Risks, hazards and vulnerability associated with overexploitation of groundwater in northwest India

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Abstract Overexploitation of groundwater in the most productive area in Indo-Gangetic plains of northwest India is a matter of concern. If the current rate of overexploitation is not stopped and the sharp fall in level of groundwater is not arrested, there is a great risk of conversion of the most productive area of northwest India into desert. Overexploitation of groundwater is mainly caused by a change in cropping pattern, increase in area under irrigation and number of tube wells, decline in rainfall and canal irrigated area, and lack of proper planning for systematic groundwater extraction. Management strategies for the arrest of declining water have been discussed. With limitation of water resources there needs to be a paradigm shift from agronomic yield maximization to maximization of water-productivity, and diversification from cultivation of high-water consuming crops to low-water consuming crops.

Key words groundwater; overexploitation; risks; management strategies

INTRODUCTION

The northwestern part of India, comprising the upper Indo-Gangetic plains supporting the Rice–Wheat (R–W) cropping system is the most productive area of the country. Although the R–W system is followed throughout the state of Punjab in northwestern India, two-thirds of Punjab's rice and wheat are produced in the central zone, where the cropping intensity is 201%. In this region, groundwater is used to irrigate almost 100% of the irrigated area. Since the early 1970s, there has been a steady increase in the depth to the groundwater in most of the R-W area of northwestern India. The increase in depth has accelerated alarmingly in some areas in recent years.

In the second half of the 20th century, there was rapid expansion in groundwater pumping from tubewells due to the inability of the supply driven canal system to meet the needs of farmers growing the new high-yielding, input-responsive rice and wheat varieties, and strongly supported by many institutional and policy factors. The average decline in rainfall during the last few years has further aggravated the problem. It is not just the amount of rainfall, but also the pattern of rainfall that is becoming erratic, possibly due to climate change.

The increase in depth of groundwater in northwestern India has three major hazards: (1) increasing energy requirement and cost of pumping groundwater; (2) increasing tubewell infrastructure costs; and (3) deteriorating groundwater quality, which will ultimately reach the degree that the groundwater becomes unusable because of upwelling of salts from the deeper native groundwater. If this trend of depletion continues, there are chances that water level may reach a depth from where the lifting of it may not be possible for irrigation. As a result of this there is a great risk of the conversion of this highly productive area into desert.

Rice–wheat cropping system in this region was prompted due to several reasons: (1) under irrigated conditions the R–W system is most sustainable and stable; (2) this is the highly mechanized cropping system in the Indo-Gangetic plain; (3) because of assured procurement by government agencies at a pre-announced price this is the most profitable cropping system for the farmers; (4) subsidized/free electricity is provided to the farmers for running tubewells for lifting groundwater for irrigation. Due to these factors, it becomes difficult to convince the farmers to shift to other less remunerative cropping systems to prevent the alarming depletion in groundwater.

In an attempt to solve the various problems of R–W systems in the Indo-Gangetic Plain (IGP), many improved technologies referred to as "Resource Conserving Technologies" (RCTs) and "Integrated Crop and Resource Management" (ICRM) have been developed over the past couple of decades. These technologies are targeted at increasing the productivity, sustainability, and profitability of rice-based cropping systems through reducing and reversing soil degradation, reducing air pollution, and increasing nutrient, labour, and especially water-use efficiencies. The management strategies include: improvement in irrigation efficiencies; reduction in application losses; improved irrigation methods; water saving in paddy; zero tillage technology; bed planting; mulching; crop diversification and replacement of long duration varieties. The other strategies advocated are augmenting water resources including groundwater recharge, roof-top harvesting, and renovation of village ponds.

The performance of the technologies needs to be systematically assessed at the farmer field scale for a range of site conditions, to increase process understanding, and to develop generic knowledge to help target technologies to site conditions. Such targeting needs to be informed by the results of crop simulation modelling. The use of simulation models enables evaluation of technologies over the likely range of seasonal conditions, taking into account soil type, depth to the water table, and a range of management factors (Humphreys *et al*., 2010). Crop models also enable estimation of components of the water balance and crop water productivity, parameters which are extremely difficult to measure in the field. Models also allow analysis of risk, and trade-offs between yield, water depletion, deep drainage, runoff, etc. However, there needs to be significant investment in good data sets for model calibration and evaluation, and process understanding to capitalize on the predictive capacity of crop models to help in arresting the decline of the water table.

DISTRIBUTION OF GLOBAL WATER

Out of total available water (1385.5 million BCM) about 97.3% is salt water from oceans and only 2.7% is freshwater. Out of a total of 37.5 million BCM of freshwater, about 75.2% is in the form of polar ice and glaciers, about 10.0% as groundwater of <800 m depth, 12.6% groundwater with 800–4000 m depth, 1.9% as soil moisture and atmospheric vapour, and only 0.3% in lakes and rivers. Thus groundwater, and lake and river water that could easily be tapped for irrigation is only 0.62% of the total water and 22.9% of the freshwater.

