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Review Article

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Energy Utilization for Ground Water Pumping under Declining Water Table Scenario: A Review

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Abstract

Land and water are the most essential natural resources for sustaining life. Availability of these valuable resources for our future generations depend on decisions and efforts we make today. Groundwater nearly accounts for 61.1% of the net irrigated area in India. Farmers are growing water intensive crops and using water injudiciously, following the traditional irrigation practises. This results in declining water table which in turn results in reduced well discharge, need of replacing the centrifugal pumps with submersible pumps and higher energy consumption. There is an urgent need to address these issues related to energy utilization in ground water pumping for judicious use of natural resources for sustainable agriculture and for betterment of farming community. Farmers should adopt modern irrigation management practices like drip and sprinkler irrigation for efficient use of water. Adoption of latest technologies introduced in agriculture can increase water saving during irrigation and higher crop productivity. For present study, several components associated with energy utilization in ground water pumping were reviewed *viz.* effect of over extraction of ground water on declining water table, mechanical factors affecting overall groundwater pumping efficiency and influence of irrigation methods and agricultural practices on energy and water consumption for ground water pumping.

Keywords: Energy utilization, ground water pumping efficiency, well discharge

1. Introduction

Widespread over exploitation of ground water resources is seen worldwide. This is due to increased utilization of ground water for irrigation (Rodell et al., 2009). There has been constant decline in the watertable levels steadily which has resulted in exponential rise in energy consumption for ground water pumping (Smidt et al., 2016). Irrigated agriculture in India is becoming more dependent on groundwater. Groundwater has played significant role in increasing production and productivity of different crops to make the country self-sufficient in food security (Sharma, 2009). Several factors are responsible for manifold increase in use of ground water during the post green revolution period *viz.* advanced and modern drilling techniques, easy availability of electricity at subsidized rates and use of electrical operated pumping sets (Patle et al., 2015). These simple techniques and easy availability of resources have promoted uncontrolled and injudicious use of ground water in agricultural advanced states of India. The process of large-scale development and utilization of ground water is contributing to depletion of fresh water resources and rapidly increasing in number of dark and grey blocks in the states having good quality water resources, where more than 100% groundwater has been extracted (CGWB, 2012). Intensive agriculture in Indo-Gangetic Plains (IGP) has manifested more stress on groundwater resources. Many parts of the IGP are facing decline in groundwater levels. Rice-Wheat cropping system is the main reason behind the water level decline in the region leading to reduction of aquifer yield and drying of shallow dug wells and tube wells (Ambast et al., 2006). With increasing population dependent on agriculture, per capita land availability which was 0.4 ha in 1900 declined to less than 0.1 ha in 2000 (Scott and Sharma, 2009), putting more stress on currently available land water resources.

Major challenges for sustaining the present growth rate of Indian agriculture sector are: declining water table, climate change and degrading soil health etc. Most important step that can be taken to deal with these problems is with the efficient irrigation water management. Collective efforts are needed for judicious use of natural resources at farm level (Kaur et al., 2012). Green revolution in one way resulted in appreciable improvements in crop harvests but in another way, through depletion of natural resources has created number of secondgeneration problems in the food basket states likewestern Uttar Pradesh, Haryana and Punjab. The Rice–Wheat cropping system is continuously spreading to even those areas/soils otherwise unsuitable for this cropping sequence. It is hardly possible to fulfill the irrigation requirement of Rice-Wheat cropping pattern through rainfall and limited canal water supplies in the semi-arid regions. Hence, groundwater development proliferated and resulted in installation of large number of shallow tube wells. The pumping sets which were operated by diesel engines are shifting to electricity operated submersible pumping sets due to continuous decline in water table, inducing high energy requirement. For present study, several components associated with energy utilization in ground water pumping were reviewed *viz.* effect of over extraction of ground water on declining water table, mechanical factors affecting overall groundwater pumping efficiency and influence of irrigation methods and agricultural practices on energy and water consumption for ground water pumping.

