of the pump used. When the load on the motor is either less or more than that corresponding to duty point, the power consumption by the tube wells would be different than that computed as per the HP of the motor. In view of the above reason, the computed value of efficiencies of tube wells based on MHP will not be discussed further.

5.2.3 Efficiencies of tube wells based on actual power consumption (η_{AP})

The overall efficiencies of selected tube wells based on actual power consumption (η_{AP}) *vis a vis* motor horse power (η_{MHP}) and BIS based expected minimum efficiency (η_{EXP}) are shown in Fig. 5.6 & 5.7 for Sonepat & Rai block, respectively. As stated in section 3.5.1, the efficiency of tube well based on actual power consumption was computed as the ratio of estimated power consumption based on WHP to actual measured power consumption. The overall efficiencies of selected tube wells as computed based on actual measured power consumption varied from 10.1 to 56.6% in Sonepat block (Table 4.11 & Fig. 5.6) and 15.3 to 52.8% in Rai block (Table 4.12 & Fig. 5.7).

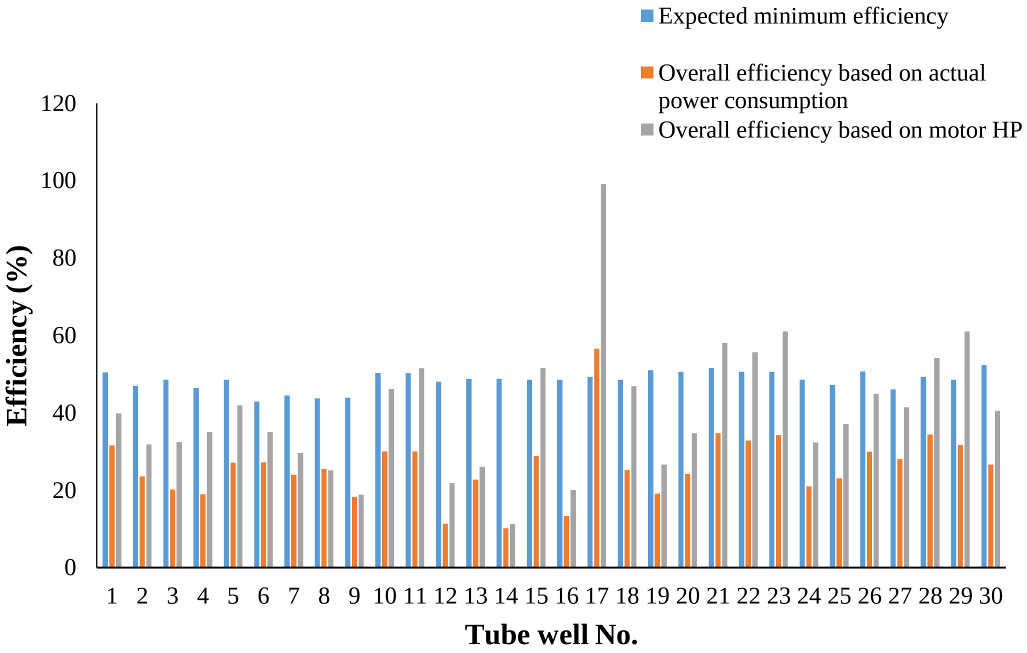


Fig. 5.6: Overall efficiencies of selected tube wells based on actual measured power consumption *vis a vis* motor horse power and expected minimum efficiency of Sonepat block

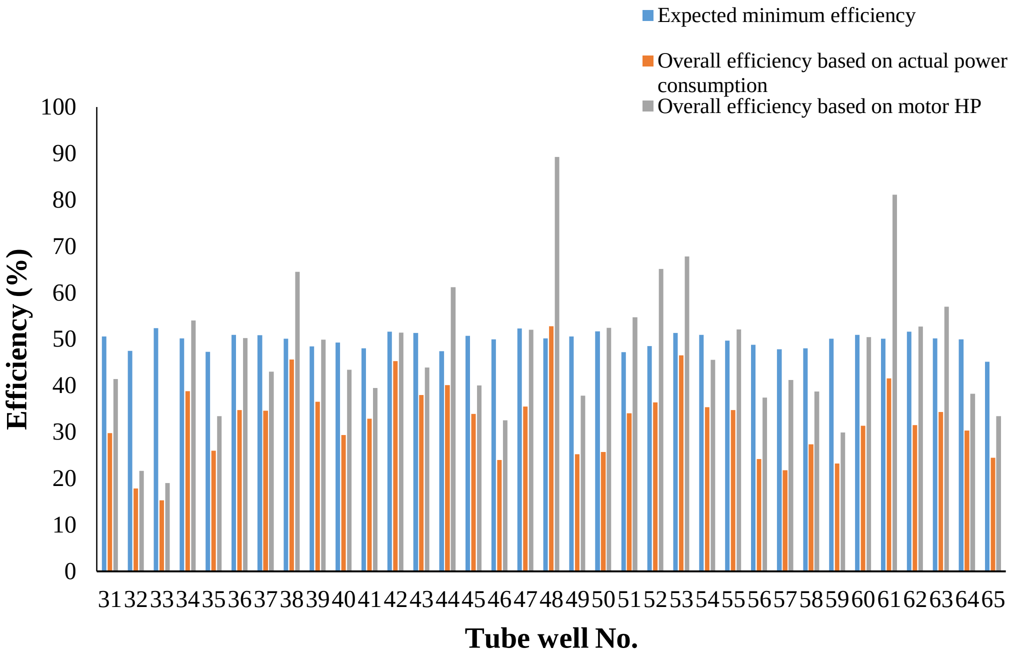


Fig. 5.7: Overall efficiencies of selected tube wells based on actual measured power consumption *vis a vis* motor horse power and expected minimum efficiency of Rai block.

It can be seen that the actual overall efficiency of only two of the selected tube wells (TW-17 & TW-48) was higher than the minimum expected overall efficiency in the study area. The actual overall efficiency of TW-17 was noted as 56.6% (Table 4.11 & Fig. 5.6) against the minimum expected overall efficiency of 49.25% (Table 4.9 & Fig. 5.6), while the actual overall efficiency of TW-48 was noted as 52.8% against the minimum expected overall efficiency of 50.16% (Table 4.10). The possible reason for good efficiency of these tube wells may be that both the tube wells were newly installed at the time of observation *i.e.*, TW-17 (8-month-old) and TW-48 (3-month-old).

In order to identify the reasons for relatively low overall efficiency of other tube wells in the study area, some of the tube wells are discussed in brief.

Tube well 12 &14: Tube well 12 & 14 were found to be working at overall efficiency of 11.3 & 10.1% (Table 4.11), respectively. Some of the salient features of TW-12 & 14 are summarised below :

TW No.	Q, lps	H, m	WHP	Actual MHP	Power consumption, kW		Efficiency, %		
					Required/estimated as per MHP	Measured	Minimum expected	MHP	Power consumption
12	8.53	14.53	1.63	7.5	5.6	10.8	48.0	21.8	11.3
14	6.52	25.99	2.23	20.0	14.9	16.4	48.8	11.2	10.1

Exceptionally higher consumption of electric power by TW-12 (10.8 kWh against expected 5.6 kWh) indicates that the motor is overloaded due to some mechanical fault, as load due to WHP was only equivalent to 1.22 kW (WHP = 1.63), be it misaligned impeller, bearing failure, lack of lubrication etc. Only slightly higher consumption of electric power by TW-14 (16.4 kWh against expected 14.9 kWh) suggests two possible reasons for low efficiency i) mechanical fault and ii) poor hydraulic efficiency of pump. The poor hydraulic efficiency of pump may be due to improper selection of pump as per the site condition and wear & tear of pumping element.

TW-53 & 59: TW 53 & 59 were found to be working at overall efficiency of 46.5 & 23.2% (Table 4.12), respectively. Both these tube wells were reported to be fitted with 12.5 HP submersible pump & had almost equal total head i.e. 22.91 m for TW-53 & 23.83 m for TW-59. The only difference was that TW-53 was fitted with relatively new submersible pump (2 year old) as compared to TW-59 (15 year old).

TW No.	Q, lps	H, m	WHP	Actual MHP	Power consumption, kW		Efficiency, %		
					Required/estimated as per MHP	Measured,	Minimum expected	MHP	Power consumption
53	28.10	22.91	8.47	12.5	9.3	13.6	51.31	67.8	46.5
59	11.90	23.83	3.73	12.5	9.3	12.0	50.05	29.9	23.2

Further interaction with the concerned farmer revealed that the motor of TW-59 was got repaired from local mechanic for rewinding & bush maintenance. The low efficiency of TW-59 as compared to TW-53 is due to less discharge of TW-59 (11.90 l s^{-1}) as compared to TW-53 (28.10 l s^{-1}). The possible reason for low efficiency of TW-59 may be i) poor repair ii) wear & tear of pumping element over a period of 15 years.

TW-48 & 44: Similarly, TW-48 & 44 had equal MHP of 10.0 HP and almost same total head of 35.07 & 35.69 m (Table 4.10), respectively. However, the actual overall efficiency estimated for TW-48 & 44 was reported 52.8 & 40.1% (Table 4.12), respectively. The tube well 48 & 44 were established 3 month and 12 years before this study, respectively.

TW No.	Q, lps	H, m	WHP	Actual MHP	Power consumption		Efficiency, %		
					Required/estimated as per MHP	Measured, kW	Minimum expected	MHP	Power consumption
48	19.32	35.07	8.92	10.0	7.46	12.6	50.16	89.2	52.8
44	13.04	35.69	6.12	10.0	7.46	11.4	47.36	61.2	40.1

Hence, TW-48 had new motor and pump, that did not face any problem at the time of this study, while TW-44 had undergone a major repair of its submersible motor and pump. This factor has contributed to major difference in actual overall efficiency of these tube wells.

It is stated that in the vicinity of the study area, there is non-availability of any authorised service centre of submersible motor and pumping sets by the manufacturing company. The farmers generally go to the nearest available local mechanic for repairing their motor and pump. The local mechanic, who is not so trained and also not having appropriate apparatus, machines and tools for repairing these motors & pumps and also do not use official parts and good quality material during repairing, which effects the performance of motor & pump. Hence, the system delivers less overall efficiency in actuality.

TW-55 & 46: The effect of voltage on actual overall efficiency was examined by comparing TW 46 and TW 55, both were having same MHP of 15.0 HP and operating at almost equal total head i.e. TW 46 (32.37 m) and TW 55 (33.92 m) (Table 4.10).

TW No.	Q, $l\ s^{-1}$	H, m	Voltage, V	Actual MHP	Actual overall efficiency, %	Measured power consumption, kW
55	17.51	33.92	392	15.0	34.7	16.8
46	11.45	32.37	270	15.0	23.9	15.2

However, there was voltage difference at the time of observation TW-46 (270 V) & TW-55 (392 V) (Table 4.6) and the actual overall efficiency was recorded 23.9 and 34.7% in TW-46 and TW-55 (Table 4.12), respectively. It was reported that both the submersible tube wells had undergone through repairing. Hence one of the possible reasons for low efficiency of TW-46 may be due to very low supply voltage 270 V against standard requirement of 415 V.

