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EFFICIENT USE OF GROUND WATER FOR SUSTAINABLE AGRICULTURAL PRODUCTION: PROSPECTS IN BANGLADESH

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ABSTRACT

Bangladesh is a developing country where contribution of agriculture in national gross domestic product is 12.68%. In agricultural sector, about 79% irrigation has been provided by groundwater. This review paper is prepared on the developing scenario of groundwater and its utilization efficiency, problems in groundwater use and relevant remedies to attain sustainable agriculture in Bangladesh. Due to the over extraction of groundwater, the depth of groundwater table has been declined (15%) miserably. Using redundant amount of irrigation water, conveyance loss (8-40%), arsenic contamination, insufficient recharge of groundwater etc. are the major problems behind inadequate groundwater use efficiency. Using alternate wetting and drying (AWD) method, reducing conveyance loss, diversifying cropping pattern, reforming national policies etc. are some effective measures to increase groundwater use efficiency required for sustainable agriculture. About 10,000 Tk. ha^{-1} can be saved just by minimizing the cost required to extract excess groundwater for irrigation. In Bangladesh, maximum national policies are focusing exclusively to the resource development rather than the resource management. The awareness can be built through different teaching programs among all the stakeholders. Rather than just imposing restriction on installation of tubewells, more constructive policies have to be announced by the policy makers. Seven different agencies are now working for the management of groundwater in Bangladesh. Besides other technical solutions, there should be a coordination among different organizations related to the groundwater management for the effective implementation of their target policies.

Keywords: Efficient water use, sustainable agriculture, underground water

Introduction

The water level found underneath the surface margin, in spaces and cracks between the soil, sand and rocks is known as groundwater. It remains as stored water and moves gently within the aquifers. A unit of underground rock or an unconsolidated geological formation of soil, rock and sand deposition is referred to as aquifer. At the groundwater table, pore spaces into the soil, all the cracks and voids in rocks become fully saturated with water. About 95% of the freshwater of our earth is carried out as groundwater. It is the most essential and dynamic natural resources which is required for almost all the living beings of this planet for their survival. Groundwater is one of the most important resources of water which is required for the crop production and also to maintain sustainable agricultural improvement.

Bangladesh is a riverine country and located at the bottom-most level of Ganges-Brahmaputra-Meghna river system. This river system covers about 1.72 million (m) km^2 of land. However, Bangladesh is blessed with only 8% of watershed (Ahmed *et al.* 2011, Chowdhury 2010). Hydrological regions of Bangladesh (Cell 2009) are presented in figure 1.

Rice is the major staple food of Bangladesh which comprised about 75% of total agricultural land and supplying 90% of total food grain production (Rahman *et al.* 2008). Due to unplanned installation of tubewells, increasing rate of operational and energy-using cost, declining trend of groundwater level in intensive irrigated areas of northern region of Bangladesh, deterioration of groundwater quality can lead Bangladesh to a crucial phase against to attain sustainability in agriculture sector (Qureshi *et al*. 2014).