2. Declining of Groundwater table and Groundwater Resources

The fast rate of groundwater exploitation is due to rapid expansion and use of groundwater based irrigation systems which are very reliable and easily accessible. This over exploitation of water not only depleting the most precious and essential natural resource for agriculture but also increasing the cost of crop production. There has been observation of the formation of regional depression of potentiometric levels in several aquifer systems due to excessive groundwater useand which is a cause of serious concern (Custodio, 2002). The trend of groundwater withdrawal is rapid and continuous worldwide (Van et al., 2010). Thirty-eight percent of total 301 million ha irrigated area of the world is irrigated by groundwater (Siebert et al., 2010). Estimated annual withdrawal of groundwater in India which is a prominent consumer of groundwater exceeds over 230 km^3 per annum (Chinnasamy and Agora Moorthy, 2015). Worldwide usage of water for various purposes includes agriculture (69%), industry (23%) and domestic use (8%). However, in developing countries like India and Africa, water use in agriculture is 80–90%, industries is 5–12% and domestic is 5–7%. The share of water in agriculture is very high in developing countries and farmers are using these precious resources inefficiently. Goyal et al. (2010) studied variability of groundwater in Haryana and reported declining trend in groundwater levels in the state. Panda et al. (2012) analyzed 555 monitoring wells over Gujarat state and reported large scale decline in ground water level. Patle et al. (2015) observed near 0.267 m $annum^{-1}$ decline in groundwater level in Karnal district of Haryana. In another similar study, among the 893 monitoring wells observed over Haryana state, there was a decreasing trend ingroundwater level with decline of about 32 cm $annuum^{-1}$ (Singh and Kasana, 2017). Major reason behind this fast declining water table in these states which are bigger contributors of food grains to central pool is attributed to rapidly increasing areas under paddy cultivation. Adoption of high rate of paddy cultivation is due to availability of good quality water and remunerative price of this crop along with possible easy availability of electricity at very nominal charges. Paddy is the most water intensive crop and farmers still using inefficient methods which needs large amount of water, most of which is lost by evaporation and through percolation. This has led to over exploitation of groundwater resources and rapidly declining groundwater level which in turn led to drying up of dug wells and increasing well failure causing higher cost of installation and pumping in new tube wells.

Currently, 972 out of 6881 blocks (groundwater observation units) in India are overexploited (CGWB, 2017). In the north-western states, which have been an epicentre of the Green Revolution like Haryana and Punjab, groundwater use exceeds natural recharge by 49% and 35%, respectively (CGWB, 2017). In the areas where extraction of groundwater exceeds its replenishment either naturally or artificially, the aquifer faces stress resulting to declining water table, increasing the cost of groundwater abstraction and creating ecological imbalance, leading to many environmental issues like deteriorating water quality, land subsidence, vegetation loss and decreased porosity etc. (Biswas, 2003). Most directly adverse impact of declining water level on the environment is indicator of groundwater depletion threating sustainability of aquifer system (Konikow and Kendy, 2005; Akther et al., 2009) (Figure 1).

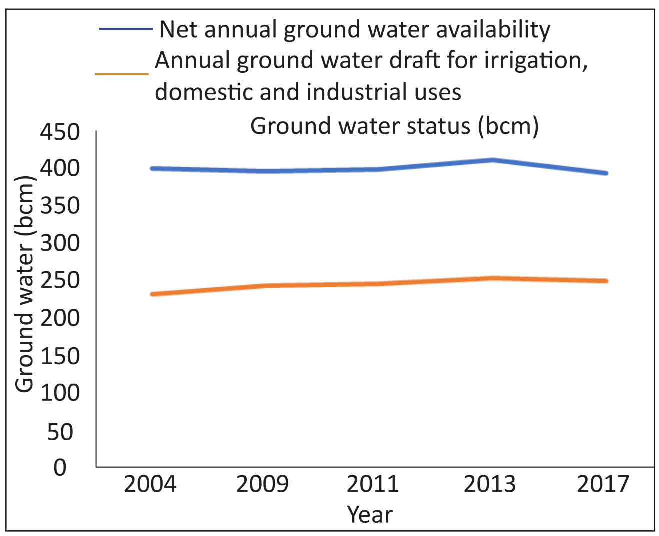

Figure 1: Ground water status in terms of net availability and draft (bcm) during 2004 to 2017 (CGWB, 2017)

In face of hydroclimatic variability and lower availability of surface water sources, groundwater has become a main source of water, which has been a strategic for climate change adaptation is now on the verge of exhaustion and overexploitation. Climate change directly impacts water resources accessibility and availability, also influencing the hydrological processes over the short to long term (Roy et al., 2012). Water scarcity and quality degradation issues created by climate change are some of major challenges, especially in arid and semi-arid regions. In recent times, we have seen erratic weather pattern and behaviours like extended drought, wildfires, flash floods, change in rainfall patterns, heat waves and declining water levels in recent times. Hydrological changes, variable stream flow, rainfall variability and changes in seasonality have made us question reliability of surface water as a source of supply for irrigation, industry and other human uses. This has resulted in increased dependence on groundwater resources contributing to increased groundwater pumping. Intensification of groundwater use and decreased ground water recharge raises important questions for adaptation. Challenges of reliability and availability of surface water sources resulting in drawdown of shallow aquifer levels, increased energy demand and associated emissions for groundwater extraction (Barlow and Leake, 2012). This causes serious threat especially to irrigated agriculture, agricultural productivity and rural livelihoods. There is need to promote sustainable use of groundwater and go for adaptive strategies, use of appropriate management systems to put constrain on overuse and depletion.

