Understanding energy and groundwater irrigation nexus for sustainability over a highly irrigated ecosystem of north western India

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Abstract
This paper examines various features of energy and groundwater irrigation nexus in a highly irrigated ecosystem of north western India. The study is based both on primary and secondary sources of data. Electric tube-wells account for about 72 percent of the total tube-wells population and consume about 40 percent of the total electricity consumption. Power subsidies account approximately 46 percent of the total subsidies disbursed which stimulate the groundwater development. The area irrigated by means of tube-wells has enlarged from 22 to 58 percent. Rice and sugarcane crops are the key consumers of energy both in terms of average energy consumption as well as per hectare of cultivated land. The average use factor of tube-wells is about 7.5 times high during kharif than in rabi season. Farmers have yielded high economic productivity under all crops with the exception of rice than other states such as Uttar Pradesh, Bihar and Gujarat.

Keywords Energy · Groundwater · Irrigation · Productivity · Farmers · Perception · India

Introduction
Of late, groundwater irrigation has prospered as a key resource for assured supply of water to farmers. Its smoothness and flexibility in relation to other sources of irrigation has resulted in an increasing groundwater withdrawal (Srinivasan and Kulkarni 2014). About 75 percent of rural population and more than 50 percent of the total population in India, directly or indirectly depend on groundwater for their livelihoods (Sharma et al. 2004). Groundwater irrigation infrastructure contributes over 10 percent of India’s gross domestic product and 60 percent of irrigation requirements (Shah 2007; Scott and Sharma 2009). It accounts for about 70–80 percent of the farm value output, which is 1.2–3.0 times higher than those of canal irrigation (Dhawan 1995; Sharma et al. 2004). Surprisingly, only 58 percent of the identified groundwater resources have been developed till now, reflecting much scope for their development in India (Shankar et al. 2011). Groundwater development is modest in eastern region (less than 50 percent), whereas its development is more than 150 percent in the major food grains producing states of Punjab, Haryana and Uttar Pradesh. Currently, 972 out of 6881 blocks (groundwater observation units) in India are overexploited (CGWB 2017). In the north western states, which have been an epicenter of the Green Revolution like Haryana and Punjab, groundwater use exceeds natural recharge by 49 percent and 35 percent, respectively (CGWB 2017). In the state of Haryana, Singh and Kasana (2017) have used the data of 893 monitoring wells and observed a decreasing trend in groundwater level with decline of about 32 cm annuum−1. India’s groundwater consumption dramatically increased from 50 in 1970 to 250 km³ in 2010 (Shah 2014). Of 250 km³, more than 90 percent is used for irrigation alone. Overall, the groundwater irrigated area increased from 12 million ha to 40 million ha in between 1970 and 2010 (MoSPI 2015). Due to the rapid growth in groundwater irrigated area, there has been a sharp growth in the electricity use in the agriculture sector, especially since the 1980s. The abstraction of groundwater for irrigation is closely coupled with access to subsidized or free electricity in the country (Rajan and Ghosh 2019; Sarkar 2020). Supply of free electricity has led to the

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pervasive groundwater energy nexus in the country. Electricity consumption in agriculture has increased approximately 54 times from 1969 to 2016 in India (Dharmadhikari et al. 2018). The running of tube-wells account for about one-third of the India’s total electricity consumption, which varies from 27 to 45 percent in different states of India (Sharma et al. 2004; Scott and Shah 2004; Kumar et al. 2013). Currently, there are nearly 20 million operational groundwater wells in India, in which approximately 70 percent are relying on electricity (Dharmadhikari et al. 2018). Accordingly, both energy and groundwater development are inextricably linked because groundwater withdrawal through tube-wells rests directly on energy supply. This association between the two is frequently known as energy groundwater irrigation nexus, which has significantly improved agricultural productivity, livelihoods and food security as well as the social and economic development (Shah et al. 2003; Dubash 2007).

**Setting up the argument**

Energy use for groundwater withdrawals has been a subject of discussion since the early 1970s. All state electricity boards have been charging their tube-well owners based on meter consumption, but, due to a range of administrative issues (rampant tempering of meters, under-billing and dishonesty at the level of meter readers, maintaining an army of meter readers etc.), this has been changed to a flat tariff in the early 1980s (Shah et al. 2007). These flat tariffs have remained perpetually low over the years on account of an electoral tool of appeasement by many state governments, incurring huge losses to state electricity boards to the tune of Rs. 260 billion (Dubash and Rajan 2001; Sharma et al. 2004). Energy subsidies in farm sector on account of flat tariffs in the country stand at Rs. 45,561 crores (Mukherji and Das 2012). Government generally provides subsidies on electricity for pumping wells used for irrigation but there are huge environmental costs, especially groundwater exploitation (Jessoe and Badiani 2019; Singh et al. 2021). (Barik et al. 2017) has witnessed a negative correlation between groundwater level and energy consumption. Any further subsidies in energy supply for withdrawal of groundwater for crop production would result in its over-exploitation to 30 percent, which will subsequently threaten the groundwater resource sustainability (Kumar 2007; Kondepati 2011). Electricity subsidies have contributed significantly in this as subsidies incentivise increased groundwater extraction and shifting toward more water intensive cropping (Badiani and Jessoe 2013; Sarkar 2020). Likewise, low cost of pumps and massive investment in rural electrification will enhance the energy consumption and use of groundwater (Kumar 2005; Mukherji et al. 2012). Recently, Sidhu et al. (2020) have found that flawed tariff policies, in conjunction with rampant subsidies have caused extensive groundwater pumping leading to rapid decline in groundwater level in different regions as well as causing huge financial losses to governments. Estimated average annual energy use per hectare of groundwater irrigated area has been found as high as 6,997 kWh for Karnataka, 5,863 kWh for Andhra Pradesh, 5,630 kWh for Tamilnadu, and 5,297 kWh for Gujarat (Shah 2009). Tason et al. (2020) have reported similar results with respect to Spanish irrigated agriculture in the period 1950–2017.

Implementation of a flat tariff on energy for groundwater pumping does not reflect the actual unit of consumption. Therefore, it has been universally written off as inefficient, irrational and responsible for wastage of both energy as well as groundwater resources (Saleth 1997; Kumar and Singh 2001; Sharma et al. 2004; Scott and Shah 2004; Mukherji et al. 2009; Kumar et al. 2011). Also, the quality of energy supply in terms of voltage, interruptions, and timing will decline quickly, resulting in higher reparation costs on farmers (World Bank 2001; Monari 2002). At the same time, a low flat tariff with subsidy has been criticized from an equity perspective. It has been frequently alleged that most of subsidy benefits are percolated to large farmers as they have higher share of the tube-wells fitted with electricity (Kumar and Singh 2001; World Bank 2002). The large farmers on an average receive energy subsidy to the tune of Rs. 29,710 per year, which is almost 10 times the subsidy received by a marginal farmer (Howes and Murgai 2003). Conversely, flat tariff has been advocated by farmers on account of higher water pumping rate without tension of billing, no need of pilferage, no need of meter tempering and groundwater selling to neighboring farmers at low rates (Qureshi et al. 2003).

Meanwhile, controlled pricing of energy on pro-rata (metering) basis has been increasingly advocated as a tool of management for energy and overdraft of groundwater (Dubash 2007; Scott and Sharma 2009). The energy consumption is nearly 35 percent below the estimates based on pump metering, thereby improving the quality of power supply (World Bank 2001; Mukherji et al. 2009). A judicious management of energy and groundwater revolves around metering of tube-wells, energy rationing using prepaid meters, denial of energy connections in regions which have experienced groundwater overdraft and restricting the permits for installation of new pumps (Shah et al. 2004a; Shah et al. 2004b; Dubash 2007; Malik 2009; Kondepati 2011; Kumar et al. 2011). An enhancement in energy tariffs on pro-rata basis can be introduced to promote efficiency, equity and sustainability in groundwater use (Saleth 1997; Shah et al. 2003; Kumar et al. 2011). But on the other hand, a complete withdrawal of energy (electricity) subsidy (Fig. 1) and metering on actual consumption basis will destroy the agricultural activities in India (Kumar et al. 2010; Mukherji et al. 2012).
While, the arguments made above are valid for the whole of India, however, the studies pertaining to association among energy and groundwater use in agricultural sector with respect to the state of Haryana are rather scanty. This study, therefore, examines the energy and groundwater irrigation nexus in the state, which enjoys the enormous energy subsidies. The paper also examines the overall impact of changing pricing policy on groundwater development, use factor, physical productivity and net returns from crops and perception of farmers regarding energy supply and its pricing. The results of this study will provide a feedback to energy and groundwater managers in formulation of suitable policies for the judicious energy use and sustainable development of groundwater resources.

Materials and methods

Study area

The state of Haryana, located in north western part of India, lies between 27° 39' and 30° 55’ N latitudes to 74° 28' and 77° 36’ E longitudes (Fig. 2). It occupies approximately 44,212 km² area (1.4 percent of country’s total geographical area). A large proportion of state is irrigated by the two main surface irrigation systems i.e., western Yamuna canal and Bhakra canal systems. In spite of this, area under tube-wells irrigation is comparatively very high than area served by canal systems. Farmers extract huge amount of groundwater through tube-wells to fulfill the needs of irrigation to support its agrarian economy. Therefore, overall groundwater development level in the state is about 133 percent (CGWB 2013). The depth to the groundwater level varies from less than 4 m to as deep as 65 m and about 86 percent of the districts are over-exploited or critical. The long-term average fall of groundwater levels has been witnessed to the tune of 20 cm per year.

