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Conjunctive Water Management in the Fixed Rotational Canal System: A Case Study from Punjab Pakistan

Asad Sarwar Qureshi*

Senior Scientist-Irrigation and Agronomy, International Maize and Wheat Improvement Center (CIMMYT), Dhaka-Office, Bangladesh

Abstract

In the fixed rotational irrigation system of Pakistan, canal water supplies are usually deficient to meet crop water requirements. Therefore groundwater is widely used to supplement surface supplies. In most of the canal command areas, groundwater is used in conjunction with the surface water to decrease the salinity of irrigation water in an attempt to avoid soil salinization. However, conjunctive use of surface water and groundwater is equally practiced in head and tail ends of the canal system. This results in rising groundwater tables leading to waterlogging in the upstream areas and aggravating salinity problems in the tail areas due to less canal water availability and the poor quality of the groundwater. Therefore strategies need to be developed for surface and groundwater use in such a way that equity in availability of water of acceptable quality is ensured all along the channel. This paper suggests three options to achieve this objective; (1) development of guidelines for proper mixing ratios of surface water and groundwater to maintain acceptable salinity levels; (2) revisiting canal water allocations to provide more canal water to tail-end farmers due to poor quality of groundwater whereas encouraging head farmers to extract more groundwater to meet their demands; and (3) facilitating farmers to develop on-farm storage ponds to store their meager share of canal water and use it through high efficiency irrigation systems such as drip and sprinkler. All these options would require necessary changes in the government policies, institutional arrangements and wide scale dialogue with farmers. For this purpose, network of existing water user associations may play a vital role.

Keywords: Conjunctive water management; Soil salinity; Groundwater; Rotational canal system; Canal water; Pakistan

Introduction

Surface water and groundwater typically have a natural hydrologic connection. Conjunctive water use is an approach that recognizes this connection and facilitates the use of the overall water supply more efficiently. Conjunctive water use may differ in scope and scale. At a local scale, groundwater use by an individual farmer to supplement surface water supplies is generally referred as conjunctive water use. Others envision conjunctive water use as large, elaborated regional water management programs that store large volumes of surface water below ground during floods and heavy rainfall seasons and then use it by pumping during drought or low rainfall seasons Dudley and Fulton [1]. In these approaches, surface water and groundwater is used together to manage diminishing surface water supplies and improve availability and reliability of water.

It is important to distinguish between the terms "conjunctive water use" and "conjunctive water management". Conjunctive water use is a transferal between surface water and groundwater sources to cope with changes and shortages. Conjunctive water use may prove productive for an individual or group of farmers but it might be detrimental for the rest of the farming community due to depletion or quality degradation of groundwater. Conjunctive water management involves development of principles of conjunctive water use. It includes evaluation of monitored data to develop and enforce local management strategies and practices. This requires a clear understanding of the geology of aquifer systems, flow directions and gradients and deterioration in quality and decline in groundwater table depths.

A critical aspect of conjunctive water use which must be thoroughly understood is that surface water and groundwater are not necessarily equally exchangeable. These two sources can only be compared if their price is essentially the same and if water quality does not threaten crop yields and/or soil salinization. In Pakistani Punjab, the average cost of irrigating with groundwater is about 30 times higher than that of surface irrigation [2]. The cost of canal water per year per hectare is US$ 5.5, whereas the groundwater is marketed as 167 US$ per hectare per year [3]. This discrepancy in prices is based on the fact that surface water is highly subsidized by the government whereas groundwater extraction is becoming expensive due to increasing energy prices. The optimal farm level production performance is achieved where farmers are able to use the less expensive surface water and supplement with groundwater to fill the shortfalls [4,5]. Under these conditions, conjunctive water management becomes much more complex because of its important role in improving livelihoods of farmers and rural economies.

The irrigation system of Pakistani Punjab is based on a continuous water supply and is not related to actual crop water requirements. Irrigation canals are usually not allocated more than their design capacity, of which a typical value is about 2 mm d^{-1} against crop evapotranspiration of 3-8 mm d^{-1}. Despite significant increases in storage capacities, it is essentially a supply-based system [6]. Hence, it cannot adequately accommodate inter-season and intra-season changing water demands.