3. Impact of Different Mechanical Factors on Ground Water Pumping Efficiency

Overall pumping plant efficiency (OPPE) is the total product of the combined efficiencies of both motor and pump. Irrigation pumping systems commonly used include the power unit, gear drive, well intake screen and pump/bowl assembly etc. Most commonly used pumping system includes the ones run by diesel engine or electric motor. Efficiencies of pumping plants normally used for irrigation are generally found to be low in field conditions,which can be attributed to incorrect selection of pump, operating condition in consistencies, pump impellers that are misaligned, incorrect design of pump bowl, damaged impeller and poor plumbing in horizontal axis (Chavez et al., 2011). Cavitation, sand pumping and improper impeller adjustment are the major causes of impeller damage resulting to quickly decrease in pump efficiency. The misaligned impellers are the easiest to fix and most cost effective to correction. Selection of motor for irrigation pumping system needs special attention. Electric irrigation pumping plants with poor motor selection is main reason behind deterioration of pump performance due to overloading i.e., shaft power exceeds the rated power of the motor. Overheating of motor due to overloading affects its performance and life. Overloading will draw higher current to generate sufficient power that needed for driving theload, this results in generation of heat and rise in temperatures.

Optimum working life of a pumping system can be obtained by regular and efficient servicing of various components. Effective maintenance can enhance reliability, performance, productivity and minimize cost of operation to a great extent. Following the manufacturers' guidelines and recommendations during operation of the pumps play an important role in achieving high energy savings. When pumps are not properly maintained, motor may get burnt and need rewinding and repairing. Even though rewinding of a motor costs less than the cost of a new one but rewound motors works less efficiently even after taking much care (Saidur, 2010). Operation of a pumping system correctly is as important as its design for efficient energy utilization. Peak efficiency is obtained at particular discharge rate and head, operating pump at a different condition reduces efficiency (Loftis and Miles, 2004). Use of technology like electronic adjustable speed drives (ASDs) that adjust electric motor speed by means of regulating the power delivered corresponding the motor speed to the specific demands (Brar et al., 2017). This can help in saving significant amounts of energy by as much as 50% and allows operators to fine-tune pump leading to reduced energy usage and lower equipment maintenance cost (Gude, 2015). This benefit varies depending on system variables such as load profile, pump size, amount of static head, and friction.

The efficiency of induction motor can be improved by using Die-Cast Copper Rotor (DCR) technology in place of Copper Fabricated Rotor (CFR). Due to adoption of this slot design, efficiency of submersible motor increased by 4-5% (Subramanian et al., 2010). The main losses in an induction motor comprise of resistance losses in the rotor case and stator winding, friction and windage losses, iron losses and stray losses. The resistivity of copper and aluminium for circular mil, per foot at 20°C were observed 10.37 Ω and 16.06 Ω, respectively. Substitution of copper for aluminium resulted in 35.4% reduction in resistance losses for producing same current (Deivasahayam, 2005). This is a simple process of increasing the efficiency of motor, although cost of copper is higher than aluminium, it also increases the cost of motor. Pumps efficiency decrease with time due to pump wear, variations in groundwater situations and irrigation system (Hanson, 1988). Operation range of different pumps needs to be specified as different pumps of the same size exhibit maximum efficiency at different total head and discharge. Improper selection of pump, prime mover and their accessories are the major factors contributing to lower pumping set efficiency.