In summary, different tube wells of the study area can be categorised into the following categories in relation of the computed values of overall efficiencies based on actual power consumption (η_{AP}), motor horse power (η_{MHP}) & BIS based expected minimum efficiency (η_{EXP}).

1) $\eta_{AP} \simeq \eta_{MHP} < \eta_{EXP}$ [*e.g.* TW no. 8,9,14]

The low η_{AP} may be attributed to

- Improper selection of pump
- Poor efficiency of pump sets

2) $\eta_{AP} < \eta_{MHP} < \eta_{EXP}$ [*e.g.* TW no. 1,2,3,4,5,6,7 & several others]

The low η_{AP} may be attributed to

- Excessive load on motor due to severe friction between the moving & stationary parts
- Improper selection of pump
- Poor efficiencies of pump sets
- Improper voltage supply

3) $\eta_{AP} \geq \eta_{EXP}$ [*e.g.* TW no. 17 & 48]

The performance of tube wells in this category indicates that with proper selection & operation, it is possible to achieve the minimum expected efficiency under field conditions.

4) $\eta_{AP} < \eta_{EXP} \leq \eta_{MHP}$

[*e.g.* TW no. 11,15,21,22,23,28,29,34,36,38,39,42,44,47,50,51,52,53,55,61,62,63]

The tube wells in this category emphasise the need to compute the efficiency of tube wells based on actual power consumption rather than based on MHP, as the efficiency computed based on MHP give wrong impression that the tube well is working efficiently.

5.3 Pumping energy requirement for different crops

The amount of irrigation water to be pumped by the tube well is directly related to the water consumption of crops during the growth period minus effective rainfall. Irrigation in Sonepat and Rai block is mostly done by the means of electric submersible tube wells. Electricity consumption for pumping is based on the crop water requirement, water table depth, pumping set efficiency, water application efficiency and total area under irrigation.

Wheat, paddy, sugarcane and cotton were the major crops in the study area (Fig. 5.8). Required gross depth of irrigation based on average water application efficiency of 62.58% (Table 4.12) in the study area for different major crops was 51.8 cm for wheat, 99.7 cm for sugarcane, 59.8 cm for cotton and 155.5 cm for paddy (Fig. 5.9).

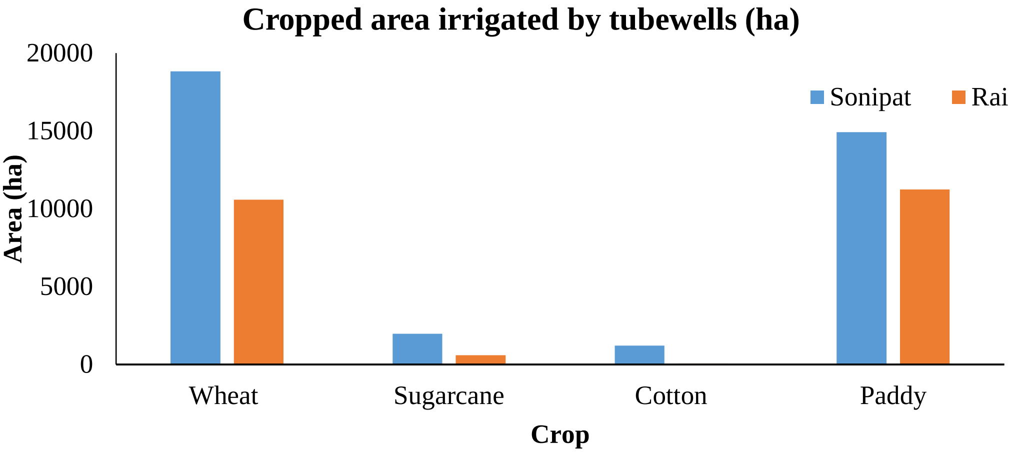


Fig. 5.8: Cropped area irrigated by tube wells (ha) of major crops in Sonepat and Rai Block

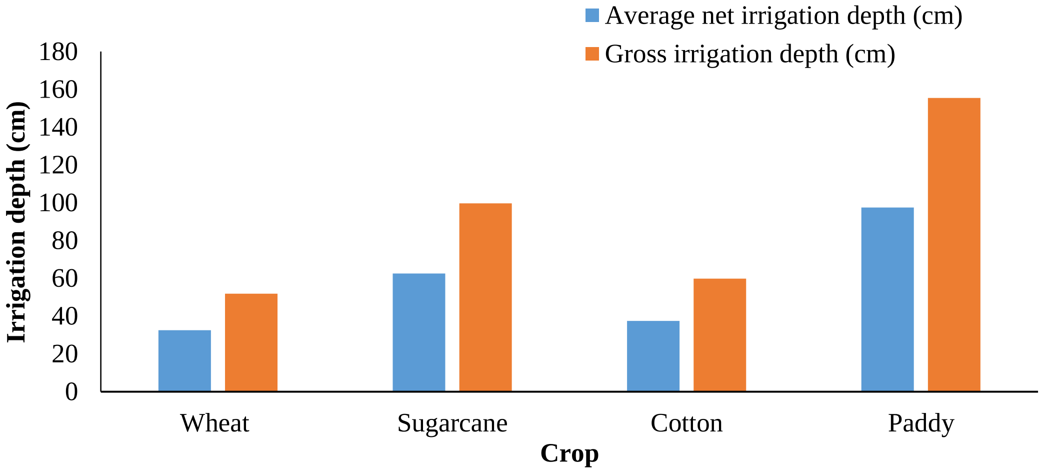


Fig. 5.9: Average net and gross irrigation depth of major crops

The water table depth in the study area was being monitored by the Groundwater Cell of Agriculture Department, Govt. of Haryana through a network of observation wells. Groundwater depth is recorded twice in a year *i.e.*, in the month of June (pre-monsoon depth) and October (post monsoon depth). The average groundwater depth for the years 2020 (average of June & October values) was 15.97 and 8.57 m for Rai and Sonepat blocks (Fig. 5.10).

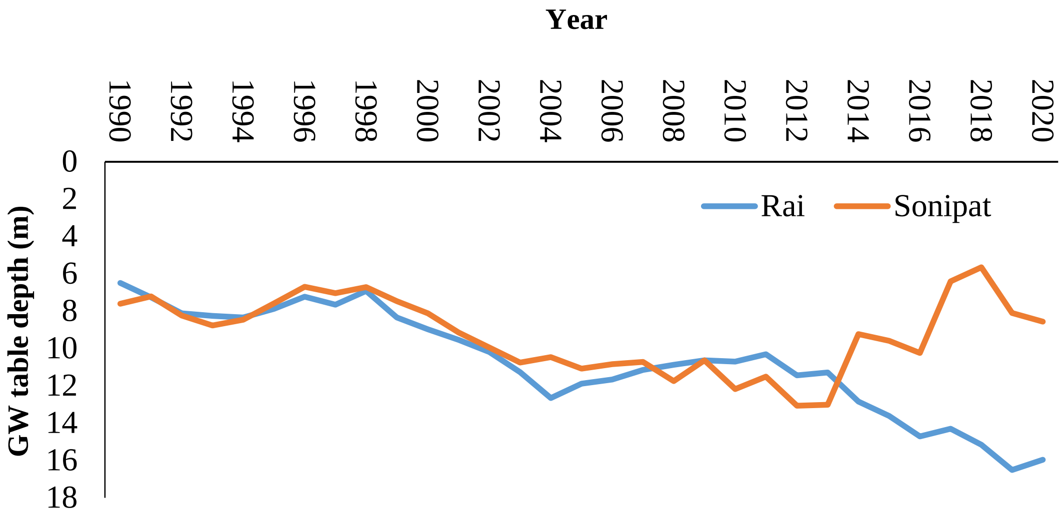
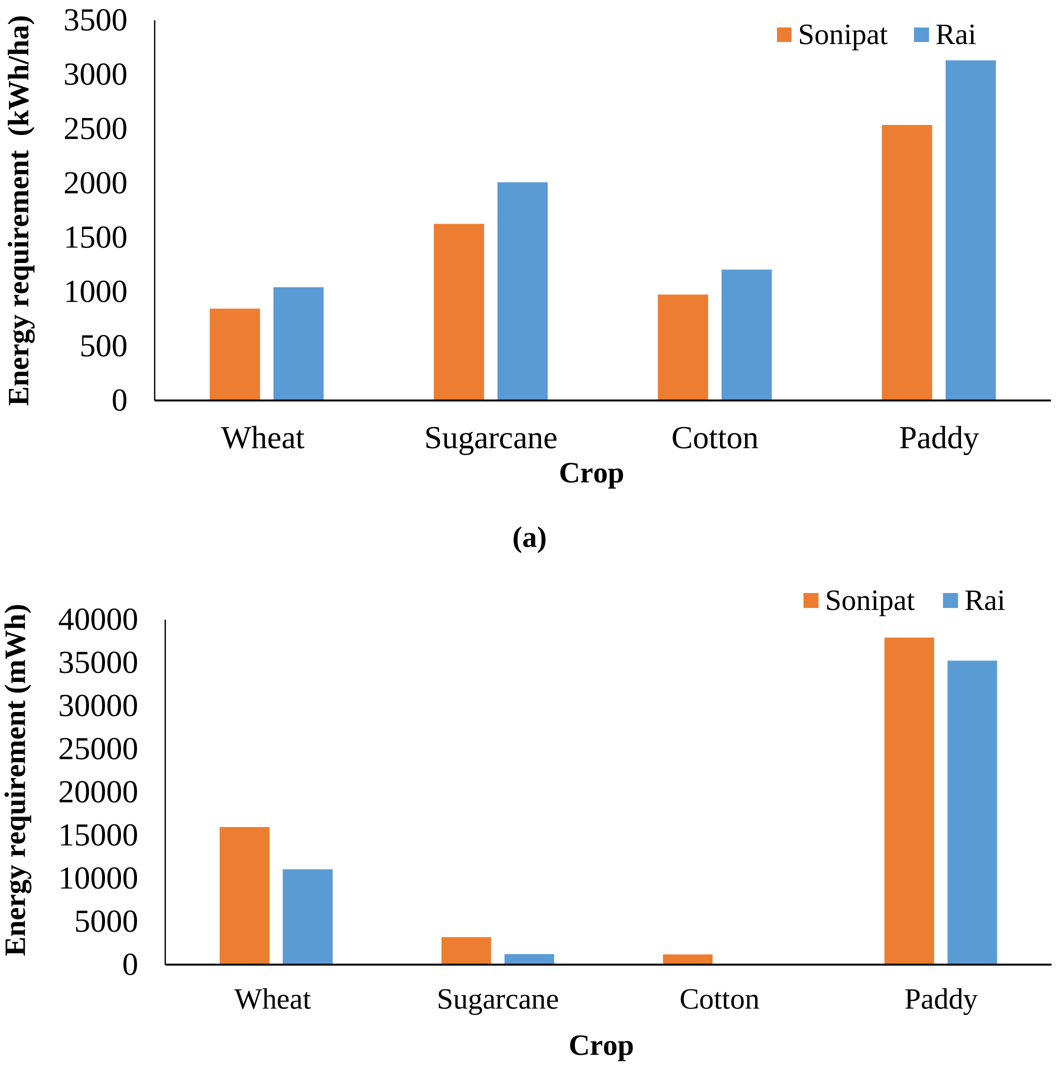


Fig. 5.10: Annual average ground WT depth in Sonepat and Rai block

Groundwater pumping energy requirement for different crops (kW ha^{-1}) in the study area for the year 2020 was computed using equation 3.18 and is shown in Fig. 5.11a. Despite higher overall efficiency of tube wells in Rai block (32.52%) as compared to Sonepat block (26.10%). Relatively high energy requirement in the Rai block for different crops is due to deeper groundwater depth in the Rai block as compared to Sonepat block. Further it may be noted that the energy requirement for paddy crop is much higher than other crops (Fig. 5.11) due to its high-water requirement (Fig. 5.9). Similar observations were realized by Khan *et al.* 2010. The annual energy requirement (kW ha^{-1}) in the study area for different crop rotation is also shown in (Fig. 5.12). Note that sugarcane is an annual crop while other crops are seasonal and are often taken on the same field in rotation *e.g.* Paddy-wheat, cotton-wheat etc. Therefore, annual energy requirement for sugarcane is less than the other crop rotation prevalent in the study area. Hence, if reduction in energy consumption for groundwater pumping is to be achieved, the first priority must be paid to the paddy-wheat rotation followed by cotton- wheat rotation. The estimated total energy consumption for groundwater pumping considering the total area under different crops & water table depth for the year 2020 with overall average actual efficiency of 26.10 and 32.52% in the Sonepat and Rai block, respectively, for major crops is shown in (Fig. 5.11b). Despite high energy requirement per hectare in Rai block, the total energy consumption in Rai block is less as compared to Sonepat block is due to less area under different crops in the Rai block as compared to Sonepat block.