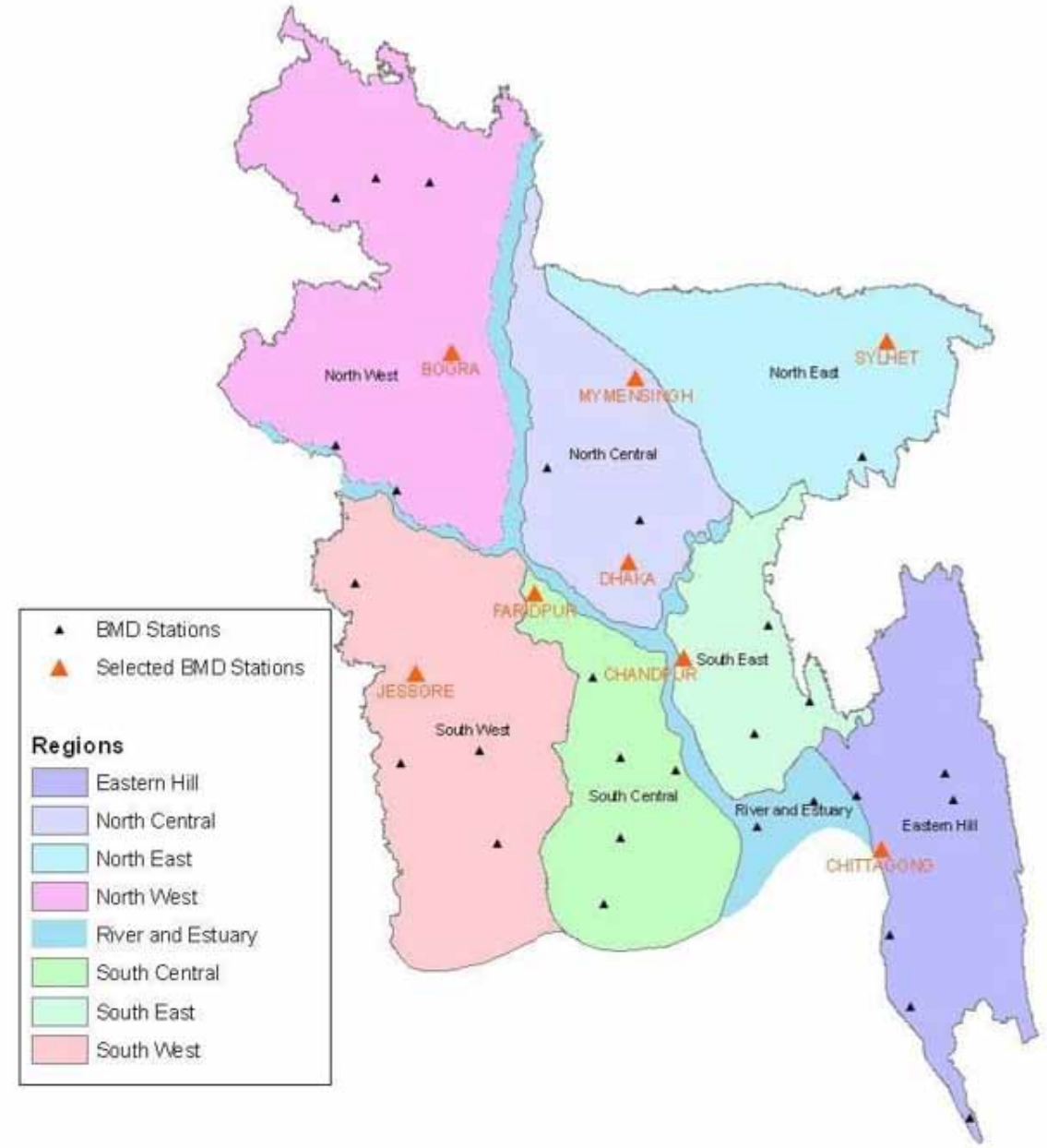


Figure 1. Hydrological regions of Bangladesh.

In 2018, the total population of Bangladesh was 161.4 m which is expected to reach 182 m within 2030. To meet the food demand of increasing population, we have to rise rice production to 39 m tons, wheat production to 0.65 m tons, maize production to 1.46 m tons year^{-1} (Amarasinghe *et al*. 2014). To meet this huge food production target, a remarkable imbalance might be observed between the groundwater recharge and discharge in different regions of Bangladesh. Also, the management of efficient groundwater utilization with the existing government policies is also a challenge. Without solving this unavoidable problem, attaining sustainable agriculture to meet Bangladesh's future food demand is not feasible.

There is a lack of adequate knowledge about the aquifer reserves, the extraction pattern of groundwater, transformation of the quality of groundwater and also the impact of using this water for irrigation. This paper will help to have knowledge about the scenario of

groundwater use development, obstacles related to groundwater development and upcoming challenges in Bangladesh. The existing national policies related to management of groundwater resources and relevant idea to modify these policies to ensure sustainable agriculture in Bangladesh have also been discussed. The objectives of the review paper are to know the scenario of groundwater development and level of groundwater use efficiency in Bangladesh and to identify the problems in groundwater utilization and management policies to attain sustainable agriculture in Bangladesh.