In Punjab Pakistan, generally two approaches are used for using surface water and groundwater resources. In the first approach, surface water and groundwater is used separately in a cyclic mode and in the second approach these waters are used simultaneously in a blending mode. Cyclic use is adopted to accommodate significant fluctuations in the canal supplies due to rotational system. This approach is also used as a strategy to maintain favorable salt balance in the root zone. Simultaneous use or blending strategy is mainly used because surface

***Corresponding author:** Asad Sarwar Qureshi, Senior Scientist-Irrigation and Agronomy, International Maize and Wheat Improvement Center (CIMMYT), Dhaka-Office, Bangladesh, Tel: +88-02-9896676; E-mail: a.sarwar@cgiar.org

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supplies are usually inadequate and mixing of groundwater with the surface water is necessary to get required flow for proper irrigation. By mixing groundwater with good quality surface water, farmers tend to decrease the salinity of the irrigation water in order to reduce the risk of soil salinization. Although evidences exist that blending of saline and non-saline irrigation water is less effective in keeping soil salinity levels lower than applying cyclic irrigations [7,8], this strategy is still widely practiced. Figure 1 show that during the last two decades that has been a paradigm shift in the conjunctive use of surface and groundwater. The area irrigated by conjunctive use of surface and groundwater has

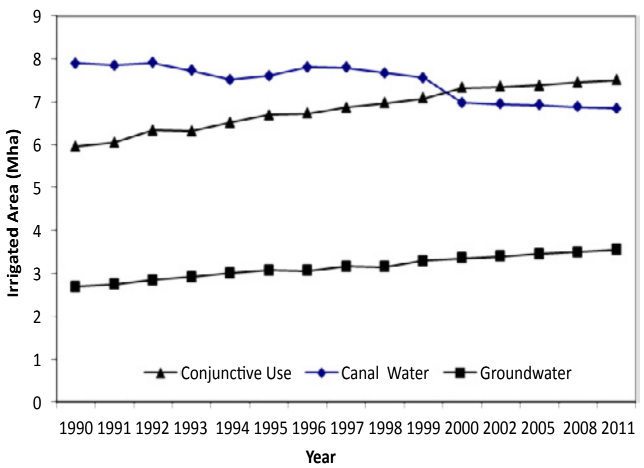

Figure 1: Area irrigated by different modes of irrigation in Punjab, Pakistan.

increased from about 6 million ha (Mha) to 7.5 Mha. The area irrigated by canal water alone has reduced by one Mha over the same period. The area irrigated by groundwater alone initially increased but then became remains constant mainly due to quality concerns.

This paper discusses conjunctive water use patterns and its consequences on cop production and soil salinization with a special reference to decreasing surface water availability and increasing groundwater salinity from head to tail end of a typical (Hakra) canal command system in the Punjab Pakistan. The paper also recommends potential management strategies of managing surface water and groundwater resources to foster crop production and control soil salinization in a fixed canal rotational system.

Contours of Conjunctive Water Use in Hakra Branch Canal

Hakra canal is a part of the Sadiqia Canal system, which is linked to the Sutlej River at Sulemanki Headwork Figure 2. The groundwater quality in this canal command area is relatively poor as compared to other areas of the Punjab Province. However, the surface water flow, cropping pattern, soil salinity conditions and groundwater use patterns of the Hakra branch canal reflects true picture of most of other canal command areas in the Punjab province.

The average annual rainfall in the Hakra branch canal command area is 250 mm against average annual potential evapotranspiration of 2200 mm [9], which necessitates irrigation for crop production. The major crops of the area are wheat and cotton covering more than more than 40 percent of the area. Rice and sugarcane are also planted on about 10 percent of the area mainly in the head reaches of the canal