(a)

(b)

Fig. 5.11: Per Hectare (a) and Total (b) estimated annual energy requirement for major crops in Sonepat and Rai block

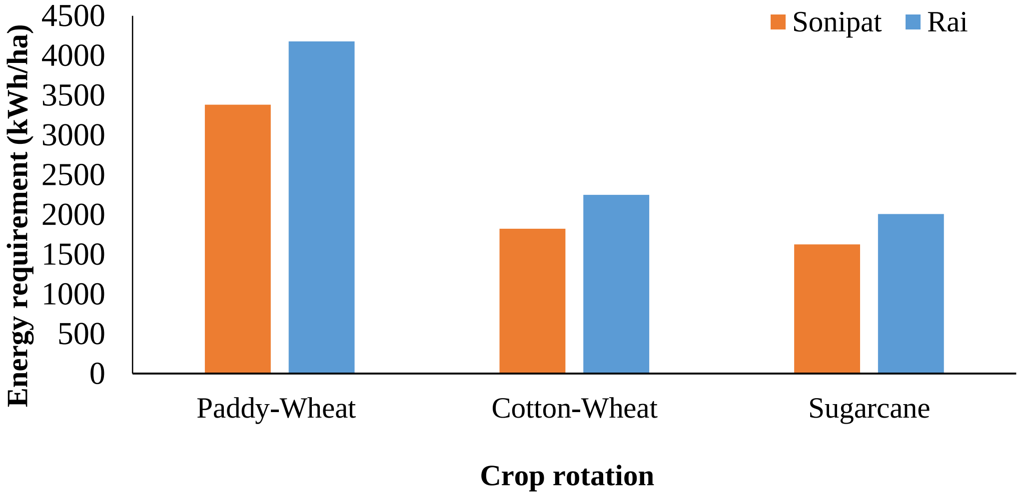


Fig. 5.12: Per Hectare estimated annual energy requirement for different crop rotation in Sonepat and Rai block

5.4 Evaluation of different irrigation and management practices in terms of energy consumption and water saving

To examine the water saving and energy consumption under different irrigation practices in wheat crop, volume of water pumped out was calculated on the basis of discharge and running time of electrical submersible tube well to irrigate different treatments for each irrigation event. Accordingly, depths of irrigation, water application efficiency, water distribution efficiency, water use efficiency (WUE) were determined for each treatment to see the effect of different management practices on energy consumptions and water saving.

5.4.1 Depth of irrigation

The required net depth of irrigation for different irrigation events for wheat crop varied from 5.51 to 6.25 cm with mean depth of 5.87 cm during 2017-18 and 5.59 to 6.32 cm with a mean depth of 5.93 cm during 2018-19 (Table 4.14).

A fixed depth *i.e.* 6.00 cm was applied in treatment T_4 (micro irrigation) for all the irrigation events during both the years. For other treatments, as per the prevalent practice of surface irrigation, water was applied till the water advance reached the end of the border strip. The mean applied depth of irrigation for different surface irrigation treatments (T_1, T_2, T_3 & T_5) varied from 6.66 to 8.53 cm during 2017-18 and 6.83 to 9.34 cm during 2018-19 (Table 4.15). The applied irrigation depth among surface irrigation treatments was observed highest for treatment T_5 (Farmers' practice) & lowest for treatment T_3 (Laser land levelling field) during both the years of study. Similar results were observed by (Naresh *et al*. 2014). Stored depth of irrigation varied among different treatments during both the years of study. No fixed trend was observed in stored depth of irrigation. However, relatively less stored depth was recorded in treatment T_4 (micro irrigation) due to application of fixed depth (6.00 cm) of water during all the irrigation events in both the years of the study period (Table 4.16). The mean applied depth based on stream discharge for different surface irrigation treatments (T_1, T_2, T_3 & T_5) varied from 6.88 to 8.96 cm during 2017-18 and 7.06 to 9.82 cm during 2018-19 (Table 4.17). The maximum applied irrigation depth based on stream discharge among surface irrigation treatments was observed in treatment T_5 (Farmers' practice) and minimum in treatment T_3 (Laser land levelling field) during both the years of study. Slight difference in the depth of water applied (as estimated based on infiltration opportunity time) and depth of water delivered (as estimated based on inflow stream discharge and cut off time) in surface irrigation treatments was observed. The difference in applied and delivered depth may be attributed to i) conveyance losses in the channel from location of submersible tube well to entry point of water to experimental plot ii) spatial variability in infiltration characteristics. Different irrigation depths averaged over the two seasons for different treatments is given in Fig. 5.13

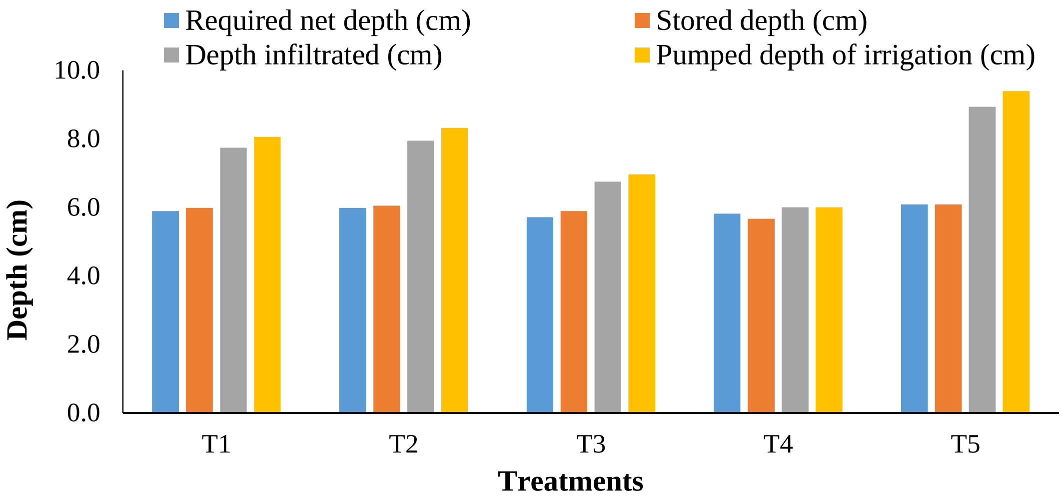


Fig. 5.13: Different irrigation depths (cm) for various treatments

5.4.2 Efficiency of irrigation

Water application efficiency during different irrigation events varied between 66.9 to 97.9 % and 61.7 to 97.6 % in the years 2017-18 and 2018-19, respectively (Table 4.18). Maximum application efficiency was recorded in treatment T_4 (Micro sprinkler irrigation) in both the year. Similarly, it was least for treatment T_5 (Farmer's practice) in both the years. Likewise, other researchers observed better results in micro sprinkler irrigation (Rana *et al*. 2006 and Liu *et al*. 2013). Water distribution efficiency for different irrigation events varied between 84.2 to 95.1% and 83.6 to 94.4% in the years 2017-18 and 2018-19, respectively (Table 4.19). Highest water distribution efficiency was obtained in treatment T_4 (Micro sprinkler irrigation) in both the year. Similarly, it was lowest for T_5 (Farmer's practice) in both the years.

Among the surface irrigation, treatment T_3 (Border irrigation with laser guided land levelling having 0.3% longitudinal slope) had better water application efficiency (87.5%). Similar observations were found by (Abdullaev *et al*. 2007) and water distribution efficiency (91.8%) in both the seasons on average basis after treatment T_4 (micro sprinkler irrigation). Water application and distribution efficiency averaged over the two seasons for different treatments is also shown in Fig. 5.14.

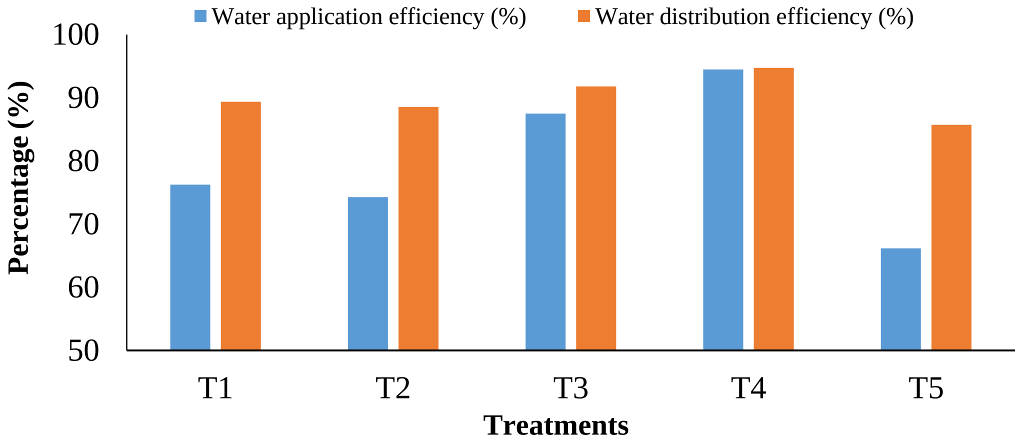


Fig. 5.14: Water application and distribution efficiency for various treatments

5.4.3 Yield and Water use efficiency

Grain yield (q ha^{-1}) varied between 37.6 to 45.0 q ha^{-1} and 38.1 to 46.1 q ha^{-1} in the years 2017-18 and 2018-19, respectively (Table 4.21). It was highest in treatment T_4 (Micro sprinkler irrigation) in both the year. Similar results were observed by (Liu *et al*. 2013 and Sharma *et al*. 2018). Likewise, it was least in treatment T_5 (Farmer's practice) in both the years. The grain yield among different treatments differed significantly during both the years. Straw yield (q ha^{-1}) ranged between 47.1 to 56.8 q $ha^{-1}$and 49.5 to 60.4 q ha^{-1} in the years 2017-18 and 2018-19, respectively. It was highest in treatment T_4 (Micro sprinkler irrigation) in both the year. Similarly, it was least in treatment T_5 (Farmer's practice) in both the years. Straw yield also differed significantly among all the treatments during both the years. Total irrigation depth applied (cm) ranged from 36 to 53.8 cm and 36 to 59.0 cm in the years 2017-18 and 2018-19, respectively. It was lowest in treatment T_4 (Micro sprinkler irrigation) in both the years due to application of recommended fixed depth of irrigation for wheat crop. Similarly, it was highest for treatment T_5 (Farmer's practice) in both the years due to larger plot size non-graded field for same discharge of tube well (Table 4.21). Total irrigation depth applied, grain and straw yield averaged over the two seasons for different treatments is given in Fig. 5.15.