Groundwater use development in Bangladesh

Scenario of groundwater use development

The first deep tubewell (DTW) of Bangladesh was installed in late 1960s, but the number of installations was getting increased drastically in late 1980s. About 25,500 DTWs were installed in all over the country. At present years, approximately 34,332 DTWs are providing water to supply irrigation water. The increasing trend of DTW was slowed down due to the expansion of the installation of shallow tubewells (STW, discharge capacity 10-12 liter per second). In 2013, there were about 1,523,609 shallow tube wells and 169,670 low lift pumps for providing irrigation water (BADC 2018-19). Due to the hazardous flood in 1988 and subsequent cyclone in early 1990s, government upraised maximum of the restrictions and embargoes on the import of agricultural equipment rather than increasing subsidies for agricultural inputs like irrigation, seed expansion and irrigation (Hossain 2009, Mandal 2000, Saleh and Amin 2005).

Utilization of groundwater

Groundwater is the source of 30% of freshwater in Bangladesh. About 84.47% of this groundwater has been used for agricultural purpose (Aghlmand and Abbasi 2019). Bangladesh is an agricultural country. According to the water table (WT) time-series data for 2007–2019, the annual groundwater budget for discharge and storage was 2,772 and 2,442 Mm^3, respectively. Thus, the annual scarcity of groundwater was 330.4 Mm^3 (13.5%) (Mohammad and Syed 2021). Due to the shortage and unpredictability of surface water, groundwater plays a vital role to meet agricultural water demand. About 60% of agricultural water requirement has been fulfilled by groundwater which covers more than 50% of irrigated area (Shah *et al*. 2003). About 4.2 m hectares (ha) of land are irrigated by groundwater (both STWs and DTWs), where surface water is used for 1.03 m ha by using low lift pumps. There was a subsequent expansion of area irrigated by groundwater from 1983-2005. After 2005, that increasing rate is slowed down due to the declination of groundwater table depth. This condition results in increasing of groundwater abstraction cost. The surface irrigated area was also decreased from 76% to 23% within the time period of 1981-2012.Whereas, the groundwater irrigated area expands drastically from 16% to 80% within these years (BADC 2018-19).

In last two decades, use of groundwater for irrigation purpose has been increased drastically. On the other hand, less attention has been given to the use of surface water irrigation. A proper refinement in the performance of existing irrigation system can increase water use efficiency in both farm and regional level (Dey *et al*. 2006).

The highest amount of groundwater has been used by North West and north central hydrological region of Bangladesh. Over a seven-month period of dry season groundwater irrigation relies on the adequate amount of water recharge in the five-month monsoon period. If the recharge is not higher or at least similar to discharge, a huge depletion of groundwater will be observed due to all year-round irrigation. The depletion rates vary from 0.00 to 2.92 cm/year for mean depth of phreatic surface. Maximum depth of phreatic surface varies from 1.20 cm/ year to 14.45 cm/year (Mohammad 2014).This condition will cause excess decline in water level (Shamsudduha *et al*. 2009). The annual precipitation in north-east region is higher than the south and north-west region in Bangladesh. But higher groundwater irrigated area in north-west and north-central region (Table 1) of Bangladesh reported by BADC (2018-19).

The higher precipitation rate may result in increased shallow aquifer recharge through rainfall. Due to this situation, surface irrigation is higher in north eastern region. Table 1 shows that about 80% of total groundwater is being used within only three divisions of Bangladesh and they are located in north western and central hydrological zones. These divisions are - Dhaka, Rajshahi, Rangpur (Table 1).

Table 1. Population and irrigated area by deep tubewells and shallow tubewells in different divisions of Bangladesh.