The energy and groundwater irrigation nexus are of high importance to Haryana because energy subsidy has been used as a tool to encourage the groundwater development. Irrigation sector uses approximately 40 percent of total energy consumption on account of lowest energy tariffs for its consumers across India. Energy subsidies for irrigation sector nearly amounts to 46 percent of the total subsidies (Sharma et al. 2015). These enormous subsidies have led to a booming of groundwater withdrawals with depleted aquifers and exploitation of energy economy. Given the heavy subsidies on energy, the state electricity board has faced substantial losses, adversely affecting its overall supply and quality of life in rural as well as urban areas. Table 1 summarizes the energy and groundwater irrigation scenario in Haryana and other states of India.

Data sources and methods

The present study is based on both primary and secondary sources of data. Data have been collected in 2015–16 via individual respondent face-to-face interviews using a pre-tested standardized questionnaire in order to evaluate the energy and groundwater irrigation nexus. The respondents (farmers) in this study have been selected using multi-stage sampling techniques as outlined in Table 2. Since all respondents have cooperated and enthusiastically participated in the survey, the response rate has been found extremely high (100 percent). In comparison to postal and other forms of surveys, face-to-face interview surveys yield higher response rates (Bowling 2005). Filling out the questionnaire with each respondent has took about 30 min. Farmers have been interviewed in their fields much of the time. On-the-ground conversations have allowed them to publicly share their thoughts, beliefs, and perspectives.
about the energy-groundwater irrigation nexus, as well as to expand on the specific problems. The questionnaire has been given out in English, but it has been translated and interpreted into the local languages (Hindi and Haryanvi) to bridge the communication gap, explain questions, and obtain more detailed answers. A total of 25 respondents over the age of 25 have been interviewed. These are older ages, reflecting a purposeful sampling bias in favor of
older respondents in order to capture the energy-groundwater irrigation nexus.

Apart from this, secondary data on number of electric connections in irrigation sector, consumption, tariffs and subsidy have been collected from published and unpublished records of Haryana Vidyut Prasaran Nigam Limited, Panchkula for the period 1990–2013. Likewise, data pertaining to number, density and irrigated area for the same period have been collected from Statistical Abstract issued by Department of Economic and Statistical Analysis, Haryana. Information regarding depth of irrigation and water productivity under major crops for tube-well and non-tube-well owners for other states has been collected from published research papers.

Several indices such as cropping intensity, operating and use factor of tube-wells and physical and economic productivity of water have been computed from the above collected primary data to highlight the energy and groundwater irrigation nexus. A comprehensive procedure for computing these indices has been discussed by Qureshi et al. (2003), Shah et al. (2003), Shah et al. (2006), Kumar et al. (2008), Kumar et al. (2010) and Kumar et al. (2011). In addition, grouping of respondent farmers based on land holding size has been done as small (0.0–2.0 ha), medium (2.1–4.0 ha) and large (4.1 ha or more) (Singh and Singh 2015). This grouping of respondents by their landholding size shows the land ownership pattern in Haryana. Finally, to summarize quantitative data, descriptive statistics involving frequency distribution, tables and graphs have been prepared. The statistical program MS EXCEL has been used to handle and analyze the data.

**Table 1** Comparison of energy-groundwater irrigation scenario in Haryana and other states of India

| Indicators                                      | Andhra Pradesh | Bihar | Gujarat | Haryana | Maharashtra | Punjab | Uttar Pradesh | West Bengal |
|-------------------------------------------------|----------------|-------|---------|---------|-------------|--------|---------------|------------|
| Level of groundwater development (percent)*     | 45             | 44    | 67      | 133     | 53          | 172    | 74            | 40         |
| Over-exploited blocks (number)*                 | 83 (7)         | 0 (0) | 24 (11) | 71 (61) | 10 (3)      | 110 (80)| 111 (14)      | 0 (0)      |
| Average annual rainfall (mm)*                   | 575            | 1030  | 915     | 468     | 705         | 497    | 906           | 1148       |
| Nature of aquifer*                              | Hard rock      | Alluvial | Alluvial and hard rock | Alluvial | Hard rock | Alluvial | Alluvial | Alluvial |
| Annual per capita energy consumption in agricultural sector (kWh)** | 223.9 | 89.2 | 226.8 | 368.8 | 217.7 | 367.8 | 43.1 | 14.4 |
| Consumption of electricity in agricultural sector (percent of the total electricity consumption)** | 29.8 | 17.8 | 24.9 | 39.4 | 31.87 | 28.2 | 20.0 | 3.9 |
| Transmission and distribution losses (percent)*** | 15.3 | 35.0 | 22.3 | 22.7 | 21.6 | 16.8 | 24.4 | 22.3 |
| Percentage of electric tube-wells to total tube-wells **** | 93.5 | NA | 54.5 | 63.1 | NA | 73.3 | NA | 8.2 |
| Flat tariff rate (Rs./HP/Year) ****             | Free           | NA   | 850     | 420     | NA        | Free  | NA            | 1760–2160  |
| Electricity subsidy (percent of fiscal deficit) **** | 54 | 01 | 56 | 78 | 26 | 38 | 13 | 0.8 |

Figures the parentheses indicate toward percentage
NA: Data not available
Source: CGWB (2013) ** (Mukherji 2007) *** (Raju et al. 2013) **** (Mukherji et al. 2009); (Department of Economic and Statistical Analysis 2012)

Results and discussion

Groundwater economy

Groundwater irrigation has reduced the dependency of farmers on rainfall and other irrigation sources. Irrigated agriculture in Haryana increasingly depends on groundwater use and has a long history of its use. Traditional irrigation sources were important until 1970. Extraction of groundwater through Persian wheels from dug wells accounted for about a quarter of the net irrigated area. Later, during 1970–90, dependence on dug wells have reduced sharply and tube-wells irrigated area has enhanced from 34 to 48 percent, with a growth of 132.4 percent. This remarkable increase in area under tube-well irrigation in the state can be ascribed to the decreasing canals discharges and rising requirement for timely and sufficient quantity of water for crops with the introduction of Package Technology. The Package Technology basically refers to Green Revolution introduced in agriculture. The package that comes with it are High Yielding Variety of seeds, modern equipments of...
## Table 2  Details of sample design and data collection for energy-groundwater irrigation linkages in Haryana

| Districts                        | Climatic zones* | Rainfall (mm) | Temperature (°C) | Sample districts             | Sample block | Category of block | Sample villages | Latitude      | Longitude | Altitude (m) | Number of respondents |
|----------------------------------|-----------------|---------------|------------------|-----------------------------|--------------|-------------------|----------------|---------------|-----------|---------------|-----------------------|
| Ambala, Panchkula, Yamunanagar   | Sub-Humid Zone  | 750–1050      | 24               | Panchkula, Yamunanagar, Ambala | Raipur Rani | Over-exploited    | Rampur         | 30° 60'N  | 77° 04'E  | 345        | 30                     |
|                                  |                 |               |                  |                             | Radaur       | Over-exploited    | Bhadurpur       | 30° 05'N  | 77° 23'E  | 268        | 49                     |
|                                  |                 |               |                  |                             | Ambala-II    | Critical          | Bhilpura        | 30° 33'N  | 76° 94'E  | 280        | 46                     |
| **Total**                        |                 |               |                  |                             |              |                   |                |              |           |              | **125**                |
| Faridabad, Gurgaon,              | Semi-Arid Zone  | 500–750       | 26               | Karnal, Kurukshetra, Palwal  | Gharaunda    | Over-exploited    | Kohand          | 29° 49'N  | 30° 76'E  | 243        | 30                     |
| Jhajjar, Kaithal, Karnal,        |                 |               |                  |                             | Thanesar     | Over-exploited    | Dhurala         | 30° 05'N  | 76° 80'E  | 258        | 40                     |
| Kurukshetra, Mewat, Palwal       |                 |               |                  |                             | Hathin       | Critical          | Bahin           | 28° 03'N  | 77° 32'E  | 189        | 30                     |
| **Total**                        |                 |               |                  |                             |              |                   |                |              |           |              | **100**                |
| Bhiwani, Fatehabad, Hisar, Jind, | Arid Zone       | 300–500       | 27               | Sirsa, Mahendergarh, Hisar  | Sirsa        | Over-exploited    | Bhrokhan        | 29° 61'N  | 75° 17'E  | 203        | 25                     |
| Mahendergarh, Sirsa              |                 |               |                  |                             | Kanina       | Over-exploited    | Sehlang         | 28° 40'N  | 76° 21'E  | 243        | 60                     |
| **Total**                        |                 |               |                  |                             | Hansi-II     | Critical          | Khand-Kheri     | 29° 18'N  | 76° 22'E  | 223        | 50                     |
| **Sample Total**                 |                 |               |                  |                             |              |                   |                |              |           |              | **135**                |

Source: *(Government of India 2011)*

The boldface values are showing the average values
tilling the soil, organic fertilizers, pesticides etc. to farmers. This technology aims at yielding maximum benefits in less period of time in agriculture. These characteristics have provoked the farmers to set up their individual tube-wells during the period 1970–90. However, till 2000, tube-well irrigated area has exceeded the canal irrigated area (Fig. 3). Current estimates show that canal irrigated area has declined from 77 to 42 percent, and tube-well irrigated area has increased from 22 to 58 percent during 1966–2013. The consciousness of farmers about groundwater is evident from the increasing use of resource. But on the other hand, this impressive growth in groundwater irrigation during the last five decades has adversely affected the groundwater resources of Haryana.