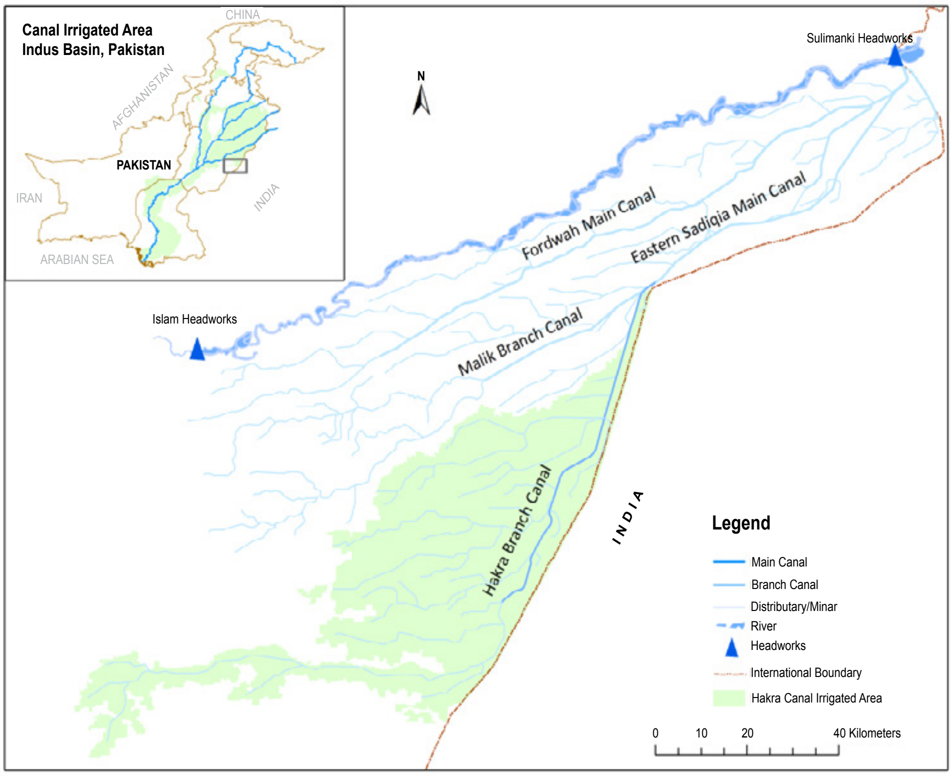

Figure 2: Location map of the Hakra Branch Canal command area.

system where groundwater quality is relatively better. More than 80 percent of the area has soil salinity between 2 to 4 dSm^{-1}. In the rest of the area, salinity levels are higher approaching to 15 dSm^{-1} in tail-end areas of the system. Crop yields are low to moderate due to salinity and water scarcity problems [9-11].

The distribution of canal water is done on a controlled rotational system called 'warabandi'. This system allows each farmer to take an entire flow of the canal outlet once in seven days and for a period proportional to the size of his land holding. The water amount is usually insufficient to irrigate the entire farm in one irrigation turn, and the farmer can decide whether to under-irrigate all land or leave a fraction un-irrigated [3]. On average, the surface water availability is about 0.21|s^{-1} ha^{-1}. Due to this meager surface water supply, farmers depend largely on groundwater for irrigating their crops.

The canal water is allocated based on constant time per unit area without considering the seepage loss along the channel and is the major cause of inequitable water distribution at a tertiary level [11]. The rate of seepage loss increases with increase in length canal thus the farmers in the lower reaches get much less water per unit area. The tail-enders get 20 percent less water than middle-enders, who in turn get 20 percent less water than the farmers located at the head reaches of the canal. Similar trends are observed in the productivity levels of head, middle and tail reached of the same canal system. The issue of bringing transparency in running an equitable water distribution system therefore remains a challenge.

Under current circumstances, groundwater plays more important role in irrigation than surface water, ranging from 65% dependence on groundwater in head areas to over 90% dependence in tail areas. This means that groundwater is no longer supplemental to surface water, but has become an integral part of the irrigated agricultural environment. Groundwater use has been the single most important contributor to agricultural growth in is this area during the last thirty years. The production of major crops such as wheat, cotton, rice and sugarcane is only sustainable because of the use of groundwater for irrigation. However, this growth has also led to problems of overdraft, falling water tables and degradation of groundwater quality especially in the tail reaches of the system where recharge from canal system is low. The secondary salinization associated with the use of poor quality groundwater for irrigation is one of the major reasons for low crop yields in this area [12].

Currently, more than 2500 private tube wells are working in the command area of Hakra branch canal [3]. On average, every fourth farming family has a tube well and a large proportion of non-owners purchase groundwater through local, fragmented groundwater markets [12]. Their behavioral patterns are highly variable and they understand little about any adverse interaction, which is likely to result due to unsystematic and erratic nature of groundwater exploitation.