Divisions	Deep tubewells		Shallow tubewells	
	Population (No.)	Area irrigated (ha)	Population (No.)	Area irrigated (ha)
Dhaka	6918	170,088	408,767	1,054,963
Rajshahi	16352	467,133	348,267	713,389
Rangpur	6515	157,798	414,546	785,944
Chittagong	2329	62,720	63,047	166,268
Khulna	3064	68,895	218,824	484,944
Barisal	1	20	45	240
Sylhet	143	7688	6,534	36,692
Total	35322	934,352	1,523,609	3,242,440

Problems and limitations in groundwater use

Depletion of groundwater level due to over extraction

According to Bangladesh Water Development Board, declining area of having water level less than 8 meter in depth has increased noticeably over time. This area was near about only 4% of the country's total, in between the year of 1998-2002. But the amount area has increased to 11% in 2008 and surprisingly it has become 14% in 2012 (Qureshi *et al*. 2014) (Figure 2). These surface maps were made by observing the time series data of groundwater level from Bangladesh Water Development Board (BWDB) using multi Gussian Kringing.

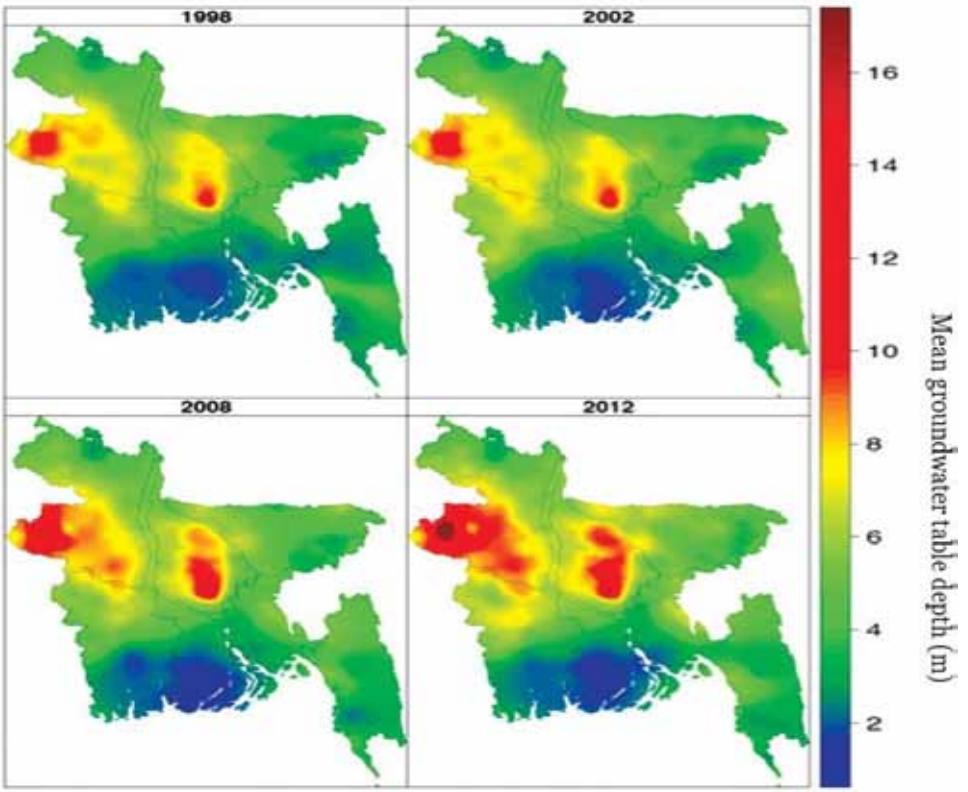


Figure 2. Mean ground water table depth (m) in the peak of the dry season (March, April and May).

Relationship between groundwater and energy source in Bangladesh

The diesel operated shallow tube wells are mainly used for the irrigation of Boro rice in north-west region and to some extent, for subsidiary irrigation to Aman, Aus and other crops in Bangladesh. Table 2 shows that average operational hours of both deep and shallow pumps are 1,445 in Boro season and for other crops and season, the operational hours are 300-400, which is comparatively very low (Al-Masum *et al*. 2017). A conservative estimation shows that an individual pump used for the irrigation of Boro rice is operated for 1,900 hours within a year in Bangladesh (Mukherji *et al*. 2009) (Table 2).