Recent estimates show that net groundwater available in the State is 9.79 billion cubic meters, while the net groundwater draft is 13.06 billion cubic meters, thus leaving an annual deficit of 3.27 billion cubic meters, which can result a serious groundwater crisis in near future. Figure 4 shows an increasing trend in groundwater exploitation through tube-wells. The major reason for increased tube-well pumpage may be ascribed to low setting up cost of electric tube-wells with high efficiency, subsidized energy supplies and commencement of horse-power rating based flat tariff of the tube-wells after the year 1978. The farming community of the state has favored flat tariff on account of higher pumpage without tension of billing, no need of pilferage and meter tempering and groundwater selling to nearby farmers at economical rates than diesel tube-wells. Other benefits of electric tube-wells include-easy handling, low operating cost, better pumping efficiency and performance for extraction of deep groundwater. An electric tube-well is a downhole pump which is powered by electricity, and used for lifting groundwater from an aquifer.

Table 3 shows the growth in net area sown, number of tube-wells, number of tube-wells per 1000 hectare of net area sown, tube-well irrigated area, area irrigated per tube-well in hectare and annual growth rate of tube-wells in Haryana.

Fig. 3 Growth of irrigated area through canals and tube-wells in Haryana during 1990–2013

Fig. 4 Trends in groundwater draft in Haryana during 1995–2013
The tremendous annual growth in number and density of tube-wells (2.3 and 2.4 percent, respectively) exhibits the growing importance of groundwater irrigation in agricultural development of the state. Several factors such as soft loans, subsidies and rural electrification explain the growth in tube-well numbers. The installation of large number of tube-wells has helped the farmers to exploit groundwater resources to add-on their water supplies, which resultantly increased the cropping intensities in the state from 144 in 1970s to 185 in the year 2015. Besides, farmers across the state have adopted high yielding cereal crops, initially wheat and subsequently rice with moderate to high and very high-water demand. At present, rice–wheat is a very common cropping system covering more than 3.75 million ha (approximately 60 percent of total cropped area). This may be a result of combination of high and guaranteed purchasing prices and subsidized inputs for these crops. Additionally, general shift from metering to a flat rate energy tariff for irrigation sector has induced new entrants to the groundwater economy. In contrast, negative annual growth in number of tube-wells during some of the years can be attributed to shifting of shallow tube-wells (centrifugal) to deep tube-wells (submersible) as a result of declines in groundwater levels throughout except the central tracts, where both waterlogging and poor quality impede the development of resource. Also, the area irrigated per tube-well shows that in spite of rise in the number of tube-wells in recent period, the area irrigated per tube-well has not increased, indicating clearly that the groundwater development has crossed its limits and exhibiting scarcity.

### Energy economy

Groundwater withdrawals hinges directly on energy delivery and tariffs. During the ‘Green Revolution’ period (1960s and 1970s), World Bank has showered enormous investments and funds to enhance electricity infrastructure in rural areas to stimulate the groundwater irrigation standings of India in general and of Haryana in particular. Given the importance of groundwater irrigation in agricultural economy, the state government has implemented several policies and programs. Additionally, government has started to offer loans for digging wells, funds for deep tube-wells, concessions on

| Year | Net area sown (million ha) | Number of tube-wells (million) | Number of tube-wells per 1000 ha of net area sown | Tube-well irrigated area (million ha) | Area irrigated per tube-well (ha) | Annual growth in number of tube-wells (%) |
|------|---------------------------|-------------------------------|-----------------------------------------------|-------------------------------------|-----------------------------------|-----------------------------------------|
| 1990 | 3.58                      | 0.50                          | 139.2                                         | 1.24                                | 2.49                              | 8.77                                    |
| 1991 | 3.51                      | 0.51                          | 145.4                                         | 1.26                                | 2.46                              | 2.55                                    |
| 1992 | 3.49                      | 0.52                          | 149.7                                         | 1.24                                | 2.37                              | 2.48                                    |
| 1993 | 3.51                      | 0.52                          | 148.4                                         | 1.27                                | 2.43                              | -0.28                                   |
| 1994 | 3.56                      | 0.53                          | 150.2                                         | 1.30                                | 2.44                              | 2.51                                    |
| 1995 | 3.59                      | 0.54                          | 150.7                                         | 1.35                                | 2.50                              | 1.08                                    |
| 1996 | 3.62                      | 0.56                          | 154.3                                         | 1.35                                | 2.43                              | 3.20                                    |
| 1997 | 3.64                      | 0.57                          | 155.8                                         | 1.36                                | 2.41                              | 1.59                                    |
| 1998 | 3.63                      | 0.58                          | 158.6                                         | 1.40                                | 2.42                              | 1.59                                    |
| 1999 | 3.55                      | 0.60                          | 168.6                                         | 1.43                                | 2.39                              | 4.08                                    |
| 2000 | 3.56                      | 0.59                          | 165.6                                         | 1.37                                | 2.32                              | -1.53                                   |
| 2001 | 3.57                      | 0.60                          | 167.0                                         | 1.50                                | 2.52                              | 0.96                                    |
| 2002 | 3.46                      | 0.60                          | 174.1                                         | 1.52                                | 2.53                              | 1.09                                    |
| 2003 | 3.53                      | 0.59                          | 167.7                                         | 1.55                                | 2.62                              | -1.54                                   |
| 2004 | 3.53                      | 0.58                          | 165.4                                         | 1.51                                | 2.59                              | -1.56                                   |
| 2005 | 3.57                      | 0.58                          | 162.5                                         | 1.59                                | 2.75                              | -0.69                                   |
| 2006 | 3.56                      | 0.63                          | 175.9                                         | 1.67                                | 2.66                              | 7.96                                    |
| 2007 | 3.59                      | 0.66                          | 184.3                                         | 1.63                                | 2.46                              | 5.91                                    |
| 2008 | 3.58                      | 0.68                          | 189.7                                         | 1.60                                | 2.36                              | 2.38                                    |
| 2009 | 3.76                      | 0.67                          | 179.4                                         | 1.78                                | 2.65                              | -0.66                                   |
| 2010 | 3.68                      | 0.72                          | 196.6                                         | 1.65                                | 2.28                              | 7.39                                    |
| 2011 | 3.52                      | 0.74                          | 209.6                                         | 1.88                                | 2.55                              | 1.90                                    |
| 2012 | 3.51                      | 0.75                          | 214.2                                         | 1.76                                | 2.33                              | 2.08                                    |
| 2013 | 3.50                      | 0.77                          | 220.8                                         | 1.77                                | 2.29                              | 2.62                                    |

Source: Statistical Abstracts of Haryana (1990–2013)
pumps and highly subsidized energy tariffs. Figure 5 shows the quantum of electricity tariffs applicable since the beginning of flat tariff rates in the year 1978. The marginal cost of groundwater extraction is nearly zero after switching from a meter-based tariff system to a flat tariff system based on the motor horsepower rating. Moreover, these policy interventions have not only kick-started a massive tube-well irrigation economy leading to depletion of aquifers, but have also contributed toward the increasing subsidized energy bills (Table 4). Cumulative subsidies provided to groundwater irrigation sector at current prices (when energy reforms have been started) have increased from Rs.1906 million in 1990–91 to Rs. 54,360 million in 2013–14. Despite the introduction of minimum tariff rates under the common minimum plan for power sector reforms, there has been an increase in subsidies. Besides, increasing energy subsidy bills have mainly been owing to political intervention in pricing of energy and usually it has been in the form of waiver of energy dues as part of political populism. However, this has encouraged the farmers’ nonpayment approach, who expects another round of waiver in near future. Energy subsidies thus have become the reason as well as the consequence of groundwater depletion. Therefore, energy subsidy has substantial impacts on sustainability of groundwater resources of the state.

Energy consumption for groundwater withdrawals is an indication of density of tube-wells and its use in a region. Table 1 clearly shows that the proportion of both groundwater and energy use is very high in the state and differs completely from other Indian states. The principal source of energy for pumping groundwater in the state is generated and purchased electricity. The share of energy purchased by the state has increased from about 34 percent of its generated units in 1990 to around 71 percent of its generated units in 2008 (Fig. 6). According to a recent estimate, electric tube-wells accounts for about 72 percent of the total tube-well population in Haryana (Sharma et al. 2015). Electric tube-wells as a percentage of total tube-wells for groundwater irrigation are depicted in Fig. 7. In addition, electric tube-wells have consumed approximately 45 percent of consumption of total energy in 1990, while it has declined to 28 percent during the year 2013 (Fig. 8a). The increased usage of energy in the domestic and industrial sectors can be due to the decline in energy use by tube-wells. Conversely, Fig. 8b–d shows an increasing trend in number of electric tube-well connections, total consumption of energy in irrigation sector and energy consumption per electric tube-well. A significant increase in these attributes over the last 24 years clearly exhibits the increasing curiosity of farmers in electric tube-wells. This triggering interest toward electric tube-wells among farmers can be anomalously attributed to farmer-centric energy policy of the state government. Nonetheless, these increasing trends have placed a phenomenal pressure on groundwater resources as well as on the energy supply agencies like state electricity board of the state.