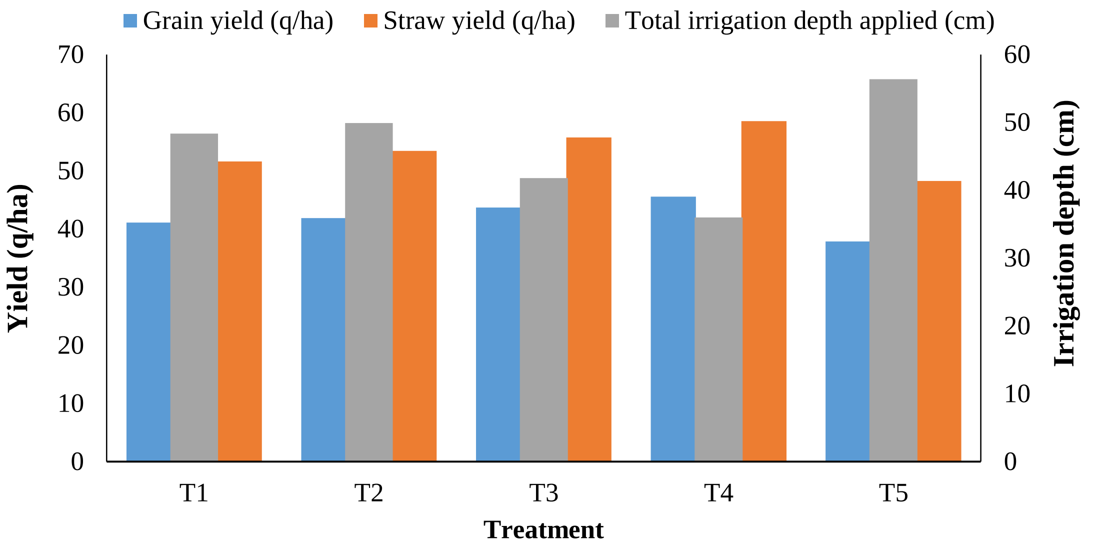


Fig. 5.15: Total irrigation depth applied, grain and straw yield for various treatments

Water use efficiency (WUE) for grain was calculated by dividing the respective yield by the total irrigation depth applied. WUE Grain (q $ha^{-1}cm^{-1}$) varied between 0.7 to 1.25 q ha^{-1} cm^{-1} and 0.65 to 1.28 q ha^{-1} cm^{-1} in the years 2017-18 and 2018-19, respectively. It was maximum in treatment T_4 (Micro sprinkler irrigation) in both the year. Likewise, it was minimum for treatment T_5 (Farmers' practice) in both the years. The water use efficiency differed significantly among all the treatments during both the years except in treatment T_2 in the year 2017-18. Similar outcomes were found by (Rana *et al*. 2006). Highest grain yield, straw yield and WUE of grain was obtained in treatment T_4 (micro sprinkler irrigation) is due to application of recommended irrigation depth and uniform distribution of water over the field (Table 4.21). Water use efficiency (WUE) for grain averaged over the two seasons for different treatments is given in Fig. 5.16

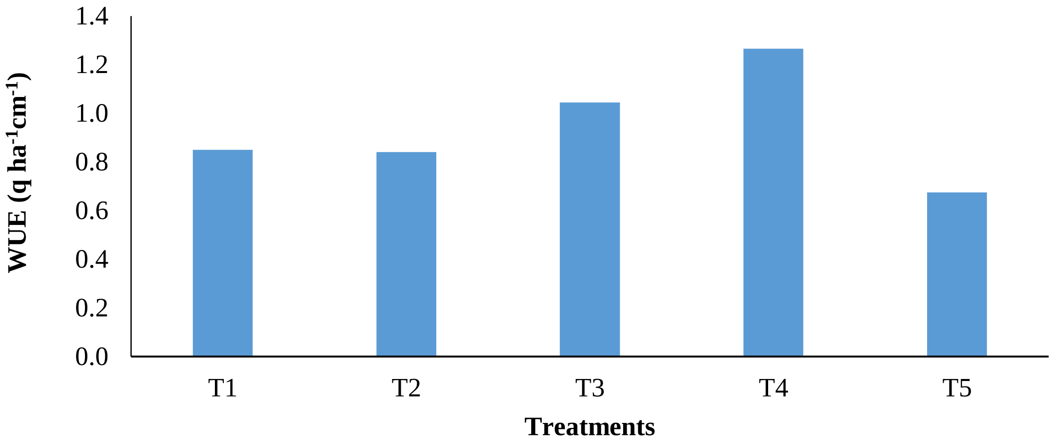


Fig. 5.16: Water use efficiency for grain (WUE_{Grain}) in various treatments

5.4.4 Energy utilization and water use

Energy consumption for groundwater pumping during complete growing season for wheat crop varied between 1000.1 to 1399.2 kWh ha^{-1} and 1025.2 to 1427.3 kWh ha^{-1} in the years 2017-18 and 2018-19, respectively among the different treatments. It was found lowest in treatment T_3 and highest (1399.2 kWh) in treatment T_4 in the year 2017-18. Proper grading of field contributed to improve water application efficiency, thereby reducing the energy consumption in T_3. However, during the year 2018-19 highest energy consumption (1427.3 kWh) was recorded in treatment T_5. Higher energy consumption in T_4 (Micro sprinkler irrigation) despite lowest water use can be attributed to the need for extra energy required to operate the micro irrigation system. Higher energy consumption in the year 2018-19 as compared to the year 2017-18 was due to application of higher irrigation water depth (Table 4.20).

Volume of irrigation water applied over the two study years for wheat crop is calculated for different treatments based on total irrigation depth applied over the crop growing season and is converted to m^3 ha^{-1} for comparison and it is given in Table 4.20. Volume of irrigation water applied (m^3 ha^{-1}) in different treatments varied between 3600 to 5378.2 m^3 ha^{-1} and 3600 to 5893.4 m^3 ha^{-1} in the years 2017-18 and 2018-19, respectively. Least volume of irrigation water was applied in treatment T_4 (Micro sprinkler irrigation) in both the year. This was same in both years as a fixed depth *i.e.* 6.00 cm was applied during all six irrigations in the treatment T_4. Maximum volume of irrigation water was applied in farmers' practice treatment (T_5) in both years due to lower water application efficiency.

Energy consumption and volume of irrigation water applied over the two seasons for different treatments is given in Fig. 5.17 and 5.18, respectively.

Therefore, it may be concluded that for the prevailing water table condition & irrigation water requirements, use of laser levelled fields may be adopted to minimize the energy consumption. Although use of micro sprinkler irrigation has the maximum potential to save water but it may not necessarily result in energy saving due to the need of extra energy required to operate the system.

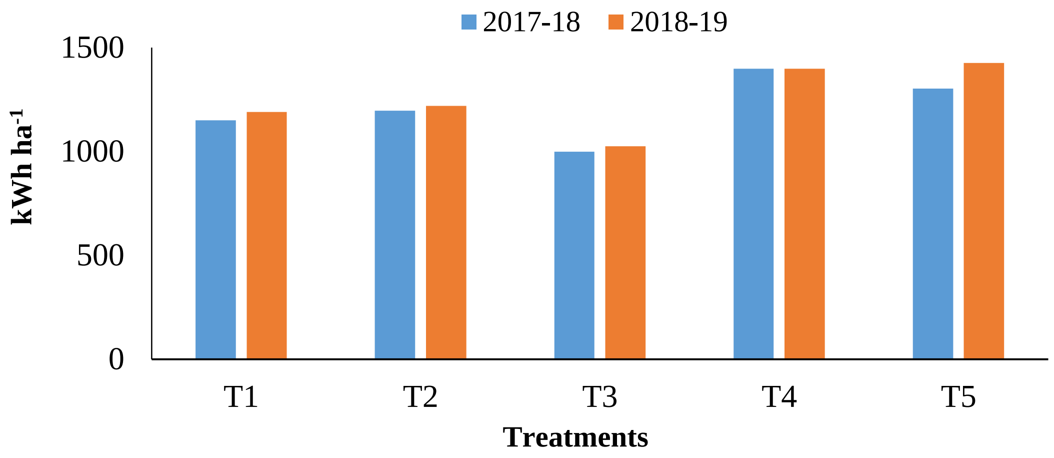


Fig. 5.17: Energy consumption (kWh ha^{-1}) in different treatments during 2017-18 and 2018-19

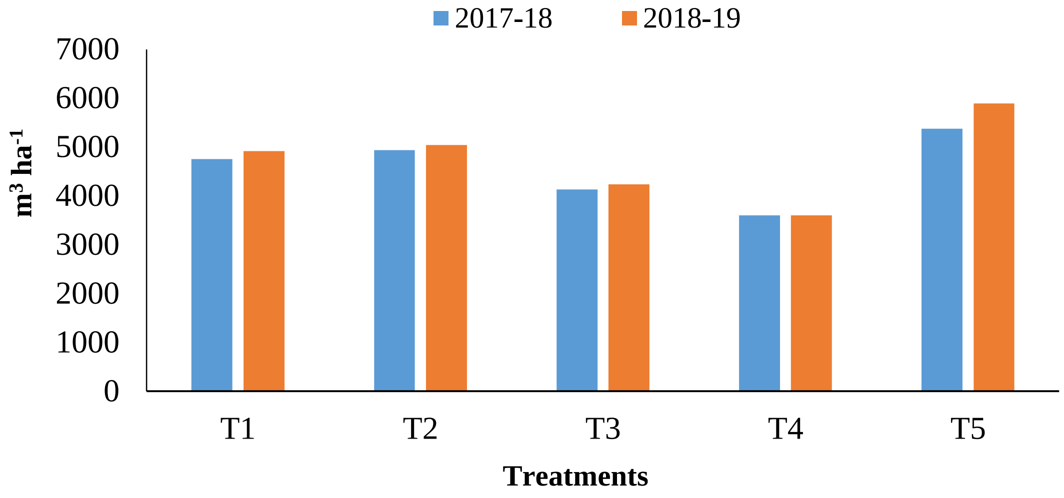


Fig. 5.18: Volume of irrigation water applied (m^3 ha^{-1}) in different treatments during 2017-18 and 2018-19

5.5 Assessment of potential energy saving for groundwater pumping

Based on discussion in the previous sections, it may be stated that most of the pump sets working in the study area are not efficient, due to improper selection and poor maintenance of the pumps. Declining groundwater depth in the Rai block has resulted into increase in energy demand over the years & there is need for improvement of water application efficiency and groundwater status in the study area. Accordingly, assessment has been made for the potential energy saving for groundwater pumping in the study area through suitable interventions. However, it may be noted that the total potential energy saving as a result of implementing all the proposed interventions would not be the same as some of the potential energy saving for individual intervention.

i. Replacement of inefficient pump sets

The tube well pumping sets in the study area were found to be working at an overall average actual efficiency of 26.10 & 32.52% (Table 4.11 & 4.12) against the minimum expected average efficiency of 47.62 & 49.74% in Sonepat & Rai block, respectively. Further, it was also observed that some of the tube wells (*e.g.* 17 & 48) were found to be working at reasonably good efficiency, which was higher than the respective expected minimum efficiency. The annual energy needed in the study area for different major cropping pattern (kW ha^{-1}) at present average level of efficiency and that needed if the pumps can be operated at the minimum expected efficiency is shown in Fig. 5.19 & 5.20.