In 2000, the cost of one liter of diesel was equivalent to the price of 2.0 kg of rice grain. But this equivalency has decreased into 1.36 kg, in 2013 (BBS 2008). However, the increasing trend of the price of wheat remains consistent in relation to diesel price. So, the profit level for wheat production remained very low (to buy one liter of diesel requires 2.6-2.27 kg of wheat).Perhaps, this can be the potential reason for higher Boro rice production in rabi cropping season, despite of other water availability challenges. This consistency of Boro rice production may change if the price of diesel is increased or if the government even reduces the subsidies partially.

The water lifting cost by diesel operated STWs is USD 51 per hectare, where the cost of lifting water by electricity operated pump is only USD 20 per hectare having the same capacity (12 liter per second). 57% of total production cost of Boro rice has been used for the irrigation by diesel operated STWs, compared to only 42% for electricity operated pumps. For diesel operated DTWs, cost of lifting water is 70 USD per hectare, electrical pumps require only 40 USD per hectare. Farmers use about 41% of their total production cost of Boro rice for diesel operated DTWs and only 34% for electricity operated DTWs with equal capacity which is 50 liter per second (Dey *et al*. 2013). Despite of the subsidies on electricity, a reason behind the higher cost of diesel operated pumps is their low efficiency (not more than 25%) compared to 35% for the electric pumps (Hossain and Deb 2003).

Contamination of groundwater by Arsenic

Rather than the drinking water issue, arsenic contamination in groundwater has a great impact for agricultural use and potable supplies. In between 2000-2003, Bangladesh Arsenic Mitigation and Water Supply Project (BAMWSP) operated a blanket screening of near about 5 m tubewells for detection of arsenic contamination nationwide. That survey revealed that about 29.1% of the examined tubewells exceeds the Bangladeshi Standard of Arsenic in drinking water which is 0.05 mg/L (Shafiquzzaman *et al*. 2009). Arsenic concentration is mainly higher from shallow aquifers to groundwater with the depths of less than 100 meter (Figure 3).

The groundwater from shallow aquifer is mainly used for irrigation of different crops, usually for the Boro rice cultivation. An estimation said that about 24% area among the total groundwater irrigated Boro rice area is

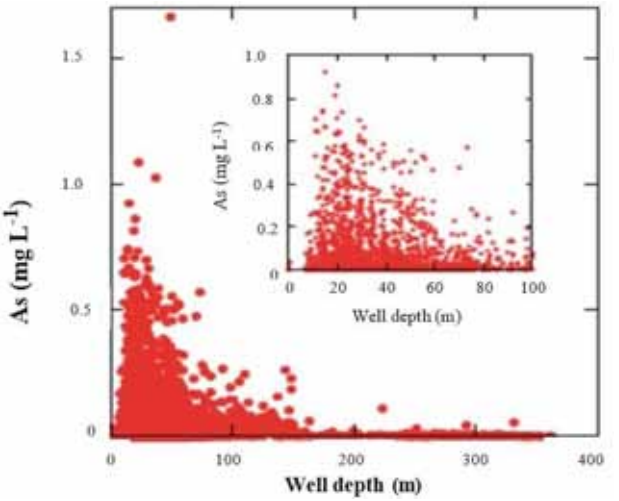


Figure 3. Arsenic contamination at different depth of groundwater level(BGS-DPHE 2001).

Table 2. Operational characteristics, and use of deep and shallow pumps.

Pump type	Hp	Operation per boro season (days)	Operation per day (hours)	Total operation (hours) in boro season	Total operation (hours) in other season	Fuel consumption (litres/hr)
Deep pumps	56	85	17	1,445	300	4.25
Shallow pumps	10-15	85	17	1,445	400	1.5-2.5