Energy and groundwater irrigation nexus

Operating factor of tube-wells

There is a close link between energy and groundwater economy of the state, as energy pricing and supply policies significantly affect the operational factor of tube-wells i.e., per tube-well mean annual operational hours. The State Government has abandoned farm energy supply based on metering in the year 1978 and has switched to flat-rate energy tariff related to horsepower rating of tube-wells. With the introduction of the flat tariff, energy subsidy emerged as
by far the strongest tool for populist policies, marking a seminal moment in the evolution of the state's groundwater economy. Given the situation, it has been hypothesized that the operating factor of electric tube-wells would be significantly high on account of effective and substantial energy subsidy. Figure 9a shows the electric tube-wells total average hours and hours per hectare of pumping. Electric tube-wells have significantly higher operating hours of pumping. These results are well in correspondence with other Indian states, which enjoy an energy subsidy and a flat tariff rate.
Fig. 7 Electric tube-wells as percent of total tube-wells used for groundwater irrigation in Haryana during a 1990, b 1998, c 2006 and d 2012
Interestingly, it has been also revealed that electric tube-well owners are paying a flat tariff to operate their tube-wells for 40–250 percent more hours per year than owners of diesel tube-wells in different parts of the country. Figure 9b–f shows the total average hours of irrigation used and hours per hectare to irrigate major crops. These results are broadly in conformity that more operating hours of pumping as well as hours per hectare for rice cultivation are required. Furthermore, if there is a significant difference in the energy rating of the tube-wells, operating hours of electric tube-wells pumping cannot be a true representative of energy usage and groundwater extraction per electric tube-well. Figure 10a shows average energy consumption in kilowatt hours and energy consumption per hectare of cultivated land. As a result, electric tube-well owners in Haryana have been observed to make more intensive use of energy for groundwater withdrawal in irrigating their crops, as the marginal cost of running electric tube-wells is substantially lower due to flat tariff rates. Also, Figure 10b–f demonstrates the similar attributes in relation to major crops grown and it has been observed that rice and sugarcane are the key consumers of energy both in terms of average energy consumption as well as per hectare of cultivated land. Again, it can be attributed to significant effective subsidy on energy use.

Apart from this, energy subsidies are usually validated on the basis that they reach up to poor or small farmers. Tables 5 and 6, however, show that both hours of pumping as well as consumption of energy among the large farmers is higher than the twofold of small farmers. This analysis clearly validates that large farmers have acquired more benefit from the subsidized energy than small farmers. Similar results have been noticed in a study of Karnataka state of India, which has shown that energy subsidies allocated to small farmers are often trapped by wealthy farmers (Howes and Murgai 2003). It has been observed during the field survey that energy supply in the state is unreliable and farmers having larger size of landholdings invest in higher horsepower rating tube-wells to extract more groundwater to irrigate their lands. Surprisingly, about 15 percent of large farmers in Haryana have 4 tube-wells with higher horsepower ratings, consuming more energy and groundwater (Table 7).

**Use factor of tube-wells**

The use factor of tube-wells is among the most important parameters to estimate the total groundwater extraction. It depends on several factors comprising tube-well type, cropping season, climatic zone, groundwater markets, tariff and energy policy (Qureshi et al. 2003). Table 8 shows a significant difference in average use factor depending on...
landholding size of farmers, cropping season and climate. The usage factor of large farmers is more than double that of small and medium farmers, confirming the fact that large farmers consume more energy and profit from subsidies. Higher use factor of large farmers can be ascribed to higher average number of days per year for which they operate their tube-wells in a year. The higher number of tube-well operating days in case of large farmers are owing to the fact that each tube-well is serving about 6.3 hectare of irrigated land, which is more or less twofold of the land irrigated by small farmers and the average area irrigated by each tube-well (Tables 7 and 8).

The use factor also significantly differs during diverse growing seasons. During the kharif season, the average use factor is around 7.5 times higher than during the rabi season (Table 8). During rabi season, evapotranspiration is modest due to cool climatic conditions and mostly less water consuming crops are grown (mustard and wheat). Among the climatic zones, sub-humid zone has the highest use factor followed be semi-arid and arid zone (Table 8).
The wide ranges of use factor among the climatic zones are attributed to diversified cropping patterns. Among the zones where wheat, cotton, mustard and bajra cropping pattern is dominant, the use factor is comparatively low as these crops consume less water. However, in the zones where rice and sugarcane crops are dominant, both water requirement and subsequently use factor is high. The survey data have conspicuously revealed that the amount of groundwater applied to rice and sugarcane crops is about 6 and 2.5 times more than wheat and cotton, respectively.
found even higher than the sugarcane crop although growing period for rice is less than half of the sugarcane. The usage factor is also influenced by the average area irrigated by each tube-well. According to the results of the survey, each tube-well irrigates an average of 3.4 hectares. In arid and semi-arid zones, where rainfall is low to moderate, the average area irrigated by each tube-well is higher than that in the sub-humid zone (Table 7). Additionally, changes in the tariff policy for tube-wells have a direct impact on use factor of tube-wells. During the metered tariff period, the average annual use factor in Pakistan Punjab has been observed to the tune of 8.8 percent, whereas in the present study it has been found 11.7 percent during the flat tariff regime of energy supply, which is relatively on the higher side. Accordingly, metered tariff policy may be more advantageous in regulating excessive pumping of groundwater in Haryana.

Groundwater application and cropping patterns

The use factor of tube-wells leads to development of groundwater resources and thus supports in selecting the cropping patterns of an area. Therefore, analyses of cropping pattern of tube-well owners and non-tube-well owners (buyers) have been presented in Table 9. The major crops grown in the study area are wheat, rice, sugarcane, cotton, mustard, bajra and fodder. During the kharif season, both tube-well and non-tube-well owners allocate the larger portion of their landholding to rice crop. Tube-well owners cultivate rice crop over approximately 58 percent of the gross cropped area, while non-tube-well owners only over about 28 percent. In addition, tube-well owners also grow sugarcane, cotton and fodder crops, whereas the non-tube-well owners assign higher percentage of their cropped area to cotton, bajra and fodder crops. Wheat, fodder, and mustard are the main crops grown during the winter season (rabi). The percentage area allocated for fodder and mustard crops is low both for owners and buyers, while area allocated to wheat is very high in both the cases. Surprisingly, there is no discernible difference in cropping patterns between tube-well owners and groundwater buyers during the rabi season. Similar results have been observed under different climatic regimes of the state except mustard crop in arid region. Overall, tube-well owners allocate large area to wheat, rice and sugarcane crops, whereas groundwater buyers allocate it to bajra, cotton, fodder and mustard crops, which consume less water.

Groundwater application, productivity and net returns

Adoption of water efficient crops and appropriate cropping patterns can play a major role in reducing the groundwater use for irrigation and increasing the water productivity and sustaining groundwater aquifers. Table 10 shows the estimates of irrigation water application, physical water productivity (kg/m³) and water productivity in economic terms (Rs. /m³) for major crops grown by tube-well owners and non-tube-well owners (buyers). Higher physical productivity of irrigation water use for a specific crop denotes more effective irrigation water use via on-farm water management, while higher water productivity in economic terms denotes better irrigated output viability if land is plentiful (Kumar et al. 2011). While comparing the water application and water productivity of crops raised by two categories of farmers the analysis shows that tube-well owners and non-tube-well owners grow almost similar crops during kharif and rabi season. However, for all of the major crops grown, the overall amount of irrigation water applied for crop production is higher for owners than for buyers because owners have a much greater access to water. Further, for most of the crops physical productivity of water is higher for buyers as compared to tube-well owners. In contrast, economic productivity of water except the mustard crop is higher for tube-well owners. Similar results for different climatic zones have been observed. These results from this study do not correspond with the earlier findings in Uttar Pradesh, Bihar and Gujarat, where buyers have achieved higher economic productivity (Shah et al. 2003; Kumar et al. 2011). This can be corroborated to the fact that water buyers incur higher cost (Rs. /hr) for irrigation water in volumetric terms, which ultimately lowers net return from crop production than their counterpart farmers in Uttar Pradesh, Bihar and Gujarat. Besides, owners as compared to buyers achieve higher economic productivity on account of prevailing flat tariff rates of energy in Haryana (Table 1; Fig. 5). This study, therefore, contradicts the earlier findings that economic productivity of owners under flat rate provision is comparatively less than the farmers who have metered connections in India (Shah et al. 2003; Kumar et al. 2011). Additionally, the results of this study reveal that tube-well owners in Haryana are able to maintain high soil moisture, which reduces the need for fertilizer input and thus minimizing the input cost and enhancing the economic productivity. These results indicate that Haryana has reaped the optimum benefits of Package Technology; however, growing of rice crop has completely depleted the water resources.