Most farmers use groundwater in conjunction with the canal water whereas the rest provides irrigation based on groundwater alone. Groundwater is used when surface water is not available or the amount of delivered water is not enough to grow sensitive crops. As groundwater quality in most parts of the Punjab is not suitable for irrigation (EC 2 to 5 dSm^{-1}), farmers prefer to use groundwater in conjunction with the surface water in an attempt to keep the salinity of irrigation water low to avoid soil salinization [13].

In Pakistani Punjab, conjunctive use of surface water and groundwater is equally practiced in head and tail ends of the canal system. Factually head farmers should use less groundwater as their canal water allocations are much higher than the tail farmers. However, contrary to this common wisdom, head farmers use more groundwater than tail farmers in an attempt to maximize their crop production. One of the key disadvantages of this unmanaged conjunctive use is that upstream areas are occasionally subjected to rising water tables and waterlogging whereas tail-end farmers increase their salinity problems due to excessive use of poor quality groundwater. The groundwater table depth in the 33 percent of the total area (mainly head reaches of the system) fluctuates around one meter below soil surface during the cropping season. In the middle reaches of the system, groundwater table depth remains below 2 m whereas in tail end areas groundwater table depth is well below 3 m.

The groundwater quality deteriorates as we move from head to tail reaches of the system. The groundwater quality at the head reaches of the system is less than 1 dSm^{-1} (due to seepage from the canals) and may reach to 5.0 d Sm^{-1} as we move towards the tail-end of the system [9,10,14]. Due to cost of pumping and poor quality of groundwater, tail end farmers use less water per unit area, thereby reducing the leaching requirements and increasing soil salinity. The increased soil salinity reduces crop production and net income of the tail end farmers. In a similar study on the Central Bari Doab Canal system of Punjab, Latif and Ahmad [15] has found that the net income of the farmers using poor quality groundwater to supplement canal water is 43% to 59% less than those fully dependent on good quality canal water.

Options for Improving Conjunctive Water Management

Development of appropriate guidelines for mixing ratios of surface water and groundwater

The central issue for salinity management in the irrigated agriculture is the ratio of surface water and groundwater conjunctive use (regardless whether blending or cyclic strategy is used). Farmers of the Hakra canal mix surface water with groundwater in different proportions without considering resultant quality and its consequences on crops and lands. Due to acute shortage of canal water, the ratio of canal water mixed with the groundwater is usually very low resulting in higher salinity of the mixed water. Consequently, resultant irrigation water qualities are much higher than the FAO international standard of "good" quality irrigation water (0.7 dSm^{-1}). As a result, achieving the goal of minimizing salinity of irrigation water to avoid soil salinization remains a challenge. For this reason, large tracts of irrigated lands are already salinized and many are under threat. Therefore, in order to keep the average irrigation water salinity of the mixed water within the FAO, farmers of the middle and tail reaches of the system must be supplied with additional canal water. This additional amount of water can be made available by reducing the share of head-end farmers of the same canal. The head-end farmers should be encouraged to use more groundwater to meet their crop water requirements as the quality of groundwater at the head of canal is good and recharge is sufficient to replenish the groundwater withdrawals.

In the existing water short and fixed rotational canal system, provision of additional surface supplies is not an easy solution. Therefore, there is a strong need to make a thorough investigation of the required amounts of canal water supplies that are needed to mix with the groundwater to mitigate the adverse effects of poor quality groundwater on soil salinization. These information need to be generated separately for fresh, marginal and saline groundwater zones. This can provide an opportunity to divert additional canal water to the areas where groundwater is of poorer quality and the need for fresh water resources is more pressing.

Revising canal water allocations

The existing canal water distribution system of Hakra (like most of the Punjab province) is characterized as 'protective irrigation', which is meant to distribute the little water available to the greatest possible number of users to prevent crop failure and avoid famine [16]. The current water supply system does not takes into account long-term impacts of these water allocations on environmental parameters such as soil salinization, drainage requirements and changes in groundwater table depth and quality. Due to increasing shortage of surface water and poor system management, the current allocation system is widely abused. The farmers located in the head reaches of the system get their share of surface water while farmers in the lower reaches get much less water than their share and are forced to use poor quality groundwater to meet their crop demands which resulted in increased soil salinity and lower crop yields.