using water having >50 µg/L Arsenic and 7% of land is using water having >100 µg/L Arsenic (Ross *et al*. 2006). The highest concentration of arsenic has been found in south-east and south-central area of Bangladesh below the union of Ganges and Meghna rivers (Duxbury *et al*. 2003). Arsenic accumulation in the soil of rice field has a great impact on the yield of rice production. The concentration rises from 10 to 60 mg/kg reduced the yield of a farmer's field from 7-8 to 2-3 tons ha^{-1} gradually (Duxbury *et al*. 2003, Panaullah 2009). It is a matter of concern that arsenic contamination transforms from grain field to human body by food consumption. 400g of rice having 2.5 mg arsenic per hg provides an equivalent threat to the consumption of 2 liters of arsenic contaminated water at the Bangladesh limit of 0.05 mg per liter (Ahmed *et al*. 2011, Duxbury *et al*. 2003, Williams *et al*. 2006).

Groundwater management for sustainable agriculture

In Bangladesh, government has always given their prime concentration to the 'resource development' rather than 'resource management'. This condition has become a serious issue because the excessive extraction of groundwater results higher depletion of key aquifers which creates a vulnerable situation for the sustainability of the resource. The undeniable fact that about 85% Bangladeshi people are still living in rural area and depending on agricultural activities for maintaining their livelihood (BARI 2013-14). Unfortunately, there is no easy scape from this complicated problem, but for long-term sustainability in agriculture sector, over extraction of groundwater has to be terminated without having any negative impact. There should be a balance between groundwater extraction and recharge, other substitution ways need to find out to reduce excess pressure on the energy source using for irrigation purpose and also there should have an intensive concentration on both supply and demand side solutions (Qureshi *et al*. 2014).

Improving groundwater use efficiencies

Due to lack of proper knowledge of irrigation scheduling and uncertainty about availability of irrigation water at the required time, farmers generally do not plan for their irrigation schedule before application. Farmers mainly apply irrigation water by observing the visual plant stress symptoms which lead them to delayed water application at too late stage (Maher Salman 2019). Actual application rate of groundwater is typically higher than required water for irrigation and conveyance loss is also a common drawback. Due to the lack of hose pipe, lined irrigation is not possible in some areas. In those areas, groundwater irrigation has been given through unlined irrigation channels to the fields which are not properly levelled. The result of this situation is the over application of water and for this improper management of directional flow causes a serious problem which is drainage (Chowdhury 2010). According to Hossain *et al*. (2014), higher conveyance loss has been observed from unlined canals. The range of conveyance loss from lined canal irrigation is 1.06 to 8.3%, where in unlined canals are wasting about 12.5 to 40% of groundwater using for irrigational purpose through conveyance loss. Unlined irrigation with proper compaction of canals can reduce groundwater conveyance loss. In case of the unavailability of hose pipe and inability of line irrigation, cowdung, rice husk and other compaction material can be used as lining material for decreasing the rate of conveyance loss. (Dey *et al*. 2013, Karim *et al*. 2009, Rashid *et al*. 2009, Sarkar and Ali 2010). In Boro rice field, water requirement varies from 4,840 to 5,720 m3/ha in Dhaka district and 6,000 to 7000 m3/ha in Barind area (Karim *et al*. 2009, Rashid *et al*. 2009). But surprisingly, about 12,800 m3/ha water has been applied on the Boro rice field in Mymensingh (north central) region and 13,500 m3/ha in Barind (North West) region of Bangladesh (Dey *et al*. 2013). Among the total amount of water applied on the field, only 55% has been used for ET. Considering the water loss due to seepage and percolation, also required land preparation is taken into account, only 79% of applied groundwater in Boro rice field has been used for production purpose, other 21% of water is wasted (Dey *et al*. 2013).