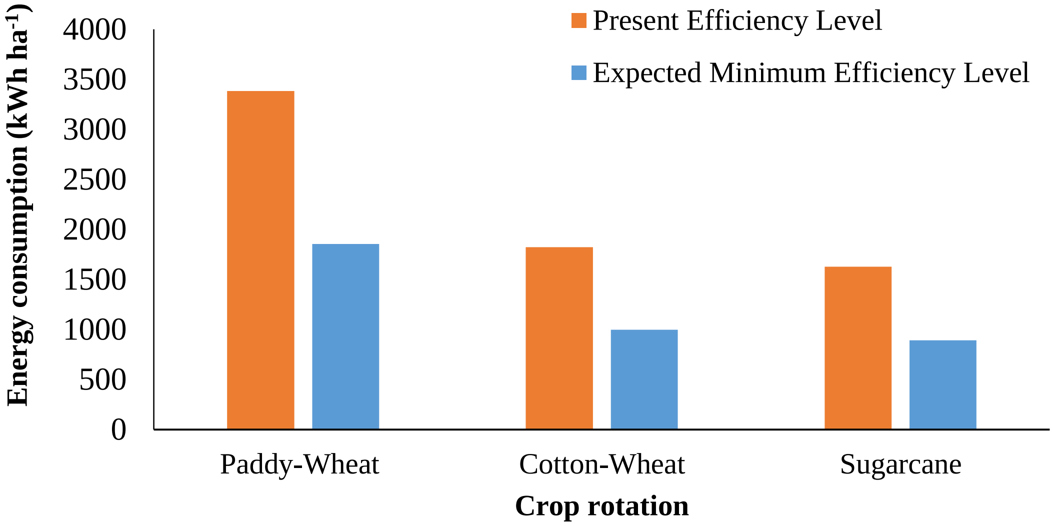


Fig. 5.19: Per Hectare energy consumption in the study area for major cropping patterns at present and minimum expected level of efficiency in block, Sonepat

It can be observed from the figure Fig. 5.19 & 5.20 that there is great potential for energy saving in the study area by replacing the existing pump sets with suitable efficient pump sets. However, the above intervention will be difficult to implement in Rai block, where water table is declining at relatively rapid rate as compared to that in the Sonepat block. Under declining groundwater condition, properly selected pump according to the groundwater depth at the time of installation may soon become less efficient due to the more rapidly changing groundwater depth with time. Therefore, in Rai block, until and unless suitable measures to control decline in groundwater depth is undertaken (such as groundwater recharge and crop diversification towards less water demanding crops), it may be very expensive to frequently replace the pumping sets to suit the resulting head on the pump due to declining groundwater depth. However, in Sonepat block, where groundwater is not declining very rapidly, immediate replacement of existing inefficient pump sets with properly selected and efficient pump sets may be attempted to achieve the potential energy saving in groundwater pumping.

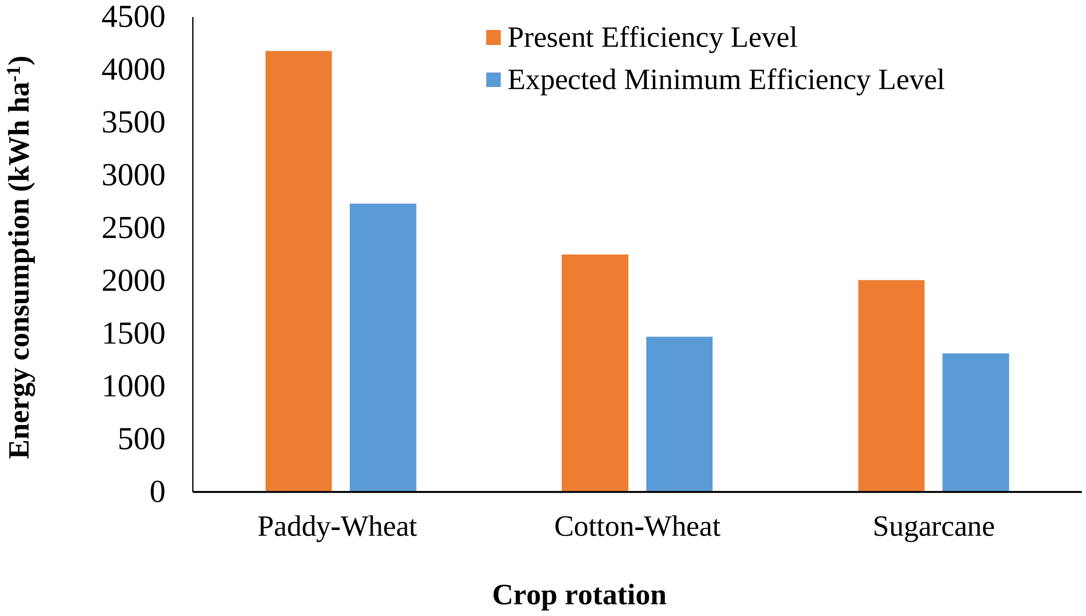


Fig. 5.20: Per Hectare energy consumption in the study area for major cropping patterns at present and minimum expected level of efficiency in block, Rai

ii. Proper maintenance of existing pump sets

Consumption of excessively higher energy by most of the pump sets as compared to expected energy consumptions based on installed pump HP in the study area indicates that poor maintenance of pump sets is contributing a lot towards wasteful use of energy for the purpose of groundwater pumping. Assuming 8-hours of operation per day, typical computation for potential energy saving as a result of proper maintenance of pump sets in the study area for the selected tube wells is given in Table 5.4 & 5.5 for Sonepat and Rai block, respectively.

It is evident from the above table that for different tube wells, proper maintenance can lead to substantial energy saving varying between 2.2 kWh to 58.8 kWh for 8-hrs working in Sonepat block and from 9.6 kWh to 71.0 kWh in Rai block, respectively. Considering the total number of operating hours of tube wells in a year and the total number of electric submersible tube wells *i.e.* 6897 in Sonepat block and 5136 in Rai block during the year 2018-19 (Dept. of Agriculture, Sonepat, Haryana). It can be stated that there is lot of scope for energy saving for groundwater pumping through proper maintenance of tube wells in the study area.

Table 5.4: Potential energy saving of 8-h of tube well operation in Sonepat, block under the assumption that properly maintained pump sets will require energy consumption as per MHP

TW No.	Expected energy consumption as per MHP, kWh*	Measured actual power consumption, kWh	Potential energy saving in 8-h (kWh)
1	14.9	18.8	31.0
2	9.3	12.6	26.2
3	9.3	15.0	45.4
4	7.5	13.8	50.7
5	9.3	14.4	40.6
6	7.5	9.6	17.1
7	11.2	13.8	20.9
8	11.2	11.0	-
9	9.3	9.6	2.2
10	5.6	8.6	24.0
11	5.6	9.6	32.0
12	5.6	10.8	41.6
13	5.6	6.4	6.4
14	14.9	16.4	11.8
15	5.6	10.0	35.2
16	5.6	8.4	22.4
17	5.6	9.8	33.6
18	5.6	10.4	38.4
19	5.6	7.8	17.6
20	9.3	13.4	32.6
21	9.3	15.6	50.2
22	9.3	15.8	51.8
23	9.3	16.6	58.2
24	5.6	8.6	24.0
25	5.6	9.0	27.2
26	7.5	11.2	29.9
27	9.3	13.8	35.8
28	5.6	8.8	25.6
29	5.6	10.8	41.6
30	9.3	14.2	39.0

*Based on MHP reported by the concerned farmer. In case farmer has reported lower MHP as compared to actual MHP, the potential energy saving will be lower accordingly.

Table 5.5: Potential energy saving of 8-h of tube well operation in Rai, block under the assumption that properly maintained pump sets will require energy consumption as per MHP

TW No.	Expected energy consumption as per MHP, kWh	Measured actual power consumption, kWh	Potential energy saving in 8-h (kWh)
31	9.3	13.0	29.4
32	5.6	6.8	9.6
33	9.3	11.6	18.2
34	7.5	10.4	23.5
35	5.6	7.2	12.8
36	7.5	10.8	26.7
37	9.3	11.6	18.2
38	9.3	13.2	31.0
39	7.5	10.2	21.9
40	9.3	13.8	35.8
41	9.3	11.2	15.0
42	9.3	10.6	10.2
43	9.3	10.8	11.8
44	7.5	11.4	31.5
45	11.2	13.2	16.1
46	11.2	15.2	32.1
47	11.2	16.4	41.7
48	7.5	12.6	41.1
49	9.3	14.0	37.4
50	7.5	15.2	61.9
51	5.6	9.0	27.2
52	5.6	10.0	35.2
53	9.3	13.6	34.2
54	7.5	9.6	17.1
55	11.2	16.8	44.9
56	9.3	14.4	40.6
57	5.6	10.6	40.0
58	9.3	13.2	31.0
59	9.3	12.0	21.4
60	7.5	12.0	36.3
61	9.3	18.2	71.0
62	9.3	15.6	50.2
63	7.5	12.4	39.5
64	11.2	14.1	23.3
65	7.5	10.2	21.9

iii. Groundwater recharge

The average groundwater depth (June & October) in Sonepat and Rai block during the period 1990 to 2020 is shown in Fig. 5.10. It can be seen that the average groundwater depth in the Rai block has declined from 6.49 m in the year, 1990 to 15.97 m in the year, 2020. While, for the Sonepat block, it was recorded 7.62 m in 1990 and declined to 8.57 m in the year 2020. Estimated energy requirement in Rai block for different crops considering the water table depth in 1990 and 2020 while other aspects were kept same is shown in Fig. 5.21. The decline in groundwater depth has led to considerable increase in energy demand in Rai block. It can be clearly seen that if the groundwater level can be restored by suitable groundwater recharge interventions, the energy demand for different crops can be reduced considerably in the Rai block. For instance, the current energy demand for wheat crop in Rai block based on groundwater depth of 15.97 m is 11059.1 mWh, which would reduce to 6696.6 mWh (Table 5.6) if groundwater depth can be restored to 1990 level *i.e.* 6.49 m depth.