4. Groundwater-Electricity Nexus

Different kind of lift devices and various power sources (Diesel, Electric and Animal etc.) have been used for extracting groundwater for decades now. Increased reach of electricity which came with rural electrification transformed the irrigation sectors in the 20th century. People are pumping great volumes of ground water today all over the world in countries like China, United States, India and Mexico etc. Ease of pumping that came with electrical pumping of groundwater has caused some problems. Overpumping creating tensions in social and economic viability of groundwater-dependent agriculture (Mukherji and Das, 2014). Fluctuating nature of ground water levelhas made operation of submersible pumps impossible at designed head and discharge rates resulting in lower operating efficiency. Lower efficiencies result in higher energy consumption of energy and others costs. Drawdown which is the difference between pumping level and static water level is an important component of the total operating head of the submersible pumps and has a significant effect on pumps performance as it can change the operating head and discharge rates which can result in poor pumping efficiency. Main factors affecting the drawdown is well diameter and filter length, drawdown can be decreased by increasing well diameter and filter length to obtain constant performance from pumps (Haque et al., 2019).

Currently, there are nearly 20 million operational groundwater wells in India (70% rely on electricity, 26% are diesel-powered and rest others sources (Prayas, 2018a). However, 85% of energy required for the groundwater pumping is provided by electricity as most pumps that are installed on the deepest tube wells having higher energy requirements are largely electric (Prayas, 2018b). Electric pumpsets used for groundwater irrigation have an important role in agricultural water supply systems in India. Hence, pricing policies of electricity especially for irrigation can lead to some serious ramifications in India's agriculture sector.

Government generally provides subsides on electricity for pumping wells used for irrigation but there are huge environmental costs (Jessoe and Badiani, 2019). There is substantial evidence that supports concern in India about over-exploitation of groundwater for irrigation purpose and questions the sustainability of current ground water extraction patterns. Electricity subsidies have contributed significantly in this as subsides incentivise increased groundwater extraction and shifting towards more water intensive cropping. Impacts of subsidized electricity can have potential negative implications like over-exploitation of groundwater, increased CO_2 emissions and reduction in groundwater availability for agriculture (Badiani and Jessoe, 2013).

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 (Sidhu et al., 2020). There are two most commonly used tariff structures used by power utilities that charge groundwater consumers across different states. Firstly, there is flat rate tariffs system where amount paid for electricity is fixed according to power rating for the pumps. The second is the metered tariffs based system which charges based on units of power actually consumed. Evidence from past studies demonstrates that flat rate tariffs are easy to administrate, have low cost of management and equitable distribution, but this tariff structure provide no incentive to farmers for water conservation (Mukherji and Das, 2014). On contrary, metered tariff structure where payment is done on the basis of electricity consumed, this has potential to encourage judicious groundwater pumping. Metered tariff system has disadvantage of being expensive to manage and unfavourable to low-income farmers. There is need for rationalizing agricultural power tariffs with location-specific strategies in different regions according to the agricultural practices and groundwater availability status. States with rapidly depleting aquifers in western region of India should go towards metered tariffs system to promote and incentivize water conservation. Whereas, for regions that are rich water resources like eastern states can benefit from hybrid flat-cum-metered tariff system that promote equity by encouraging water sales. There is urgent need to address these issues to decrease indiscriminate groundwater pumping, reduce virtual water exports of important agricultural produce from regions with low groundwater availability and maintain long-term sustainability of aquifers.

5. Influence of Irrigation and Agricultural Practice on Water Saving and Energy Requirement

India faces a great challenge of doubling agriculture production that is need to be met for food security and economic needs of the projected population growth by the year 2050. Agricultural sector alone consumes 80% of the ground water for irrigation purpose (Harsh, 2017). Net irrigated area percentage of India has grown from 18 to 48% as of date. This is because of important steps taken by the government. Individuals have distinguished groundwater water system to be more dependable and easier to use. But developing need of providing for the populace and ensuring food security has squeezed water assets dry. The declining pattern of groundwater level in different regions of the country is matter of incredible concern Irrigation is largest consumer of fresh water resources. Wide use of redundant and inefficient irrigation management practices has been immense bottleneck. Most important step towards addressing the issues pertaining to groundwater decline at farm level is improvement of farm productivity and water use efficiency (Naresh et al., 2014). These can only be achieved by selection of suitable irrigation method. The method of irrigation used at farm level are broadly classified as surface, subsurface, sprinkler and drip or trickle irrigation. In surface method of irrigation, movement of water occurs by gravity flow in two dimensions in the field from head to tail end. Water is not uniformly distributed causing more percolation losses near the outlet as a result of greater infiltration opportunity time (Rajurkar et al., 2016). There are four phases during a surface irrigation event: (i) water advance phase (ii) wetting or ponding phase (iii) Depletion phase (iv) recession phase. The surface irrigation systems generally have low irrigation efficiency due to poor irrigation management and non levelled land (Darouich et al., 2017). Non-uniform distribution of water at field level leads to spatial variability in accessibility of water and important fertiliser effecting crop growth and productivity (Li et al., 2016). Flood irrigation system has low overall efficiency in the range between 25–40% and this is most widely used method of irrigation (Amarasinghe, 2007). Micro irrigation systems are superior over the other traditional irrigation methods in term of yield, energy saving, water use efficiency and economics (Chandrakanth et al., 2013). Injudicious use of ground water resources has led to decline in groundwater level which can be improved by constructing improved crop productivity, artificial groundwater recharge and adopting conservation practices (Paul and Panigrahi, 2016). Government has put a lot of emphasis on improvement of water-use efficiency and water conservation to achieve More Crops per Drop with schemes like PMKSY.