In addition, as regards the water application, physical and economic productivity, the comparative figures for the study area with that of other areas are presented in Fig. 11. When compared to Uttar Pradesh, Bihar, and Gujarat, both tube-well owners and non-tube-well owners achieve higher economic efficiency in all crops except rice, but at the expense of more water application in most crops. Therefore, it is suggested that farmers in Haryana should try to economize on the application of water since it is water deficient region in physical terms in India. Reduction in
Table 5  Impact of flat rate tariff energy pricing regime on hours of pumping and pumping hours per ha in Haryana

| Size of land holding | Average | Rice | Wheat | Sugarcane | Bajra | Cotton |
|---------------------|---------|------|-------|-----------|-------|--------|
|                     | Hours of pumping | Hours/ha | Hours of pumping | Hours/ha | Hours of pumping | Hours/ha | Hours of pumping | Hours/ha | Hours of pumping | Hours/ha |
| Sub-humid zone      |         |      |       |           |       |        |
| Small               | 862     | 788  | 927   | 1172      | 26    | 31     | 47     | 94      | –       | –      | –       | –      |
| Medium              | 1128    | 434  | 984   | 575       | 53    | 28     | 145    | 128     | –       | –      | –       | –      |
| Large               | 2164    | 297  | 1562  | 389       | 138   | 33     | 539    | 155     | –       | –      | –       | –      |
| Average             | 1385    | 506  | 1158  | 712       | 72    | 31     | 243    | 126     | –       | –      | –       | –      |
| Semi-arid zone      |         |      |       |           |       |        |
| Small               | 511     | 321  | 662   | 470       | 51    | 34     | –      | –       | 15      | 17     | 10      | 11     |
| Medium              | 803     | 255  | 738   | 288       | 90    | 33     | 129    | 160     | 15      | 16     | 48      | 30     |
| Large               | 1726    | 177  | 1264  | 172       | 303   | 34     | 309    | 118     | 54      | 16     | 29      | 24     |
| Average             | 1013    | 251  | 888   | 310       | 148   | 34     | 219    | 139     | 28      | 16     | 29      | 22     |
| Arid zone           |         |      |       |           |       |        |
| Small               | 434     | 324  | 825   | 908       | 47    | 47     | –      | –       | 17      | 33     | 23      | 40     |
| Medium              | 486     | 155  | 824   | 385       | 79    | 39     | –      | –       | 33      | 32     | 43      | 31     |
| Large               | 799     | 107  | 769   | 172       | 139   | 23     | –      | –       | 29      | 30     | 61      | 23     |
| Average             | 573     | 195  | 806   | 488       | 89    | 36     | –      | –       | 26      | 32     | 43      | 32     |
| Haryana             |         |      |       |           |       |        |
| Small               | 602     | 477  | 805   | 850       | 42    | 37     | 47     | 94      | 16      | 25     | 17      | 25     |
| Medium              | 806     | 282  | 849   | 416       | 74    | 33     | 137    | 144     | 24      | 24     | 46      | 31     |
| Large               | 1563    | 440  | 1199  | 244       | 193   | 30     | 424    | 136     | 41      | 23     | 45      | 24     |
| Average             | 990     | 400  | 951   | 503       | 103   | 34     | 203    | 125     | 27      | 24     | 36      | 27     |

The boldface values are showing the average values.
Table 6  Impact of flat rate tariff energy pricing regime on consumption of energy and energy use per ha in Haryana

| Size of land holding | Average | Rice | Wheat | Sugarcane | Bajra | Cotton |
|---------------------|---------|------|-------|-----------|-------|--------|
|                     | kWh hour| kWh /ha| kWh hour| kWh /ha| kWh hour| kWh /ha| kWh hour| kWh /ha| kWh hour| kWh /ha| kWh hour| kWh /ha|
| Sub-humid zone      |         |       |       |           |       |        |
| Small               | 3216    | 2938  | 3459  | 4372      | 98    | 116    | 174    | 352      | –       | –       | –       | –       |
| Medium              | 4208    | 1620  | 3672  | 2144      | 198   | 105    | 541    | 477      | –       | –       | –       | –       |
| Large               | 8070    | 1109  | 5826  | 1451      | 514   | 123    | 2010   | 577      | –       | –       | –       | –       |
| Average             | 5165    | 1889  | 4319  | 2656      | 270   | 115    | 908    | 469      | –       | –       | –       | –       |
| Semi-arid zone      |         |       |       |           |       |        |
| Small               | 1904    | 1196  | 2469  | 1754      | 191   | 128    | –      | –        | 57      | 64      | 36      | 40      |
| Medium              | 2996    | 951   | 2753  | 1076      | 336   | 122    | 482    | 597      | 54      | 60      | 181     | 112     |
| Large               | 6439    | 661   | 4716  | 643       | 1131  | 128    | 1152   | 439      | 201     | 60      | 108     | 90      |
| Average             | 3780    | 936   | 3313  | 1158      | 552   | 126    | 817    | 518      | 104     | 61      | 108     | 80      |
| Arid zone           |         |       |       |           |       |        |
| Small               | 1620    | 1208  | 3077  | 3385      | 177   | 174    | –      | –        | 64      | 124     | 87      | 149     |
| Medium              | 1812    | 580   | 3074  | 1435      | 294   | 146    | –      | –        | 122     | 121     | 161     | 117     |
| Large               | 2979    | 398   | 2870  | 641       | 520   | 87     | –      | –        | 109     | 110     | 229     | 86      |
| Average             | 2137    | 729   | 3007  | 1820      | 330   | 135    | –      | –        | 98      | 118     | 159     | 118     |
| Haryana             |         |       |       |           |       |        |
| Small               | 2247    | 1780  | 3002  | 3170      | 155   | 139    | 174    | 352      | 60      | 94      | 62      | 95      |
| Medium              | 3005    | 1050  | 3166  | 1552      | 276   | 124    | 512    | 537      | 88      | 90      | 171     | 115     |
| Large               | 5829    | 1640  | 4471  | 912       | 722   | 113    | 1581   | 508      | 155     | 85      | 169     | 88      |
| Average             | 3694    | 1490  | 3546  | 1878      | 384   | 125    | 756    | 466      | 101     | 90      | 134     | 99      |

The boldface values are showing the average values
Table 7  Number of tube-wells, horsepower of tube-wells and area irrigated each tube-well in Haryana

| Size of landholding | Number of tube-wells | Horsepower of tube-wells | Area irrigated by each tube-well (ha) | Number of farmers without electric tube-wells | Number of farmers owning one electric tube-well | Number of farmers owning two electric tube-wells | Number of farmers owning three electric tube-wells | Number of farmers owning four electric tube-wells | Number of farmers owning more than four electric tube-wells | Total number of farmers |
|---------------------|----------------------|--------------------------|---------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|------------------------|
| Sub-humid zone      |                      |                          |                                       |                                               |                                               |                                               |                                               |                                               |                                               |                        |
| Small               | 44                   | 7.5                      | 1.3                                   | 19 (36.5)                                     | 24 (46.2)                                     | 7 (13.5)                                      | 2 (3.8)                                       | 0 (0.0)                                       | 0 (0.0)                                       | 52 (100.0)                        |
| Medium              | 48                   | 13.1                     | 2.0                                   | 4 (10.0)                                      | 24 (60.0)                                     | 8 (20.0)                                      | 3 (7.5)                                       | 1 (2.5)                                       | 0 (0.0)                                       | 40 (100.0)                        |
| Large               | 83                   | 17.4                     | 3.0                                   | 0 (0.0)                                       | 10 (30.3)                                     | 8 (24.2)                                      | 5 (15.2)                                      | 10 (30.3)                                     | 0 (0.0)                                       | 33 (100.0)                        |
| Total/Average       | 175                  | **12.6**                  | **2.3**                               | **25 (18.4)**                                 | **58 (46.4)**                                 | **23 (18.4)**                                 | **10 (8.0)**                                  | **11 (8.8)**                                  | 0 (0.0)                                       | **125 (100.0)**                   |
| Semi-arid zone      |                      |                          |                                       |                                               |                                               |                                               |                                               |                                               |                                               |                        |
| Small               | 21                   | 7.2                      | 1.9                                   | 21 (52.5)                                     | 18 (45.0)                                     | 1 (2.5)                                       | 0 (0.0)                                       | 0 (0.0)                                       | 0 (0.0)                                       | 40 (100.0)                        |
| Medium              | 23                   | 14.9                     | 3.0                                   | 3 (13.0)                                      | 20 (87.0)                                     | 0 (0.0)                                       | 0 (0.0)                                       | 0 (0.0)                                       | 0 (0.0)                                       | 23 (100.0)                        |
| Large               | 60                   | 17.1                     | 5.5                                   | 2 (5.4)                                       | 25 (67.6)                                     | 5 (13.5)                                      | 2 (5.4)                                       | 1 (2.7)                                       | 2 (5.4)                                       | 37 (100.0)                        |
| Total/Average       | 104                  | **13.1**                  | **4.2**                               | **26 (26.0)**                                 | **63 (63.0)**                                 | **6 (6.0)**                                   | **2 (2.0)**                                   | **1 (1.0)**                                   | **2 (2.0)**                                   | **100 (100.0)**                  |
| Arid zone           |                      |                          |                                       |                                               |                                               |                                               |                                               |                                               |                                               |                        |
| Small               | 35                   | 8.4                      | 1.9                                   | 29 (48.3)                                     | 31 (51.7)                                     | 0 (0.0)                                       | 0 (0.0)                                       | 0 (0.0)                                       | 0 (0.0)                                       | 60 (100.0)                        |
| Medium              | 28                   | 8.0                      | 3.9                                   | 15 (35.7)                                     | 26 (61.9)                                     | 1 (2.4)                                       | 0 (0.0)                                       | 0 (0.0)                                       | 0 (0.0)                                       | 42 (100.0)                        |
| Large               | 26                   | 11.4                     | 8.5                                   | 2 (6.1)                                       | 26 (78.8)                                     | 2 (6.1)                                       | 2 (6.1)                                       | 2 (6.1)                                       | 0 (0.0)                                       | 33 (100.0)                        |
| Total/Average       | 89                   | **9.3**                   | **4.4**                               | **46 (34.1)**                                 | **83 (61.5)**                                 | **3 (2.2)**                                   | **2 (1.5)**                                   | **0 (0.0)**                                   | **1 (0.7)**                                   | **135 (100.0)**                  |
| Haryana             |                      |                          |                                       |                                               |                                               |                                               |                                               |                                               |                                               |                        |
| Small               | 100                  | 7.7                      | 1.6                                   | 69 (45.4)                                     | 73 (48.0)                                     | 8 (5.3)                                       | 2 (1.3)                                       | 0 (0.0)                                       | 0 (0.0)                                       | 152 (100.0)                       |
| Medium              | 99                   | 12                       | 2.8                                   | 22 (21.0)                                     | 70 (66.7)                                     | 9 (8.6)                                       | 3 (2.9)                                       | 1 (1.0)                                       | 0 (0.0)                                       | 105 (100.0)                       |
| Large               | 169                  | 15.3                     | 4.7                                   | 4 (3.9)                                       | 61 (59.2)                                     | 15 (14.6)                                     | 9 (8.7)                                       | 11 (10.7)                                     | 3 (2.9)                                       | 103 (100.0)                       |
| Total/Average       | **368**              | **11.7**                  | **3.4**                               | **95 (26.4)**                                 | **204 (56.7)**                                | **32 (8.9)**                                  | **14 (3.9)**                                  | **12 (3.3)**                                  | **3 (0.8)**                                   | **360 (100.0)**                   |