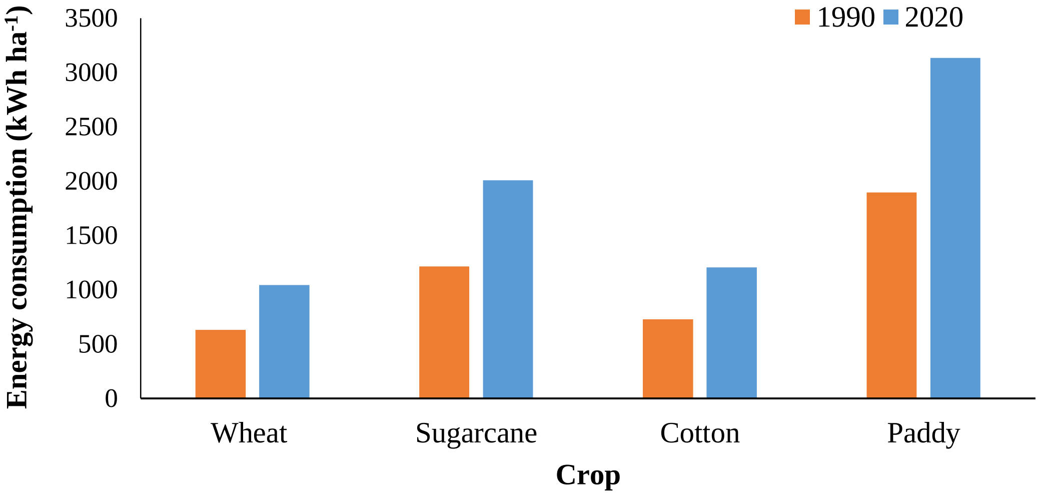


Figure 5.21: Estimated energy requirements for different crops considering the WT depth of 1990 & 2020 in Rai Block

Table 5.6: Current energy demand and if groundwater depth is restored to 1990 level for major crops in Rai, block

Crops	Energy requirement, mWh	
	At 1990 level	At 2020 level
Wheat	6696.6	11059.1
Sugar cane	733.5	1211.3
Cotton	51.1	84.4
Paddy	21327.0	35220.4

iv. Improvement in water application efficiency

The average water application efficiency in the study area as estimated based on observations at the selected farmer’ field is 62.58% (Ranging between 57.72 to 68.49%). On the other hand, the observed water application efficiency in laser levelled field in the experimental plot of the trial conducted at KVK, Sonepat was 87.45%. Comparison of water application efficiency observed at the ten selected farmer’ field from both the block Sonepat

& Rai with laser levelled field is shown in Fig. 5.22. Hence, there is a great scope for improvement of water application efficiency in the study area. No attempt is made to quantify the potential energy saving due to possible improvement in the water application efficiency in any other crops except wheat due to the fact that the experimental study consisted only for wheat crop & the findings may not be directly applicable for other crops. For example, wheat may be irrigated more efficiently with graded border while paddy in the study area is being irrigated through basin (level field) irrigation method. However, paddy can also be irrigated efficiently using graded borders if farmer adopt DSR technology instead of production of wetland paddy. Any improvement in water application efficiency would result into reduced gross depth of irrigation resulting into energy saving.

Estimated energy requirements at selected farmers' fields for wheat crop under present and improved application efficiency level is shown in Fig. 5.23. Energy requirement of wheat crop at selected farmers' fields ranged between 854.81 to 1903.48 kWh ha^{-1} (Average 1166.40 kWh ha^{-1}), this could potentially be minimized by using laser land levelling and it will come in the range of 562.56 to 1486.74 kWh ha^{-1} (Average 839.79 kWh ha^{-1}). Which would result in potential energy saving in range of 21.89 to 34.18% (28.61% on average) at selected farmers' fields (Table 4.28).

Similarly, if water application efficiency for wheat crop in a block can be improved to the level of water application efficiency observed in the laser levelled experimental plot, the potential energy demand for Sonepat block for wheat crop may be reduced from 15938.6 to 11427.7 mWh (Table 4.30). Likewise, for Rai block it may be reduced from 11059.1 to 7929.1 mWh (Table 4.31). Resulting in potential energy saving of nearly 28.3% in both blocks. Estimated energy requirements for wheat crop under present and improved application efficiency level in Sonepat and Rai Blocks is shown in Fig. 5.24.

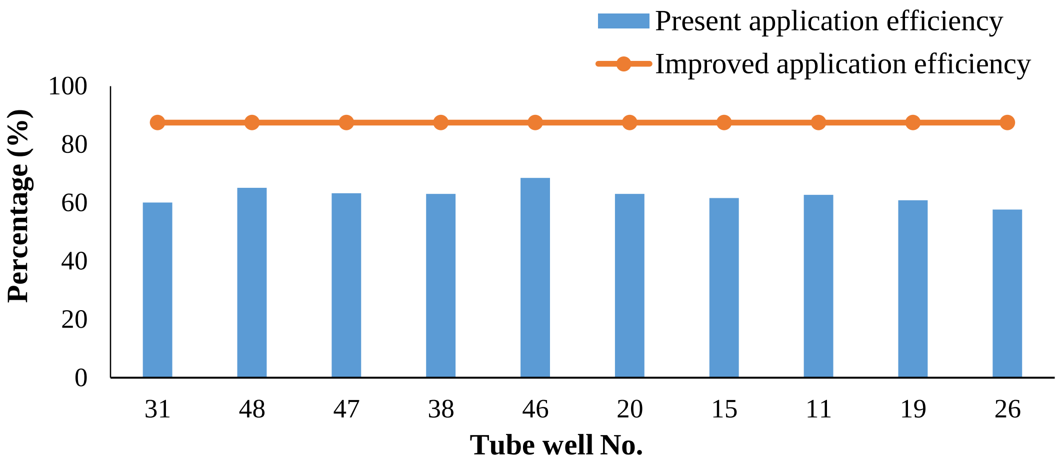


Fig. 5.22: Present level of application efficiency at ten selected farmers' field and improved application efficiency by adoption of laser land levelling at experimental site in wheat crop

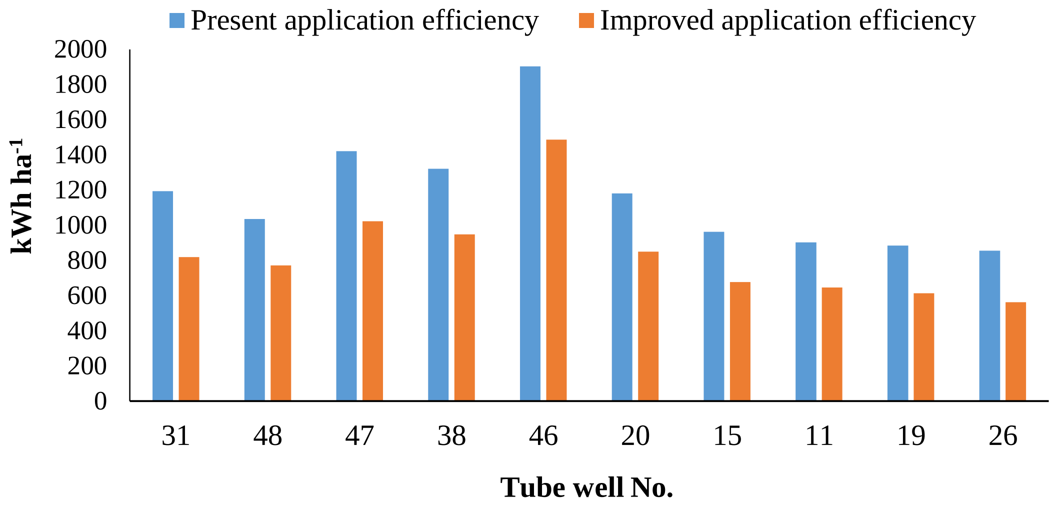


Fig. 5.23: Estimated energy requirements at ten selected farmers' field for wheat crop under present and improved application efficiency level

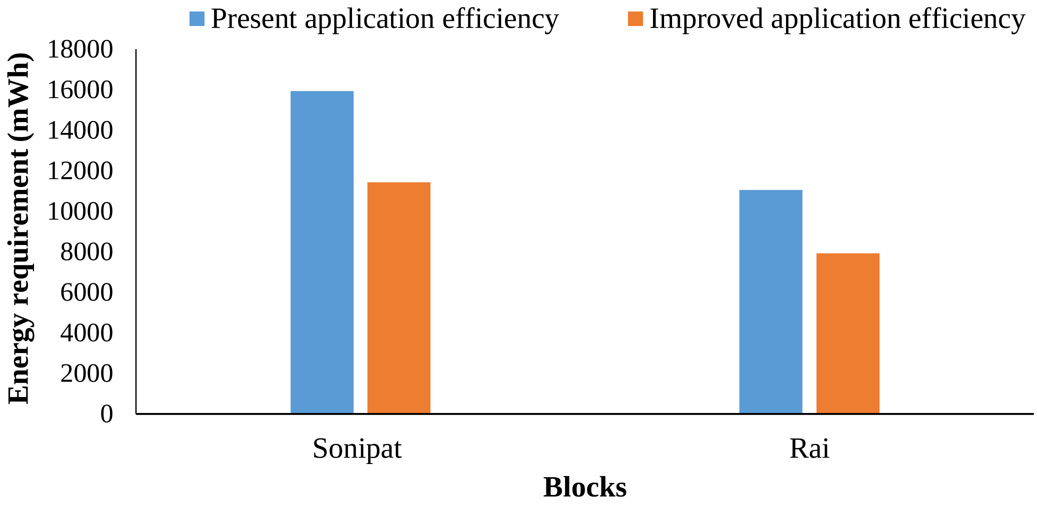


Fig. 5.24: Estimated energy requirements for wheat crop under present and improved application efficiency level in Sonepat and Rai block

v. Other factors

Most of the tube wells in the study area are already using low friction pipes (HDPE). However, in some of the tube wells it was observed that head loss due to friction was quite high due to the use of relatively small diameter column pipe. Therefore, in such tube wells replacement of existing column pipe with large diameter column pipe may help to reduce the energy consumption. Likewise, height of the delivery pipe may also be reduced to save the energy consumption to certain extent in the study area.

CHAPTER-VI

SUMMARY AND CONCLUSION

India is the world's largest user of groundwater covering more than half of the total irrigated area accounting for 70% of the production and support about 50% of the population. Currently, groundwater resources are being over exploited resulting in fast depletion of aquifers, consequentially there is decline of water table across the country. Similarly, in Haryana state, there has also been rapid expansion of groundwater resources for fulfilling agriculture needs in the past few decades, compelling farmers to shift to deeper tube wells. As groundwater level is declining with time, it is not possible to lift water using low lift centrifugal pumps. Therefore, these pumps are being replaced by electric submersible pumps under increased energy demand due to increased depth of groundwater. The pumping sets used in agriculture for irrigation purpose are often reported to have low efficiency. Some of the factors often attributed for low efficiency of irrigation pumping sets are: improper selection of pump and its prime mover, improper installation depth, poor hydraulic design of pump, poor maintenance, use of non standard parts during repair and quality of power supply. Surface method of irrigation is the most popular and commonly followed, but have low reported irrigation efficiency under field condition. Diminishing groundwater resources, high energy uses in groundwater pumping and low irrigation efficiency of commonly used irrigation methods are some major challenges for both agriculture and energy sector. Therefore, efficient utilization of water in irrigation and energy conservation in groundwater pumping are some of the most important issues to be addressed. Hence, there is an urgent need to quantify different losses in energy utilization for groundwater pumping and look for scope of energy conservation. Keeping these facts in view, the present study was undertaken. Major objectives of the study were i) quantification of different mechanical and management factors responsible for energy losses ii) identification of suitable remedial measures for energy conservation and iii) assessment of potential energy saving for groundwater pumping.