The cost of pumping this excess 21% water varies from USD 26 to USD 90 per ha. In the perspective of Bangladesh, this is a remarkable economical loss for agriculture sector. To secure sustainability in agriculture, use of excess amount of groundwater has to be minimized and the groundwater use efficiency need to be improved. An effective way of improving water use efficiency in the Boro rice field is AWD technique. In Bangladesh, 0.5 to 1.0 tons/ha yield of rice can be improved with AWD (Rahman and Bulbul 2014) and also reduction of irrigation water is

also observed (Bouman *et al*. 2007). The AWD also plays a role to minimize arsenic concentration in the soil which results in lower input of arsenic into rice grain (Roberts *et al*. 2010). This technique also enhances the concentration of essential nutrients, mainly zinc in the harvested rice grain (Price *et al*. 2013).The lower number of irrigations is directly related to the reduction of irrigation cost about 12 to 15% and fuel requirement. AWD can clearly improve the groundwater use efficiency in rice field and beneficial for marginal farmers (Alam *et al*. 2009). the use of AWD can reduce about 1470 million taka compared to the traditional irrigation system (Table 3)

Recharge and discharge of groundwater

Groundwater management hugely depends on maintaining a balanced condition between discharge and recharge components of aquifers. Comparing to the amount of discharged water, amount of rechargeable groundwater is very low which leads to the falling of the depth of groundwater table. After monitoring of 350 wells in different districts of Bangladesh within the time period from 1985 to 2016, it was observed a noticeable change in the depth of groundwater table. About 300 wells have shown falling trend of GWTs depth from ground surface, 48 wells have revealed rising trend and only 2 wells have no trend (Mojid *et al*. 2009).

In Bangladesh, a huge amount of rainfall occurs in monsoon season. Water availability is maximum in monsoon season. Harvesting rainfall and further use of this water for irrigation can reduce immense pressure on groundwater requirement. Draining rainwater from rooftops, infrastructure seepage can be collected. Draining line of storm water can be connected to tanks and river can improve the level of groundwater table with some maintenance effort (Qureshi *et al.* 2008).

Rearranging cropping pattern

Rice is the main staple food of Bangladesh. About 90% of irrigation water required for rice production has been supplied through groundwater. Being a water intensive crop, Bangladesh should minimize the rice production and utilize this ample amount of water for other income generating and food security contributing crops which will bring future food security. Having higher nutritional value, industrial and commercial demand, wheat cultivation has been decreased due to its replacement by the Boro rice production which increased groundwater extraction (Figure 4). This situation should be overcome to ensure sustainable agriculture in Bangladesh (Qureshi *et al.* 2014).

The highest wheat production has been observed in 1990-2000 which was 1.83 Mtons and after that started decreasing gradually to 0.83 mtons in 2014. On the other hand, Boro rice production has been increased drastically and reached near to rice self-sufficiency. Having less concentration in developing new high yielding varieties and reduction in cultivating area, wheat production is comparatively very low (BADC 2018-19). This situation

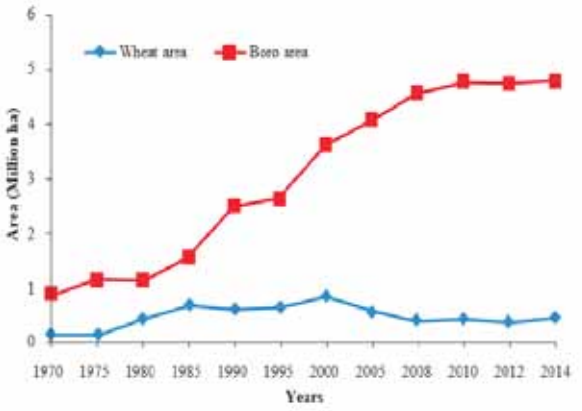


Figure 4. Changing trend of rice and wheat cultivating area from 1970 to 2014

Table 3. AWD technology to reduce irrigation cost and the number of irrigation. Average data of 2009-10 and 2014-15 seasons.

System	Irrigation (No.)	Irrigation (cost/ha) Tk for diesel	Diesel saving (Tk/ha)	Total boro area in Rangpur division (ha)	Estimated savings from reduction in diesel usage (Tk)
Traditional	14	385×14=5,390	-	804,206	-
AWD	9.25	385×9.25=3,561	1829	804,206	1470 million
AWD withherbicide	9.25	385×9.25=3,561	1829	804,206	1470 million

provides an extreme pressure on groundwater availability. The continuous higher production of Boro rice will lead to the scarcity of required groundwater, which is a great threat to sustain current agricultural growth in Bangladesh. So, changing the cropping pattern can reduce theload on groundwater requirement which will sustain its availability and maintain agricultural growth. Wheat and maize require very less amount of water which is 300 to 500 mm to meet their evaporation demand (Qureshi *et al*. 2014). The recommended crops have higher potentiality to increase their production with maximum attention by the farmers and also require comparatively less amount of water for irrigation. Using the groundwater efficiently is a key to sustain agricultural production growth and attain self-sufficiency.