To improve salinity management in the canal command areas where head and tail ends of the same system have varying soil and groundwater qualities, existing water allocation criteria needs to be revisited. These decisions have to be made at two levels i.e. system level and the watercourse level. At the same level, canal water allocations should be made considering cropping patterns, groundwater quality and soil salinity levels. For this purpose, existing water allocation criteria where everybody get equal access to canal water regardless of his location along the canal and soil and groundwater quality (warabandi system) has to be abandoned. The canal water supplies should be allocated on variable time basis i.e. less time for the head end farmers and more time for the tail-end farmers. The reduction in the canal water quota of head-end farmers can be accommodated by providing them greater access to groundwater. This is possible given the fact that in the head reaches of the canals, recharge to groundwater is high and quality of groundwater is generally very good. Therefore head reach farmers should be convinced to allow additional canal water to flow to the tail end of the system where groundwater quality is poor and canal water is of absolute importance to sustain crop production and livelihoods of farmers.

At the watercourse level, water allocations rules should be strictly followed to maintain equitable water distribution among all farmers. The extra tube wells should be installed at the watercourses located at the head of the canal system to provide more water to head-end farmers. However, farmers located at the tail-end watercourses of the system should not be allowed to use poor quality groundwater for irrigation. Instead they should be educated to use surface water more wisely to avoid salinity development.

The proposed water allocation strategies within a canal system are technical possible but might have social implications as it will not be easy to convince head-end farmers to relinquish their share of surface water. However, if the head-end farmers are relieved of economic burden of pumping groundwater by provided water through public operated tube wells and charged water fee equivalent to canal water, their cooperation could be attained.

In case head reach farmers agree to forego their right for canal water or accept less percentage of their canal water share and increase their groundwater pumping, the possible consequence could be that they will start pumping more groundwater to maintain their profitable cropping patterns. In areas where groundwater quality is good this option will be intuitively attractive. Through this excessive use of groundwater, head end farmers may face salinity problems similar to those of tail end farmers due to increase in EC of groundwater. On the other hand, tail end farmers might start changing their cropping patterns in lieu of more fresh water availability. As fresh water will not be available to meet their full crop demand, they might still go for excessive groundwater pumping resulting in increased salinity problems.

This means that simply changing water allocations would not be enough to ensure sustainability. For this purpose, policy interventions regarding cropping patterns and amount of groundwater that can be pumped to main acceptable salinity levels need also to be introduced. Currently, canal water is managed by the Punjab Irrigation Department (PID) and their allocation procedures have no relevance with the crop water requirements, quality of groundwater within the canal command area and cropping patterns. Their water allocations are entirely based on the quantity of land owned by a certain farmer. Monitoring of groundwater table depths and quality is done independently by SCARP Monitoring Organization (SMO) of the Water and Power Development Authority (WAPDA) whereas the cropping patterns and crop yield data is collected and monitored by the agricultural extension department. For the implementation of proposed water allocation plan, all three organizations need to make joint monitoring programs and develop a mechanism to share data and information with each other to improve system operation at system as well as watercourse level.

To change water allocation laws, new reforms need to be introduced. This requires political understanding of the issue and government level interventions for changing the policies and realignment of the roles and responsibilities of public sector organizations to improve their capacity to handle these complex land and water management issues. In the existing set up, water user associations can be stimulated to start the process of dialogue between head and tail farmers to persuade them of this new paradigm shift in managing surface water and groundwater resources in a canal command.

Storing canal water in on-farm ponds and irrigating through high efficient systems

In the Fordwah Eastern Sadiqia (FES) canal system, farmers usually keep half of their cultivated land fallow during each cropping season due to shortage of good quality irrigation water. Even if the reallocation of canal water is implemented as discussed above, it will be impossible to supply sufficient canal water to tail end farmers for cultivating their entire land. Therefore reducing irrigation demand could be an alternate solution. The irrigation demand can be reduced by improving irrigation efficiency. The productivity of water in Pakistani Punjab is among the lowest in the world. For wheat, for example, it is 0.6 kg m^{-3} as compared to 1.0 kg m^{-3} in India [17]. Maize yields in Pakistan (0.4 kg m^{-3}) are nine times lower than those (2.7 kg m^{-3}) in Argentina [18]. This reveals a substantial potential for increasing the productivity of water. In practical terms, about 40 percent of the applied irrigation water is lost by seepage from the irrigation canals and deep percolation in the fields [19]. Even though much of this lost water is now captured by the extensive groundwater pumping, this does not apply to the tail-end areas where groundwater is saline, and the pumping involves extra costs.