Figures within the parentheses are percentage of total
The boldface values are showing the average values
irrigation water consumption can be achieved by selecting less water consuming and highly valued crops. The comparative figures for number of watering, net water consumption, yield and returns from crop production under major crops are presented in Table 11. In Haryana, the tube-well owners water their crops for a greater number of times, therefore consume more water and obtain higher yield and income per hectare than non-tube-well owners except the mustard crop. These findings, however, are dependent on specific socioeconomic characteristics of farmer, availability and quality of infrastructure and services, including energy, and other variables that could influence income levels. Sugarcane and rice are the most remunerative crops followed by mustard, cotton and wheat among both owners and non-owners. A higher net return for different crops is attributed to cheap energy (10 paisa/kWh) in Haryana. If actual cost of energy production (646 paisa/unit) applies in agriculture sector then farmers will have higher energy bills, thereby resulting into an increase in input cost of farmers and consequently net returns will decline. Likewise, buyers will not be able to grow even less water consuming crops if actual cost of energy applies in agriculture. Certainly, power supply policies will affect the net return of farmers.

### Table 8 Variations in utilization factor as influenced by landholding size of farmers, cropping season and climatic zones under flat rate tariff energy pricing regime in Haryana

| Size of landholding | Cropping intensity (%) | Average days per year | Operating hours per day | Utilization factor (%) |
|---------------------|------------------------|-----------------------|-------------------------|------------------------|
|                     |                        | Kharif | Rabi | Annual | Kharif | Rabi | Annual | Kharif | Rabi | Annual |
| **Sub-humid zone**  |                        |        |      |        |        |      |        |        |      |        |
| Small               | 191                    | 88     | 16   | 104    | 6.6    | 6.4  | 6.5    | 18.5   | 1.0  | 9.7    |
| Medium              | 182                    | 107    | 16   | 123    | 6.5    | 5.5  | 6.0    | 24.4   | 1.7  | 13.0   |
| Large               | 161                    | 112    | 11   | 123    | 6.8    | 6.5  | 6.7    | 45.6   | 0.7  | 23.2   |
| **Average**         | **178**                | **102**| **14**| **117**| **6.7**| **6.0**| **6.0**| **29.5**| **1.1**| **15.8**|
| **Semi-arid zone**  |                        |        |      |        |        |      |        |        |      |        |
| Small               | 200                    | 67     | 15   | 81     | 7.4    | 6.3  | 6.9    | 11.2   | 1.4  | 6.3    |
| Medium              | 199                    | 88     | 23   | 111    | 7.8    | 5.7  | 6.8    | 15.7   | 2.6  | 9.2    |
| Large               | 190                    | 102    | 23   | 125    | 7.7    | 5.9  | 6.8    | 31.5   | 7.9  | 19.7   |
| **Average**         | **196**                | **86** | **20**| **106**| **7.6**| **6.0**| **6.8**| **19.5**| **4.0**| **11.7**|
| **Arid zone**       |                        |        |      |        |        |      |        |        |      |        |
| Small               | 198                    | 53     | 22   | 62     | 6.2    | 5.3  | 5.8    | 8.5    | 1.5  | 5.0    |
| Medium              | 192                    | 51     | 18   | 68     | 6.3    | 4.9  | 5.6    | 8.2    | 2.9  | 5.5    |
| Large               | 195                    | 79     | 18   | 89     | 5.9    | 4.0  | 5.0    | 19.8   | 4.3  | 11.9   |
| **Average**         | **195**                | **61** | **19**| **73** | **6.1**| **4.7**| **5.4**| **12.2**| **2.9**| **7.5**|
| **Haryana**         |                        |        |      |        |        |      |        |        |      |        |
| Small               | 196                    | 69     | 18   | 82     | 6.7    | 6.0  | 6.4    | 12.7   | 1.3  | 7.0    |
| Medium              | 191                    | 82     | 19   | 101    | 6.9    | 5.4  | 6.1    | 16.1   | 2.4  | 9.2    |
| Large               | 182                    | 98     | 17   | 112    | 6.8    | 5.5  | 6.1    | 32.3   | 4.3  | 18.7   |
| **Average**         | **190**                | **83** | **18**| **101**| **6.8**| **5.6**| **6.2**| **20.4**| **2.7**| **11.7**|

The boldface values are showing the average values

**Funding for electric tube-wells installation**

Decline in groundwater levels have compelled farmers to shift from centrifugal to submersible tube-wells, which call for large number of investments on behalf of farmers. Therefore, in the absence of desired money for tube-well installations farmers have to rely on funding from other sources. Rural credit markets in Haryana are characterized by co-existence of formal, semi-formal and informal lenders. Nationalized commercial and State co-operative banks dominate the formal lending institutions, whereas informal lenders include commission agents and money lenders. The survey results show that about 42 percent farmers acquire funds for their own tube-well installation from commission agents and money lenders, followed by own savings and commercial and co-operative banks (Table 12). The survey data also show that farmers do not choose to lend from government institutions on account of dishonesty, red-tapesim and exploitation. Therefore, informal institutions such as commission agents and money lenders are preferred over the formal, which the farmers believe is relatively hassle free for them. Conversely, these informal institutions charge very high interest rate on endowments, resulting increased indebtedness leading to suicides among farmers, which is out of scope of this study.
Farmers’ perception regarding energy supply and groundwater development

The energy and groundwater irrigation nexus cannot be understood without the farmers’ perspectives and responses. Table 13 demonstrates farmers’ perception regarding energy and groundwater irrigation nexus in Haryana state. The analyses show that most of the farmers are not satisfied with voltage and energy supply hours for irrigation, whereas a mixed response regarding energy cuts and damage of tube-wells due to poor voltage have been observed. Farmers are used to get almost 24 h of three phase power supply per day during 1980s, but at present they are getting 6–8 h per day even during the peak cropping season. The quality and timing of energy supply have become unreliable over time, compelling farmers to invest in higher horsepower of motors. Often, energy is supplied with low voltage and during nights with frequent tripping, which damages the operating efficiency and motors installed. Even knowing that poor voltage is detrimental to motors, farmers are forced to run their pumps, because the limited and restricted hours of power supply.

Additionally, joint ownership of tube-wells is an important mechanism for all categories of farmers in Haryana. An irregular supply of energy leads to disagreements and conflicts among the shareholders regarding their turns of using the tube-wells. Since, energy supply is irregular and for only a few hours, a shareholder may lose his turn, promoting many farmers to establish their own tube-well in future. Also, poor-quality energy supply leads to transformer burnouts, causing a heavy toll on net returns of the farmers due to lower crop yields caused by the lack of irrigation water, while transformers are repaired. Transformer burnouts tend to peak during July and August months of kharif season, when the irrigation requirement is greatest. Figure 12 shows the transformer burnout rates in Haryana during the year 2001 to 2015. It has been observed during the field survey that all tube-wells work simultaneously whenever
electricity comes on stream, putting a tremendous load on transformers. The high burnout rate of transformers can be partly attributed to over-loading problems caused both by too many tube-wells being connected to a transformer and the use of higher horsepower than the horsepower registered. With regard to flat tariff rates of energy supply and subsidy given to farmers for running their tube-wells, over 90 percent of the farmers have been found satisfied, however, a cut will curtail their procurement with respect to fertilizers, seeds, insecticides and pesticides. Interestingly, all farmers have supported a fixed energy policy for irrigation sector. Remarkably, 84 percent of the surveyed farmers are willing to pay more for better quality of energy supply, but if higher tariffs are loaded on without quality improvements, then burden on farmers will indeed by very high.

Table 14 shows the evaluations of the issue pertaining to the energy and groundwater irrigation nexus that have been rated as “most significant,” “second most critical,” and “third most critical.” An unreliable power supply and falling groundwater levels have been perceived to be the most critical problems by the interviewed farmers, hence, the most critical problem areas. The high rate of tube-wells failure and decreased tube-wells yield are the next criticality levels. However, high energy cost is also critical but for a minuscule proportion of surveyed farmers. Furthermore, a large number of farmers across all climate zones have described inadequate electricity supply as the most pressing issue. Conversely, falling groundwater levels and reduced tube-well yields are relatively less important issues in sub-humid and semi-arid zone, respectively. Finally, while reduced tube-well yield is a critical concern, it does not appear in the farmers’ responses, despite the fact that declining groundwater levels have been identified as the most critical.