Reforming national polices on groundwater use

In most of the policies related to agriculture do not mention about the groundwater management directly. There are some interlinked polices between the water issues and agricultural land, poverty eradication, rural development, safe water, improving environmental condition etc. (Dey *et al.* 2013). Though the Government of Bangladesh issued some policies related to the regulation and monitoring (ground) water resources over the last multiple decades. Unfortunately, those policies cannot bring any permanent solution. An ordinance was issued solely for the management of agricultural groundwater resources by the Government of Bangladesh in 1985. According to the ordinance, licensing for the installation of tube wells was announced. This policy restricted the installation of private tube wells in the areas where the depth of groundwater table is increasing drastically and also the quality of the water is deteriorating. There have also some other laws related to groundwater management, likely – the national environmental policy (1992), national policy for safe water and sanitation (1998), national water policy (1999) and the most recent water act was introduced in 2013, in which having a license or permission is compulsory for the large-scale withdrawal of groundwater by anyone or any organization rather than domestic use.

In perspective of Bangladesh, application of these laws, having license and permission system are not sufficient and cannotbring any effective result for groundwater management to ensure sustainable agriculture. Because in our country, there are large number of groundwater users. A large number of farmers are using huge amount to groundwater as irrigation to cultivate high yielding Boro rice varieties that is leading Bangladesh towards self-sufficiency. About 80%Boro rice cultivating area is using groundwater for irrigation. In northwest area, depth of groundwater table is descending rapidly comparing to the other regions due to the intensive cultivation of Boro rice. The quality of groundwater is also deteriorating gradually.

Policy makers should provide concentration to develop constructive laws which will improve the groundwater use efficiency required for sustainable agriculture. Some ordinance related to reconstruction in water pricing system, higher engagement of users, considerable investment in current water and agricultural technologies such as – paying cost for water on a volumetric basis or according to the price of specific crop can be introduced. There should have a proper market facility for the non-rice crops. Incentives can be given to encourage farmers to produce less water demanding crops and adopt alternative cropping pattern (Qureshi *et al*. 2014). Government can consider these options during generating any law or policy regarding groundwater management to ensure sustainable agriculture in Bangladesh.

Conclusion

At present about 34,332 DTWs and 1,483,332 STWs and 169,670 low lift pumps are already been installed to supply required amount of water for irrigation in Bangladesh. To increase the efficiency of groundwater use, conveyance loss should be minimized. About 30% conveyance loss can be reduced by the proper compaction of unlined canals. Due to increasing trend of Boro rice production, over extraction of groundwater has been observed in different hydrological regions of Bangladesh . Over last two decades, about 15% depletion of groundwater table has been notified. The withdrawal cost of groundwater is also increased to USD 51 per ha for STW and USD 20 per ha for DTW. An equilibrium condition should be maintained between discharge and recharge of groundwater. Harvesting rainwater in monsoon season and further use of this water can reduce the dependency on groundwater. Moreover, arsenic concentration into the groundwater is also a threat for agricultural field. The yield of rice can be decreased from 2 to 8 ton/ha due to the addition of arsenic

contaminated groundwater. The AWD technique can minimize the arsenic concentration of soil. And it also reduces the excessive use of groundwater which leads to minimizethe production cost about 1470 m Tk. year^{-1}. Diversification of cropping pattern is a time demanding requirement to increase groundwater use efficiency and assure sustainable agriculture in Bangladesh. Policies should be made to expand the cultivation of less water demanding crops. Policy makers should give concentration to introduce more pragmatic policies to increase groundwater efficiency for the sustainability in agriculture rather than just licensing over the installation of tubewells.

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