INDIAN SCENARIO

The groundwater is being increasingly depleted in Central Punjab, Haryana, Western Uttar Pradesh, Rajasthan, Tamil Nadu and West Bengal, due to its over withdrawal. The increased groundwater abstraction has been prompted by the availability of free or subsidized power and pumpsets in the rural areas since the 1980s. The decline in groundwater used for irrigating over 60% area poses a threat to food security as well as entailing mounting overhead costs to the farmers in deepening their wells, installing submersible pumps, and requiring more power to lift water from increasing depths. The hardest hit are the marginal and small farmers, whose shallow/dug wells would go dry as the water table goes deeper due to over withdrawal. For equitable resource use, India should have clearly defined property rights to surface water and groundwater. Presently, a land owner is entitled to draw any amount of groundwater, even if no water is left for others in the area. The Central Groundwater Board has drafted a Model Bill (CGWB, 2007) for adoption by the states to ensure sustainable and equitable development of groundwater resources. The bill entails registration of bore well owners, statutory permission to sink a bore well, restriction on the depth of bore wells, and creation of a groundwater regulation body, etc. The recharge of groundwater through appropriate interventions is also assuming great significance in the country. There have been spectacular increases in groundwater table (0.2–2 m) in well-managed watersheds in different parts of India. The conventional methods of augmenting groundwater recharge, such as percolation ponds and check dams, have found a major place in all watershed development programmes. However, the new recharge techniques, recharge pits and shafts and injection wells, etc., need to be evaluated for best results. The worrisome part is that groundwater is depleting fast in most productive states in India due to its overexploitation.

OVEREXPLOITATION OF GROUNDWATER: A CASE STUDY

Overexploitation of groundwater is depicted from a case study of Punjab State (northwest India), which is considered as the "food bowl" of the country. Punjab having a geographical area of about 50 362 km^2 is predominantly an agrarian state. The State of Punjab, with only 1.6% of the total geographical area of the country, is contributing 40–50% of the rice, 60–65% of the wheat and 20–25% of the cotton to the central pool for the last three decades. About 85% of the state's area is cultivated with cropping intensity of >186%. During the last 35 years the area under food grains has increased from 39 200 km^2 to 63 400 km^2 and the production of rice and wheat has increased from 0.18 to 0.32 kg/m^2 and 0.22 to 0.43 kg/m^2, respectively. This change in cropping pattern has increased irrigation water requirements tremendously and the irrigated area has increased from 71 to 96% in the state. The total surface water available at different head works is about 17 900 M m^3. Of these, 14 500 M m^3 is available at the outlet. Prihar *et al.* (1993) estimated the groundwater contribution from rainfall and seepage from canals as 16 800 M m^3, thus making the total availability of water 31 300 M m^3. The crop water demand has been worked out as 44 000 M m^3, thus leaving an annual deficit of 12 700 M m^3.

In order to meet crop demand groundwater is being over-exploited using shallow and deep tube wells in the state, the number of which has swelled from 0.192 million in 1970 to 1.193 million at the present time. The latest study of groundwater balance estimates shows that out of 138 development blocks, 103 fall in the "overexploited" category, having groundwater extraction of >100% of annual replenishment; five are classified as "critical" with extraction between 90 and 100%; four are "semi-critical" having extraction between 70 and 90%; and only 25 districts are in the "safe" category, having groundwater draft <70% of annual recharge. The irony is that "safe" blocks lie in southwest Punjab where groundwater is of poor quality, and in *Kandi* (semi hill) area, where extraction is restricted due to deeper groundwater aquifers. The water-level depth data of the monitoring network also reveal that in 44% of the State's geographical area, the water table is below the critical level of 10 m. The area having water table depth below 10 m depth has increased from a mere 3% in 1973 to 53% in 2000. The long-term fall of the water table for 1984–2002 reveals that the water table has fallen in about 80% of the State's geographical area (Takshi & Chopra, 2004). Up to 1995, the average fall in the water table in Punjab was about 23 cm per year (Khepar *et al*., 2000), which during the next 6 years (1997–2003) increased to 53 cm per year (Hira *et al*., 2004) and currently is about 70 cm per year.

REASONS FOR DECLINING TREND OF WATER TABLE

The following factors contributed to the present groundwater scenario in the state:

Change in cropping pattern The Punjab farmers shifted from low water consuming crops to a high water-requiring paddy crop. There has been a drastic increase in area under paddy from 4000 km^2 in 1971 to over 26 000 km^2 currently. Paddy consumes 62% of the total irrigation water requirement and water use of 3 m^3 per kg of output is the maximum for this crop.

Increase in area under irrigation Net area under irrigation has increased from 70% in 1970–1971 to 98% in 2009–2010. Also, there is an increase in cropping intensity from 124 to 186% resulting in an increased extraction of groundwater over the years.

Increase in number of tube wells The number of tube wells has increased from 0.192 million in 1971 to 1.193 million in 2006. This has resulted in overexploitation of groundwater.

Declining trend of rainfall As compared to the average annual rainfall for 30 years (1970–1999), which is 606 mm, it has now come down to 400 mm for the 5-year block period of 2000–2004, a significant reduction of 200 mm.