Findings, conclusions and policy implications

The energy use pattern, which is directly related with the development of groundwater, has emerged as a major concern in highly irrigated ecosystem of north western India. Therefore, the key findings emerging from the present study

Table 10 Groundwater application in major crops and their productivity (physical and economic terms) under flat rate tariff energy pricing regime in Haryana

| Crops    | Tube-well owners | Non tube-well owners (Buyers) |
|----------|------------------|-------------------------------|
|          | Depth of irrigation water applied (cm) | Water productivity (kg/m³) | Net water productivity (Rs. /m³) | Depth of irrigation water applied (cm) | Water productivity (kg/m³) | Net water productivity (Rs. /m³) |
| Sub-humid zone |                   |                               |                              |                               |                               |                              |
| Rice     | 70.4             | 0.7                           | 5.4                          | 69.6                          | 0.7                           | 1.4                          |
| Wheat    | 7.4              | 6.4                           | 35.2                         | 6.0                           | 7.0                           | 23.6                         |
| Sugarcane| 34.8             | 30.2                          | 54.5                         | 34.2                          | 27.7                          | 54.0                         |
| Semi-arid zone |                  |                               |                              |                               |                               |                              |
| Rice     | 163.6            | 0.3                           | 4.1                          | 153.3                        | 0.3                           | 3.6                          |
| Wheat    | 9.7              | 4.8                           | 36.4                         | 9.1                           | 4.7                           | 25.1                         |
| Sugarcane| 40.1             | 25.7                          | 35.2                         | 36.0                          | 27.7                          | 27.3                         |
| Cotton   | 7.0              | 2.5                           | 51.2                         | 6.2                           | 2.6                           | 43.6                         |
| Bajra    | 4.0              | 2.9                           | 4.1                          | 2.3                           | 4.9                           | 3.8                          |
| Arid zone |                  |                               |                              |                               |                               |                              |
| Rice     | 168.0            | 0.3                           | 5.3                          | 153.8                        | 0.3                           | 5.1                          |
| Wheat    | 10.4             | 4.8                           | 44.3                         | 9.9                           | 4.6                           | 30.6                         |
| Cotton   | 9.6              | 1.9                           | 27.5                         | 9.3                           | 2.0                           | 27.0                         |
| Bajra    | 2.0              | 8.7                           | 65.2                         | 2.0                           | 9.2                           | 38.9                         |
| Mustard  | 3.9              | 4.5                           | 110.5                        | 3.6                           | 5.3                           | 132.9                        |
| Haryana  |                  |                               |                              |                               |                               |                              |
| Rice     | 134.0            | 0.4                           | 4.9                          | 125.6                         | 0.4                           | 3.4                          |
| Wheat    | 9.2              | 5.3                           | 38.6                         | 8.3                           | 5.4                           | 26.4                         |
| Sugarcane| 37.5             | 27.9                          | 44.9                         | 35.1                          | 27.7                          | 40.7                         |
| Cotton   | 8.3              | 2.2                           | 39.4                         | 7.8                           | 2.3                           | 35.3                         |
| Bajra    | 3.0              | 5.8                           | 34.7                         | 2.2                           | 7.1                           | 21.2                         |
| Mustard  | 3.9              | 4.5                           | 110.5                        | 3.6                           | 5.3                           | 132.9                        |
can be summarized as follows. First, an increase in number, density and pumping of groundwater has been observed on account of higher efficiency of tube-wells, subsidized energy supplies and introduction of a flat tariff-based horsepower rating. However, the share of energy consumption in groundwater irrigation sector has declined from 45 percent in 1990 to 28 percent in 2013. The continuing energy subsidies at unmanageable levels have threatened the state’s fiscal health and also the groundwater resources. Second, the study shows that tube-wells operating hours and its per hectare running hours in addition to energy consumption and its per hectare usage in rice crop is far superior to other crops grown. Third, about 15 percent of large farmers have four tube-wells with high horsepower ratings, which use more energy and

Fig. 11 Comparison of depth of irrigation and water productivity (physical and economic) under major crops for tube-well owners and non-tube-well owners (buyer) in Uttar Pradesh, Bihar, Gujarat and Haryana
groundwater. As a result, large farmers profit more from subsidized energy, while small farmers remain excluded from energy subsidies. Fourth, subsidized energy made a great impact on the use factor of tube-wells. The use factor of large farmers is more than double that of small and medium farmers, confirming the fact that they consume more resources and benefit from subsidies. Fifth, the traditional low value crops have been replaced by high delta and high value crops like rice, cotton and sugarcane. Farmers’ secure fairly high economic productivity as compared to their counterparts in Uttar Pradesh, Bihar and Gujarat. In addition, tube-well owning farmers obtain higher net returns than buyers on account of subsidized energy. Sixth, despite the availability of excellent banking facilities, Haryana’s groundwater economy is largely supported by commission agents and money lenders, followed by personal savings. Finally, farmers are
Table 11 Number of watering, net water consumption, yield and return for major crops under flat tariff energy pricing regime in Haryana

| Crops        | Tube-well owners | Non tube-well owners (Buyers) |
|--------------|------------------|-------------------------------|
|              | Number of watering | Volume of water applied (m³/ha) | Yield (kg/ha) | Net return (Rs. /ha) | Number of watering | Volume of water applied (m³/ha) | Yield (kg/ha) | Net return (Rs. /ha) |
| Sub-humid zone | Rice | 20 | 7040.7 | 4851.6 | 35,749.8 | 19 | 6963.5 | 4875.0 | 9190.4 |
| Semi-arid zone | Wheat | 4 | 742.9 | 4260.9 | 22,705.3 | 6 | 758.3 | 3945.1 | 13,954.9 |
| Haryana      | Sugarcane | 16 | 3484.7 | 100,000.0 | 177,708.8 | 15 | 3416.7 | 91,666.7 | 180,977.8 |
|             | Wheat | 4 | 969.2 | 4304.8 | 32,316.8 | 5 | 907.7 | 4211.5 | 22,909.9 |
|             | Sugarcane | 16 | 4014.3 | 95,000.0 | 136,392.9 | 12 | 3600 | 100,000.0 | 98,250 |
|             | Cotton | 3 | 700 | 1633.3 | 41,166.7 | 3 | 616.7 | 1500.0 | 24,416.7 |
|             | Bajra | 2 | 400 | 1145.0 | 1645.8 | 1 | 229.2 | 1108.3 | 2385.4 |
|             | Mustard | 2 | 394.7 | 1733.3 | 42,543.3 | 2 | 358.8 | 1842.6 | 47,478.7 |
|             | Rice | 23 | 16,356.1 | 4403.2 | 65,393.7 | 24 | 15,332.0 | 3950.0 | 54,887.5 |
|             | Wheat | 5 | 1040.0 | 4450.0 | 40,962.2 | 4 | 990.5 | 4297.5 | 27,623.0 |
| Haryana      | Sugarcane | 16 | 4014.3 | 95,000.0 | 136,392.9 | 12 | 3600 | 100,000.0 | 98,250 |
|             | Cotton | 4 | 962.1 | 1729.8 | 26,361.4 | 4 | 931.5 | 1810.2 | 25,426.6 |
|             | Bajra | 2 | 200.0 | 1747.1 | 13,036.5 | 1 | 197.6 | 1775.8 | 7414.9 |
|             | Mustard | 2 | 394.7 | 1733.3 | 42,543.3 | 2 | 358.8 | 1842.6 | 47,478.7 |

Table 12 Different sources of funds used by farmers for tubewells installation in Haryana (percent of farmers)