To accomplish these objectives, present research work was divided into three parts to properly address the problem in a comprehensive manner. First part of the study consisted of obtaining and understanding important parameters related to electrical submersible pumping sets to find out different factors responsible for energy losses in groundwater pumping in the study area. The study was carried out at 65 selected farmers' field (30 from Sonepat block and 35 from Rai block), for collection of the required information. The second part of the study was carried out in the experimental field area of KVK, Sonepat, where, different on-farm irrigation methods were evaluated in terms of energy utilization and water use for the wheat crop which was irrigated with the help of pumped groundwater. Third part of the study involved investigation at ten selected farmers' fields in two blocks of the study area to determine the net irrigation requirement, application efficiency, gross irrigation requirement and energy requirement for wheat crop as per the current practices adopted by farmers.

During study of electrical submersible pumping sets, current status of energy utilization for groundwater pumping for irrigating major crops was assessed by recording relevant information/observation at farmers' field. Main data collected for evaluating efficiency of submersible pumps consisted of primary data of pump sets, pumping water level, tube well discharge, supply voltage and electrical power consumption. Based on the collected information, water horse power of tube wells was computed. A calibrated energy meter was used to measure the actual energy consumption by submersible pumping system. The overall efficiency of tube well was estimated based on motor horse power as well as actual power consumption. Expected minimum efficiency was also determined based on BIS code IS 8034:2002. The overall efficiency of tube well based on motor horse power, actual power consumption and expected minimum efficiency were compared to examine the performance of different electrical submersible tube wells.

The effect of different irrigation practices in terms of volume of water pumped and energy utilized was evaluated in wheat crop by conducting field experiments at CCS HAU, Krishi Vigyan Kendra, Sonepat, farm for two years *i.e.* during *rabi* 2017-18 and *rabi* 2018-19. Different treatments were consisted of T_1: check basin irrigation with zero tillage having zero slope, T_2: border irrigation with conventional tillage, T_3: border irrigation with laser guided land levelling having 0.3% longitudinal slope, T_4: micro sprinkler irrigation and T_5: farmer's practice. The performance of the border irrigation system was evaluated by estimating the water application and distribution efficiency, these efficiencies were calculated by computing required net depth, stored depth, applied depth based on infiltration opportunity time and applied depth based on stream discharge for different treatments. The performance of micro sprinkler was evaluated by estimating uniformity coefficient of the system. The energy consumption in each treatment was also determined based on volume of water applied. Yield in terms of grain and straw and irrigation water use efficiency (WUE) for grain was calculated for different treatments as well as for different irrigation events during different years of study.

After quantification of different mechanical and management factors responsible for energy losses, an assessment has been made for the potential energy saving for groundwater pumping in the study area through suitable interventions.

Based on the above study current situation in the two blocks in terms of energy utilization for groundwater pumping was assessed, different mechanical and management factors affecting energy consumption during groundwater pumping were quantified. Suitable remedial measures were identified for present study area for the potential energy saving through appropriate interventions. Major observations from the present study are as follows:

- There were large variations in the energy requirements for groundwater pumping in the 65 electricity powered submersible pump sets (*i.e.,* 30 from Sonepat block and 35 from Rai block) covering 63 villages. Likewise, the different factors affecting energy consumption for groundwater pumping were varying widely in the study area (*i.e.* pumping water level, friction losses in the associated pipes & fittings, height of delivery pipe above ground surface, overall pumping efficiency (motor & pump efficiency), water requirement of crops, total area under irrigation and water application efficiency *etc.*)
- The energy requirement for groundwater pumping on an average had highest contribution from pumping water level component of head followed by total friction losses then height of delivery pipe above ground surface and least from velocity head component of total head. Pumping water level accounted for 57.71 to 95.90% (80.68%) in Sonepat and 70.01 to 91.69% (80.25%) of the total power consumption in the Rai block.
- Total head loss due to friction included head loss due to friction in column pipe, delivery pipe and accessories (bends, valves *etc.*). Friction in column pipe had maximum share in the total head loss due to friction. It is evident that in some cases, there was higher head loss in delivery pipe due to use of 90^0 bend of inappropriate size. Therefore, it can be stated that proper selection of suitable size pipe and its accessories made up of suitable material can play important role in reducing the unnecessary power consumption to overcome friction losses.
- Minimum expected overall pumping efficiency, as per BIS code depends on three factors i) discharge of tube well ii) head per stage and iii) motor horse power. The minimum expected overall efficiency varied from 42.92 to 52.36% (48.3%) in Sonepat block and 45.14 to 52.36% (49.7%) in Rai block. Selection of pumps with higher discharge with minimum head per stage can help in obtaining higher efficiency.
- Regression equation fitted between discharge of tube well, head per stage and motor horse power can be used to predict the minimum expected efficiency with satisfactorily value of coefficient of determination (R^2 = 0.825).

  $\eta_{EXP} = 43.89 - 0.34 \text{ x } H_{stage} + 0.325 \text{ X } Q + 0.335 \text{ x MHP}$.

  However, it may be noted that this relationship is valid for pump sets with three or more stages, motor rating between 1.1 to 15 kW and bore size up to 200 mm.
- Efficiency of tube well based on MHP which was estimated as the ratio of WHP to MHP is not a reliable indicator of efficiency of tube wells especially for submersible tube wells as it is depended on the discretion of the concerned farmer to give correct information. Some farmers may hide their correct motor HP because the electricity charges for tube

wells in the study area were based on flat rate *i.e.* fixed monthly charges depending on the MHP. Further, the efficiency of tube well based on MHP is only useful when the tube well is being operated at the duty point of the pump used. When the load on the motor is either less or more than that corresponding to duty point, the power consumption by the tube wells would be different than that computed as per the HP of the motor.

- Overall efficiency of tube wells based on actual power consumption (*i.e.* the ratio of WHP to actual power consumption) is better and more reliable indicator in comparison of efficiency of tube well based on MHP. The overall efficiencies of selected tube wells as computed based on actual measured power consumption varied from 10.1 to 56.6% (26.1%) in Sonepat block and 15.3 to 52.8% (32.5%) in Rai block.
- Lower efficiency in tube wells can be attributed to mechanical faults (which can be due to motor overloaded, misaligned impeller, bearing failure, lack of lubrication *etc*.) and poor hydraulic efficiency of pump (which can be due to improper selection of pump as per the site condition and wear & tear of pumping elements *etc*.). Availability of very low supply voltage against standard requirement of 415 V was another reason for low performance in some pump sets.
- Proper selection and maintenance of pump sets plays vital role in upholding the efficiency and can significantly reduce energy consumption. Most farmers in study area use low friction HDPE pipes but some still have high fictional GI pipes. High head losses were recorded due to use of small diameter pipes. As such, replacement of existing pipes with larger diameter pipe can lead to potential energy saving. Similarly, height of the delivery pipe can also be reduced to decrease energy consumption to certain extent.
- Non-availability of any authorised service centre of submersible motor and pumping sets was another major reason behind the lower efficiency of the tube wells. As farmers generally got repair work done from local mechanic like rewinding & bush maintenance. The local mechanic has many limitations like lack of training, apparatus, machines and tools. Also, they don’t use authorised parts from reputed manufactures and good quality material for repairing these motors & pumps, this adversely affects the performance of motor & pumps.
- The average groundwater table depth for the year 2020 (average of June & October values) was 15.97 m for Rai block and 8.57 m for Sonepat block. Despite higher overall efficiency of tube wells in Rai block (32.52%) as compared to Sonepat block (26.10%). Relatively high energy requirement in the Rai block for different crops is due to deeper groundwater depth in the Rai block as compared to Sonepat block.
- Required gross depth of irrigation based on average water application efficiency of 62.58% based on data collected from ten farmers’ field in the study area for different

major crops was 51.8 cm for wheat, 99.7 cm. for sugarcane, 59.8 cm for cotton and 155.5 cm for paddy. Further it may be noted that the energy requirement for paddy crop is much higher than other crops. For reducing the energy consumption for groundwater pumping, the first priority must be paid to the paddy-wheat rotation (Currently, 3384.0 and 4178.4 kWh ha^{-1} in Sonepat and Rai Block, respectively) followed by cotton- wheat rotation (Presently, 1822.1 and 2249.9 kWh ha^{-1} in Sonepat and Rai Block, respectively) and sugarcane (Currently, 1626.9 and 2008.8 kWh ha^{-1} in Sonepat and Rai Block, respectively). Despite high energy requirement per hectare in Rai block, the total energy consumption in Rai block is less as compared to Sonepat block is due to less area under different crops in the Rai block as compared to Sonepat block. Replacing the existing pump sets with suitable efficient pump sets can lead to potential saving in the range of 45.19 and 34.62 % in Sonepat and Rai Block, respectively.

- The maximum applied irrigation depth based on stream discharge among surface irrigation treatments was observed in treatment T_5 (Farmers' practice) and minimum in treatment T_3 (Laser land levelling field) during both the years of study.
- Highest water application efficiency was recorded in treatment T_4 (Micro sprinkler irrigation) which was on average 94.5% and was highest in both the year followed by treatment T_3 (Border irrigation with laser guided land levelling having 0.3% longitudinal slope) which was on average 87.5 %. Similarly, highest water distribution efficiency was recorded in treatment T_4 (Micro sprinkler irrigation) in both the year (94.7 % averaged) followed by treatment T_3 (Border irrigation with laser guided land levelling having 0.3% longitudinal slope) which was on average 91.8%.
- Grain yield (q/ha) was highest in treatment T_4 (Micro sprinkler irrigation) in both the year which was on average 45.55 q ha^{-1} which was 16.9% higher than that in treatment T_5 (Farmer's practice) which was 37.85 q ha^{-1} and was having least grain yield in both the years. Straw yield (q ha^{-1}) was highest in treatment T_4 (Micro sprinkler irrigation) in both the year which was on average 58.55 q ha^{-1} which was 17.6% higher than that in treatment T_5 (Farmer's practice) which was 48.26 q ha^{-1} and was having least straw yield in both the years. Total irrigation depth applied (cm) was lowest in treatment T_4 (Micro sprinkler irrigation) in both the years due to application of recommended fixed depth of irrigation for wheat crop. Similarly, it was highest for treatment T_5 (Farmer's practice) in both the years due to larger plot size non-graded field for same discharge of tube well.
- Water use efficiency (WUE) for grain (q ha^{-1} cm^{-1}) was maximum in treatment T_4 (Micro sprinkler irrigation) in both the year which was on average 1.265 q ha^{-1}cm^{-1} and was 46.6% higher than that in treatment T_5 (Farmers' practice) which was 0.675 q ha^{-1}cm^{-1} and was having least WUE in both the years. Highest grain yield, straw yield and WUE

of grain was obtained in treatment T_4 (micro sprinkler irrigation) is due to application of recommended irrigation depth and uniform distribution of water over the field. Maximum volume of irrigation water was applied in farmers' practice treatment (T_5) in both years due to lower water application efficiency. It was least in T_4, where a fixed depth *i.e.*, 6.00 cm was applied during all six irrigations in the treatment T_4 in both years.