Conventional techniques of irrigation have excessive seepage loss, low efficiency, inequitable and untimely supplies. Major reason for poor irrigation efficiency in surface irrigation method is the inadequate availability of conveyance and on-farm infrastructures. Secondly, poor maintenance for irrigation water supply system (e.g. unlined canal and farm channels) which leads to poor irrigation efficiency. Average overall irrigation efficiency is observed to be around 38% and average conveyance efficiency is 70%, which are very low and below the desired efficiency. Hence, there is scope of reducing the losses at various scales. One of the most important steps that can be taken is to improve the irrigation infrastructure by undertaking activities like lining of the canal and channels. Likewise, application efficiency at farm level which is around 50% can be improved by lining of watercourses by 22.5% (Arshad et al., 2009). Canal automation, water audit/ budgeting, benchmarking of irrigation systems and adoption of appropriate pricing mechanism can lead to improved irrigation efficiency and reduced water losses. There is need for improving the efficiency of irrigation by adopting better irrigation methods according to their suitability and adaptability. Micro irrigation system can imperative in improving water use efficiency and lead to potential water saving that could ease pressure on scarce groundwater resources. Adopting sprinkler and drip irrigation can significantly improve irrigation efficiency. When different methods of irrigation were compared, highest application efficiency was found in drip irrigation (90%) and 80–90% overall efficiency (Table 1).

Laser land levelling is a good alternative land levelling technology having the primary benefit of a decreasing irrigation losses that occur due to highly undulating land. A uniformly levelled field not only improves irrigation efficiency by having better control over distribution of water but also reduces potential nutrient loss with better runoff control, greater FUE and higher yields (Jat et al., 2011 and Naresh et al., 2014). Therefore, use of laser land levelling instead of traditional land levelling methods can reduce water losses and save energy by reducing duration of irrigation. There is need for giving proper emphasis on better irrigation management.

Table 1: Efficiencies of different irrigation methods

Efficiencies of irrigation	Irrigation methods		
	Surface	Sprinkler	Drip
Conveyance efficiency	40-50% (canal) 60-70% (well)	100%	100%
Application efficiency	60-70%	70-80%	90%
Surface water moisture evaporation	30-40%	30-40%	20-25%
Overall efficiency	30-35%	50-60%	80-90%

Source: Saleth (2009); Kumar and Palanisami (2010)

Keeping all this in view, there is need of making concerted efforts to educate the farmers about efficient use of natural resources and its conservation at farm level (Kaur et al., 2012).

Water productivity denotes the amount of water depleted or diverted for producing unit amount of produce. There are few options for improving water productivity like adopting micro irrigation, growing less water intensive crop and varieties, mulching, deficit irrigation agronomic practices like raised bed planting, ridge-furrow method of sowing, subsurface irrigation and precision farming are some other ways that can be helpful in improving water productivity etc. Pricing of irrigation water or electricity for ground water pumping to some extent also motivate farmers to save water without overburdening them (Bakia et al., 2018). Reducing or abandoning subsidies for energy for water pumping for ground water irrigation and other water saving measures should be explored. This can lead to potential water and energy saving during irrigation while promoting sustainable use of groundwater without environmental consequences.

6. Conclusion

Regions of declining water table are facing various problems *viz*. drying of aquifer, groundwater pollution, salinity and increased arsenic content in shallow aquifer. The over utilization of ground water resources has resulted in high power consumption, ecological imbalance and threats to sustainable agriculture. Some measures have been suggested by the researchers to control the declining water table like shifting of cropping pattern, delayed paddy transplantation, adoption of modern irrigation methods like sprinkler and drip irrigation system and rain water harvesting techniques.

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