Decrease in canal irrigated area The percent net area irrigated by canals has decreased from 45% to only 25% during the last 30 years, with the result that dependency on groundwater has increased tremendously to meet food production targets.

Lack of proper planning of systematic groundwater extraction Overexploitation of groundwater has been taking place to meet the increased demand of irrigation water for the crop production, industrial and domestic sectors, because of property-based rights where no restriction is imposed on overextraction of water.

Overall increase in water demand To meet the increasing demand of industrial and domestic sector, groundwater extraction has been on the rise.

FORECAST OF GROUNDWATER BEHAVIOUR

Considering the present trend of fall in water table, the future projections are quite disturbing. It is estimated that by the year 2020, more than 30% additional area of the states would be included in the area where water level is already beyond the critical level of 10-m depth (Takshi & Chopra, 2004). Compared to 2001, the water table in central Punjab has fallen by 34% in 2010. Hira *et al.* (2004) predicted that by 2010 the entire central Punjab would have water table depth beyond 14 m, which has turned out to be true.

MANAGEMENT STRATEGIES

There is a possibility of managing this precious resource by saving irrigation water and by augmenting the groundwater resources through artificial recharge techniques.

Water saving techniques

Improvement in irrigation efficiencies The average efficiency of irrigation systems, at present, is very low, ranging from 30 to 40%. An increase of 5% in irrigation efficiency could increase irrigation potential by 10–15 million ha. Water is lost during conveyance through seepage. The average water losses from unlined canals, branches and distributaries, and watercourses are 8, 17, and 20%, respectively, of water released from the reservoir (Singh, 1978). Lining is an effective way of minimizing conveyance losses. Conveyance losses can also be avoided by using underground pipeline systems where the water is conveyed in a pipeline. However, it will further reduce the recharge of groundwater.

Reduction in application losses Proper selection of an irrigation method for a particular crop is very important to achieve higher application efficiency. For example, the replacement of border method of irrigation with the furrow method of irrigation in wide-row crops like cotton, sunflower and maize, save water. Similarly, precision laser land-levelling technology saves irrigation water by about 25%.

Improved irrigation methods Pressurized irrigation systems (sprinkler and drip) have the potential to increase irrigation water-use efficiency as high as 75–90%.

Water saving in paddy Paddy in Punjab is sown in an area of about 26 000 km^2. Proper scheduling of irrigation (amount and timing) to crops is an important component of water saving technologies. Intermittent irrigation in paddy, i.e. 15 days ponding followed by 2 days of drying, can result in 25% saving of water. Irrigation on the basis of "tensiometers" is another option to save water. Also shifting the date of transplanting of paddy from first week of May to third week of June checks the water table decline by 70 cm without any adverse effect on the yield (Hira *et al.*, 2004).

Zero-tillage technology Use of zero-till drills on one km^2 of land is estimated to save approximately 0.1 M m^3 of irrigation water. Adoption of zero-till practices over an area of 5000 km^2 could increase wheat production by 2 billion kg and also save 5 BCM of water each year in Punjab.

Bed planting Bed planting of wheat results irrigation water savings ranging from 18 to 25% as compared with the conventional tilled wheat (Hobbs & Gupta, 2003).

Mulching Application of straw mulch improves the water-use efficiency and helps in water saving by reducing the ET losses (Jalota *et al*., 2000) and increasing yields of a number of field crops during summer months.

Crop diversification Replacing rice with less water-guzzling crops like maize, soybean, groundnut and pulses, etc. could save substantial quantities of water.

Replacement of long-duration crop varieties Long-duration varieties of rice should be replaced by short-duration rice and superior quality basmati having lower water requirements and less duration to maturity.

Augmenting water resources

Recharge in Kandi area Kandi area experiences more than 1000 mm of annual rainfall, out of which 40% goes as runoff during the rainy season. The monsoon rainfall water in Kandi area should be recharged by constructing check dams on natural streams coupled with infiltration galleries to a tube well for artificial groundwater recharge.

Increasing groundwater recharge A number of studies in recent years have highlighted the possibilities of promoting greater recharge of aquifers with surplus runoff available during the rainy season through spreading or by injection through wells. The recharge capacity of the drains can also be increased substantially by installation of a series of recharge shafts where a drain is underlain by comparatively more impervious strata.

Roof-top rainwater harvesting Roof-top rainwater is the purest form of water before it joins the surface runoff. If this could be tapped for artificial groundwater recharge, this would help in checking the groundwater decline besides improving the quality of groundwater, reduce the load on the sewage system, and save the roads and streets from possible damage and health hazards. There is a potential of 32.2 and 70.8 M m^3 (Aggarwal, 2007) of roof-top rainwater being tapped for groundwater recharge in urban and rural areas, respectively.

Renovation of village ponds There are about 13 000 village ponds out of a total of 23 000 in Punjab, which could be used for providing irrigation after renovation. The water stored therein would thus reduce the groundwater withdrawal by about 6 cm per year.

CONCLUSION

The case study of Punjab (a highly productive area in India) revealed that the area which contributes the largest quantity of food grain to the central pool of India is quickly being depleted of its irrigation water resources. If unattended, the grave situation will endanger the food security system of the country.

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