- Micro sprinkler irrigation (T_4) may be preferable in terms of water saving with high application and distribution efficiency but this doesn't translate into energy savings due to additional energy requirements of the system under current setup. Proper grading of field contributed to improve water application efficiency, thus resulting in reduced energy consumption in T_3. Higher energy consumption in the year 2018-19 as compared to the year 2017-18 was due to application of higher irrigation water depth.
- The tube well pumping sets in the study area were found to be working at an overall average actual efficiency of 26.10 & 32.52% against the minimum expected average efficiency of 47.62 & 49.74% in Sonepat & Rai block, respectively. Replacing the existing pump sets with suitable and efficient pump sets can potentially lead to energy saving in the study area. Proper maintenance of the tube wells can substantial contribute to energy saving varying between 2.2 to 58.8 kWh for 8-h working in Sonepat block and around 9.6 to 71.0 kWh saving in Rai block, respectively.
- Average groundwater table depth in the Rai block has declined from 6.49 m in the year, 1990 to 15.97 m in the year, 2020. While, it was 7.62 m in 1990 and reduced to 8.57 m in the year 2020 for the Sonepat block. In Rai block, rapidly declining groundwater depth has resulted into increase in energy demand over the years (11059.1 mWh in 2020). This could be reduced to 6696.6 mWh if groundwater depth can be restored to 1990 level *i.e.* 6.49 m depth resulting in 39.4% energy saving.
- Improving efficiency of tube wells by replacing the existing inefficient pump set is not a sustainable solution for Rai block, it should be done in tandem with crop diversification, improving water application efficiency and groundwater status in the study area by means of improved irrigation management practices and adopting groundwater recharge techniques. However, in Sonepat block, where groundwater is not declining rapidly, replacement of existing inefficient pump sets with properly selected and efficient pump sets may be attempted to achieve the potential energy saving in groundwater pumping.
- Average water application efficiency in the study area based on survey at the fields of ten selected farmers is 62.58%, which can be potentially improved to 87.45% by adoption of graded border irrigation with laser land levelling. This can result in possibly 28.62% energy saving in wheat crop in the range of 839.79 kWh ha^{-1} on average in comparison of current average of 1166.40 kWh ha^{-1} at the fields of ten selected farmers. Similarly, at

block level, graded border irrigation with laser land levelling can result in improved water application efficiency which can amount to 28.30% energy saving in both blocks potentially reducing energy consumption from current level of 15938.6 mWh to 11427.7 mWh. Adoption of DSR technology instead of production of wetland paddy in paddy-wheat cropping system can facilitate the use of graded border in the study area.

Recommendations:

- Existing inefficient tube wells need to be replaced by installation of suitable and efficient pump sets for reduction in energy consumption in Rai and Sonepat block, however, it would be more effective if it is done in tandem with implementing measures for improving irrigation water application efficiency, crop diversification and adopting groundwater recharge techniques.
- Adoption of micro sprinkler irrigation is good option for improving water application efficiency, which can also potentially result in improved yield and WUE for wheat crop and in other crops also, however, micro sprinkler irrigation system has additional requirement for pressurizing water through network of pipes and if for a particular condition, the energy saved due to saving in water is less than the additional energy required, this may not lead to ultimate saving in energy for pumping.
- Adoption of graded border irrigation with laser land levelling can potentially lead to improved irrigation application efficiency which in turn will lead to water and energy savings. This intervention is most easy to implement and popularise among the farmers.
- Imparting knowledge of proper selection, maintenances and use of pump sets becomes very important for energy conservation in agriculture. Training and developing skilled technicians for repairing and maintenance of irrigation pump sets is important aspect to consider for improving efficiency and longevity.

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APPENDIX - A

Proforma (Electric submersible Tube wells' Study)

Name of the farmer Father's name

Village Contact no.

Land holding, ha Age Education

S. No.	Particulars	Status
1	Depth of water table	
	a. Present (Static) b. Before 5 years c. Before 10 years	
2	HP of motor (Electric submersible tube well) Load of motor kW Volt meter reading, V Current meter reading, A	
3	Capacitor available or not	
4	Total depth of bore, m	
5	Depth of motor placed, m	
6	Discharge of tube well, $l\ s^{-1}$	
7	Diameter of delivery pipe, cm	
8	Height of delivery pipe (above ground level), m	
9	Length of delivery pipe(from bend), m	
10	Type of bend & No. of bends	
11	No. of joints in delivery pipe	
12	Material of delivery pipe	
13	Material of bends	
14	Diameter of column pipe, cm	
15	Diameter of housing pipe, cm	
16	Material of column pipe	
17	Material of housing pipe	
18	Column pipes are new or old	
19	Type of tube well (filter/cavity/gravel)	
20	If cavity, depth of cavity, m	
21	If filter, length of filter, m	
22	Location of filters	
23	Area irrigated by t/w, ha	
24	Location of t/w at farm	
25	Control of t/w	

	a. Manual b. Automatic on/off c. Automatic on/off working or not	
26	Cropping pattern *a. rabi* *b. kharif*	
27	No. of irrigations in major crops a. Paddy b. Wheat c. Others	
28	Water conveyance system at farm a. lined channel 1. length, m 2. width, m b. unlined 1. length, m 2. width, m c. UGPL 1. Size, cm 2. Layout of UGPL 3. Outlet locations	
29	Field plot type a. Border size b. Check basin size	
30	Time to irrigate the field plot, h. & min.	
31	Soil sample of the field	
32	Electricity consumed per Hour, kWh	
33	Submersible Pump's age or year of purchase	
34	Pump's company BIS or local	
35	Time of repairing of pump	
36	Type of repairing (bearing/electric cable/other)	
37	Time of repairing of motor	
38	Type of repairing (rewinding/general repair)	
39	Make and model of pump	
40	Make and model of motor	
41	Pump rating if any	
42	Whether field is laser leveled or not	
43	Power available (h day^{-1})	
44	Power availability regular or not	

ABSTRACT

Title of Thesis	:	**Studies on scope of energy conservation for groundwater pumping in Sonepat district of Haryana**
Name of the degree holder	:	**Kuldeep Singh**
Title of degree	:	Doctor of Philosophy
Admission No.	:	2016AE05D
Name and address of Major advisor	:	**Dr. M.S. Sidhpuria** Professor Department of Soil and Water Engineering CCS Haryana Agricultural University, Hisar-125004 (Haryana) India.
Degree awarding University/Institute	:	CCS Haryana Agricultural University, Hisar-125004 (Haryana) India.
Year of award of the degree	:	2021
Major subject	:	Soil and Water Engineering
Total number of pages in thesis	:	103 + vii + II
Number of words in the abstract	:	560

Keywords: Groundwater pumping, Submersible pump sets, Overall efficiency, Energy conservation and Energy saving

Rapid expansion of ground water resources for fulfilling agriculture needs, compelled farmers to shift to tube wells at deeper depths leading to over exploitation of groundwater and higher energy requirements for ground water pumping. This study deals with quantification of different mechanical and management factors responsible for energy losses. To identify suitable remedial measures and assess potential energy saving for groundwater pumping. There were large variations in the energy consumption and different factors responsible for it in the 65 electricity powered submersible pump sets (*i.e.*, 30 from Sonepat block and 35 from Rai block) covering 63 villages. Percentage contribution of different heads in total power consumption was highest due to the pumping water level followed by total friction losses then height of delivery pipe above G.S and velocity head loss which on average were 80.68, 13.79, 3.77 and 1.75%, respectively in Sonepat block. Similarly, this was on average 80.25, 15.26, 3.02 and 1.46%, respectively in Rai block. The minimum expected overall efficiency of selected tube wells based on BIS code IS 8034:2002 was on average 48.3% and 49.7% and actual overall efficiency was found to be on average 26.1% and 32.5% in Sonepat and Rai block, respectively. Average water application efficiency based on data collected from ten selected farmers' field was 62.58%. Highest energy consumption for ground water pumping was observed in paddy-wheat rotation (3384.0 and 4178.4 kWh ha^{-1} in Sonepat and Rai Block, respectively) and same should be prioritised. This was followed by cotton- wheat rotation and then sugarcane. Replacing the existing pump sets with suitable efficient pump sets can lead to potential energy saving in the range of 45.19 and 34.62 % in Sonepat and Rai Block, respectively.

Based on the results of field experiments conducted at KVK, Sonepat farm, micro sprinkler irrigation (T_4) may be preferred in terms of grain and straw yield (45.55 q ha^{-1} and 58.55 q ha^{-1}, respectively), WUE_{grain} (1.27 q ha^{-1}cm^{-1}), water saving with high application (94.49 %) and distribution efficiency (94.72 %) but this doesn't necessarily translate into energy savings due to additional energy requirements of the system. Treatment T_3 (Border irrigation with laser guided land levelling having 0.3% longitudinal slope) followed after T_4 with grain and straw yield (43.70 q ha^{-1} and 55.73 q ha^{-1}, respectively), WUE_{grain} (1.05 q ha^{-1}cm^{-1}), water saving with high application (87.45 %) and distribution efficiency (91.76 %) while T_5 (Farmer's practice) had least preferable results. Proper grading of field contributed to improve water application efficiency, thus resulting in reduced energy consumption in T_3. Water application efficiency in the study area based on survey at the fields of ten selected farmers was average 62.58%, which can be potentially improved to 87.45% by adoption of graded border irrigation with laser land levelling. This can result in 28.62% potential energy saving in wheat crop in the range of 839.79 kWh ha^{-1} on average in comparison of current average of 1166.40 kWh ha^{-1} at the fields of ten selected farmers. Similarly, at block level, graded border irrigation with laser land levelling can lead to 28.30% potential energy saving in both blocks. Adoption of DSR technology instead of production of wetland paddy in paddy-wheat cropping system can facilitate the use of graded border in both seasons in the study area. There is great potential for energy conservation in the study area which can be realised by correct interventions and improve sustainability.

MAJOR ADVISOR **SIGNATURE OF STUDENT**

HEAD OF THE DEPARTMENT

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List of Publications (related to thesis work only):

Energy utilization for groundwater pumping under declining water table scenario: A Review. Paper accepted for publication in International Journal of Economic Plants (copy attached).

(Kuldeep Singh)

UNDERTAKING OF COPYRIGHT

I Kuldeep Singh**,** Admission No. **2016AE05D** undertake that I give the copyright of my thesis entitled **“Studies on scope of energy conservation for groundwater pumping in Sonepat district of Haryana”** to the Chaudhary Charan Singh Haryana Agricultural University, Hisar.

I also undertake that the patent, if any, arising out of the research work conducted during the program shall be filed by me only with the due permission of the competent authority of CCS HAU, Hisar.

SIGNATURE OF THE STUDENT