Water pricing structures which make water savings financially attractive are unlikely to be introduced in the near future. Therefore more efforts should be concentrated on adopting water conservation techniques in the irrigated agriculture sub-sector because this is by far the greatest user of water. Relatively modest increases in water productivity would result in significant increases in food production without increasing the volume of water abstracted.

In the FES scenario, there are two possible ways of using little available canal water at the tail end of the system:

- Use the little amount of surface water available through high efficiency techniques (drip and/or sprinkler) and forget about groundwater. In order to overcome the uncertainty in canal water supplies, farmers should store their weekly canal water share in naturally occurring depressions near their fields or artificially constructed on-farm storage ponds. These depressions and ponds can also be used to harvest rain water. This stored water can then be used for irrigation as and when required using drip or sprinkler systems.
- Second option is to use poor quality groundwater for irrigating crops through drip and sprinkler systems. This will minimize the inflow of salts in the soil profile due to reduced water application. The stored canal water can then be used for leaching the salts on occasional basis. The problem with this option could be clogging of emitters due to salt inflow. However, this can be managed by regular flushing of emitters with the clean water. The advantage of this option would be that part of the uncultivated lands in tail-end areas, if not all, can be irrigated which will be a great step towards improving livelihoods of the tail-end farmers.

In semi (-arid) areas, adoption of these irrigation techniques may increase the threat of soil salinization due to reduced leaching activity. Therefore evaluation of the impact of these techniques at different scales for different agro-climatic conditions within a canal command is inevitable. For successful implementation of this concept, small farmers should be provided with subsidies to shift from flood irrigation to drip and sprinkler irrigation systems and improve leveling of their fields to control field application losses. The farmers should also be provided technical assistance for establishing on-farm water storage ponds and extension services for the maintenance of drip and sprinkler systems.

Conclusions and Recommendations

The increasing shortage of surface water has prompted farmers to use more groundwater to meet their irrigation requirements. The unregulated conjunctive use of groundwater and surface water is replete with serious consequences as it created waterlogging conditions in the head reaches and increase salinity of the soils in the tail reaches of the same canal system. Due to shortage of surface water, the salinity of the irrigation water attained after mixing it with groundwater is usually much higher than the acceptable limits for irrigation. As a result, farmers' objective of keeping the salinity of irrigation water within limits to avoid soil salinization is not fully achieved which results in continuous increase in the salinity of soils in most of the canal command areas of Pakistani Punjab. This unplanned conjunctive use of surface water and groundwater resources is therefore creating more problems than benefits.

To reduce the risk of soil salinization in the tail reaches of the canal system, current fixed water allocation system needs to be revisited both at system level and the watercourse level. Surface water should be allocated keeping in view the location of land along the canal, availability of good quality groundwater and soil salinity conditions of the area. In the head reaches of the system where groundwater quality is relatively good, surface water supplies may be reduced by encouraging farmers to use more groundwater. In the tail reaches where groundwater quality is poor and soil salinization is a major problem, surface water allocation should be increased. Implementation of this option requires a well thought strategy and incentives to convince head farmers to agree on surface water reallocation. This objective may be achieved by installing public tube wells at the watercourses located at the head-end of the system to accommodate lost canal water supplies. In the watercourse located at the tail-end of the canal system, use of poor quality groundwater for irrigation should be strictly prohibited to avoid the risk of soil salinization. In addition to technical changes, this would also require policy level interventions to enforce suitable cropping patterns to avoid over-exploitation of groundwater resources.

Under the existing operational and management constraints, it would not be possible to provide enough surface water to the tail end farmers of the system. Therefore they should be encouraged to construct on-farm ponds to store canal water and use it through high efficiency irrigation systems to increase water use efficiency. These ponds can also be used for rainwater harvesting. Alternatively they can use groundwater (provided quality is manageable) for irrigation and use stored canal water for leaching salts to maintain salt balance in the root zone. This would require government to assist farmers financially and technically to construct these ponds and install drip or sprinkler systems. Farmers might also need assistance in developing new cropping systems to match with the water availability both in terms of quality and quantity. These policy decisions have to be taken if we are serious in minimizing rural poverty and improve livelihoods of farmers and ensure future food security for the country.

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