| Source of funding                      | Small | Medium | Large | Average |
|----------------------------------------|-------|--------|-------|---------|
| Sub-Humid Zone                         |       |        |       |         |
| Own savings                            | 11.7  | 28.6   | 22.2  | 20.8    |
| Commercial and co-operative banks      | 42.8  | 25.1   | 30.1  | 32.6    |
| Commission agents and money lenders    | 32.8  | 46.3   | 47.7  | 42.2    |
| Relatives, friends and others          | 12.7  | 0.0    | 0.0   | 4.2     |
| Semi-arid zone                         |       |        |       |         |
| Own savings                            | 30.3  | 35.7   | 54.2  | 40.1    |
| Commercial and co-operative banks      | 0.0   | 0.0    | 0.0   | 0.0     |
| Commission agents and money lenders    | 69.7  | 64.3   | 45.8  | 59.9    |
| Relatives, friends and others          | 0.0   | 0.0    | 0.0   | 0.0     |
| Arid Zone                              |       |        |       |         |
| Own savings                            | 18.7  | 29.4   | 23.3  | 23.8    |
| Commercial and co-operative banks      | 20.1  | 16.3   | 32.2  | 22.9    |
| Commission agents and money lenders    | 34.7  | 43.8   | 24.5  | 34.3    |
| Relatives, friends and others          | 26.4  | 10.5   | 20.0  | 18.9    |
| Haryana                                |       |        |       |         |
| Own savings                            | 17.7  | 30.6   | 29.5  | 25.9    |
| Commercial and co-operative banks      | 26.2  | 15.3   | 24.7  | 22.1    |
| Commission agents and money lenders    | 39.5  | 49.5   | 36.8  | 41.9    |
| Relatives, friends and others          | 16.6  | 4.5    | 9.1   | 10.1    |
| Particulars | Small | Medium | Large | Average |
|------------|-------|--------|-------|---------|
| **Sub-humid Zone** | | | | |
| Are you satisfied with energy supply policy related to irrigation? | 20.0 | 13.9 | 17.1 | 17.0 |
| Does energy supply for running tube-wells come according to your schedule? | 19.4 | 17.1 | 18.9 | 18.5 |
| Are you satisfied with numbers of hours of energy supply for irrigation? | 20.0 | 2.8 | 8.6 | 10.5 |
| Do you face shortage of energy for irrigation? | 93.8 | 97.1 | 94.3 | 95.1 |
| Do you experience frequent cuts in energy supply? | 38.2 | 41.9 | 37.0 | 38.7 |
| Do you experience low voltage for running tube-wells? | 26.3 | 22.1 | 30.4 | 26.3 |
| Do you experience damage to your tub-well due to low voltage? | 77.4 | 75.0 | 76.5 | 76.3 |
| Do you think metered rates for running tube-wells are satisfactory? | 17.1 | 19.4 | 14.3 | 16.9 |
| Do you think flat rates for running tube-wells are satisfactory? | 94.3 | 94.4 | 91.4 | 93.4 |
| Do you think subsidy on energy for running tube-wells is satisfactory? | 100.0 | 100.0 | 100.0 | 100.0 |
| Do you want a fixed energy policy? | 100.0 | 100.0 | 100.0 | 100.0 |
| Are you willing to pay for better energy supply? | 78.1 | 88.9 | 82.9 | 83.3 |
| **Semi-arid Zone** | | | | |
| Are you satisfied with energy supply policy related to irrigation? | 26.1 | 10.0 | 8.3 | 14.3 |
| Does energy supply for running tube-wells come according to your schedule? | 6.7 | 10.5 | 2.9 | 6.7 |
| Are you satisfied with numbers of hours of energy supply for irrigation? | 21.7 | 10.0 | 16.7 | 13.1 |
| Do you face shortage of energy for irrigation? | 86.7 | 100.0 | 100.0 | 95.6 |
| Do you experience frequent cuts in energy supply? | 51.7 | 50.0 | 46.5 | 49.4 |
| Do you experience low voltage for running tube-wells? | 0.0 | 2.6 | 2.8 | 1.8 |
| Do you experience damage to your tub-well due to low voltage? | 0.0 | 5.3 | 2.9 | 2.7 |
| Do you think metered rates for running tube-wells are satisfactory? | 56.5 | 35.0 | 52.8 | 48.1 |
| Do you think flat rates for running tube-wells are satisfactory? | 82.6 | 89.5 | 91.9 | 88.0 |
| Do you think subsidy on energy for running tube-wells is satisfactory? | 95.7 | 100.0 | 100.0 | 98.6 |
| Do you want a fixed energy policy? | 100.0 | 100.0 | 100.0 | 100.0 |
| Are you willing to pay for better energy supply? | 73.3 | 100.0 | 97.1 | 90.1 |
| **Arid Zone** | | | | |
| Are you satisfied with energy supply policy related to irrigation? | 11.8 | 20.7 | 6.5 | 10.9 |
| Does energy supply for running tube-wells come according to your schedule? | 0.0 | 0.0 | 6.3 | 2.1 |
| Are you satisfied with numbers of hours of energy supply for irrigation? | 20.6 | 37.9 | 16.1 | 24.9 |
| Do you face shortage of energy for irrigation? | 81.3 | 82.1 | 87.5 | 83.6 |
| Do you experience frequent cuts in energy supply? | 45.9 | 50.0 | 45.2 | 47.0 |
| Do you experience low voltage for running tube-wells? | 9.8 | 4.3 | 6.5 | 6.9 |
| Do you experience damage to your tub-well due to low voltage? | 25.8 | 14.8 | 12.9 | 18.9 |
| Do you think metered rates for running tube-wells are satisfactory? | 36.4 | 46.7 | 58.1 | 47.0 |
| Do you think flat rates for running tube-wells are satisfactory? | 91.2 | 100.0 | 87.1 | 92.8 |
| Do you think subsidy on energy for running tube-wells is satisfactory? | 100.0 | 96.6 | 100.0 | 98.9 |
| Do you want a fixed energy policy? | 100.0 | 100.0 | 96.8 | 98.9 |
| Are you willing to pay for better energy supply? | 80.6 | 60.7 | 96.6 | 79.3 |
| **Haryana** | | | | |
| Are you satisfied with energy supply policy related to irrigation? | 18.7 | 15.1 | 10.8 | 14.9 |
| Does energy supply for running tube-wells come according to your schedule? | 9.1 | 9.9 | 9.6 | 9.5 |
| Are you satisfied with numbers of hours of energy supply for irrigation? | 20.7 | 16.5 | 13.7 | 16.9 |
| Do you face shortage of energy for irrigation? | 87.3 | 92.7 | 94.1 | 91.4 |
| Do you experience frequent cuts in energy supply? | 43.4 | 45.9 | 42.2 | 43.8 |
| Do you experience low voltage for running tube-wells? | 15.7 | 12.9 | 15.1 | 15.6 |
| Do you experience damage to your tub-well due to low voltage? | 41.6 | 37.2 | 31.0 | 36.6 |
| Do you think metered rates for running tube-wells are satisfactory? | 34.1 | 32.6 | 41.2 | 35.9 |
| Do you think flat rates for running tube-wells are satisfactory? | 90.2 | 95.2 | 90.3 | 91.9 |
| Do you think subsidy on energy for running tube-wells is satisfactory? | 98.9 | 98.8 | 100.0 | 99.2 |
| Do you want a fixed energy policy? | 100.0 | 100.0 | 99.0 | 99.6 |
| Are you willing to pay for better energy supply? | 78.2 | 81.9 | 91.8 | 83.9 |
becoming increasingly concerned about inadequate energy supplies and declining groundwater levels.

To summarize, there is nothing that can be done in the state to boost the groundwater economy without having an effect on the energy economy. Therefore, it is suggested that farmers should make a judicious use of energy while irrigating their fields as saving of energy will save groundwater and vice versa. A robust energy policy, especially for tube-wells, must be implemented as a powerful tool for controlling groundwater overdraft. Inability to handle this nexus would be a huge opportunity for both energy and groundwater resource management to be more sustainable.

Table 14 The most critical problems faced by farmers in energy-groundwater irrigation sector of Haryana

| Percentage of farmers | High energy costs | Unreliable electricity supply | Falling groundwater levels | High rate of tube-well failure | Reduced tube-well yield |
|-----------------------|-------------------|-------------------------------|---------------------------|------------------------------|------------------------|
| Sub-humid Zone        |                   |                               |                           |                              |                        |
| Percentage of farmers who rated this as the most critical problem | 7.2 | 76.0 | 49.6 | 36.8 | 32.0 |
| Percentage of farmers who rated this as the second most critical problem | 4.0 | 23.2 | 24.0 | 28.0 | 15.2 |
| Percentage of farmers who rated this as the third most critical problem | 88.8 | 0.8 | 26.4 | 35.2 | 52.8 |
| Semi-arid Zone        |                   |                               |                           |                              |                        |
| Percentage of farmers who rated this as the most critical problem | 11.0 | 74.0 | 92.0 | 55.0 | 26.0 |
| Percentage of farmers who rated this as the second most critical problem | 10.0 | 17.0 | 8.0 | 23.0 | 35.0 |
| Percentage of farmers who rated this as the third most critical problem | 79.0 | 9.0 | 0.0 | 22.0 | 39.0 |
| Arid Zone             |                   |                               |                           |                              |                        |
| Percentage of farmers who rated this as the most critical problem | 8.1 | 75.6 | 74.1 | 51.9 | 37.8 |
| Percentage of farmers who rated this as the second most critical problem | 15.6 | 23.7 | 25.9 | 28.1 | 34.8 |
| Percentage of farmers who rated this as the third most critical problem | 76.3 | 0.7 | 0.0 | 20.0 | 27.4 |
| Haryana               |                   |                               |                           |                              |                        |
| Percentage of farmers who rated this as the most critical problem | 8.6 | 75.3 | 70.6 | 47.5 | 32.5 |
| Percentage of farmers who rated this as the second most critical problem | 10.0 | 21.7 | 20.3 | 26.7 | 28.1 |
| Percentage of farmers who rated this as the third most critical problem | 81.4 | 3.1 | 9.2 | 25.8 | 39.4 |

To solve the energy-groundwater irrigation nexus, the following options must be introduced. First, the most sensible alternative is an acceptable tariff (flat or metered) that is closer to the cost of production, as well as limits on new connections. However, doing this will remain a political sensitive issue in the state. Therefore, the scheme like Jyotigram implemented in Gujarat offers a practical solution to restore health to the finances of energy utilities. Second, proper groundwater withdrawal rationing combined with energy unit pricing can play a complex role in energy and groundwater resource management. As a result, it will be a powerful tool for achieving productivity,
Another policy choice is to ensure that all energy supplied to the irrigation sector is of prescribed quality, standard voltage, and frequency, as this will reduce motor damage and transformer burnout. One of the criticisms of the subsidized energy supply is that the subsidies in irrigation sector are regressive because higher the energy consumed by a farmer, the higher the subsidy benefits offered. Therefore, it is suggested that large farmers need to be excluded from the ambit of subsidized energy supply in a phased manner. Apart from this, to take off the burden of electricity subsidy for irrigation sector, the state government should start advocating the use of solar powered tube-wells. If installation of solar powered tube-wells becomes effective, then the state’s economy will get respite from the debits of electricity subsidy in the upcoming years. Rice cultivation in arid and semi-arid areas should also be checked for sustainable groundwater management. A good measure in this regard can be encouragement to maize cultivation through higher minimum support price (MSP) to reduce groundwater mining or provision of drought resistant rice varieties for future sustainability of agriculture in the state. Finally, prepaid meters deter energy theft and can be powered with tokens or magnetic cards, as well as digitally recharged. Such methods are extensively used to meter the energy consumption of tube-wells in the North China Plains and general energy consumers in South Africa.

To conclude, Haryana is a state in north western India. Other states sharing identical environmental conditions in north western India, are likely to be symptomatic of the energy and groundwater characteristics of the Haryana. It is, therefore, hoped that the implementation of above suggested policies in energy and groundwater sectors will not only be beneficial for Haryana but would find applications to other states of north western India.

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