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Impact of Canal Water Shortages on Groundwater in the Lower Bari Doab Canal System in Pakistan

Abdul Sattar Shakir, Habib ur Rehman, Noor M Khan and Asad Ullah Qazi

Department of Civil Engineering, University of Engineering and Technology, Lahore, Pakistan.
E-mail. shakir@uet.edu.pk

Abstract

This paper presents rigorous analysis of shortage of canal water supplies, crop water requirements, and groundwater use and its quality in the command of Lower Bari Doab Canal, Pakistan. The annual canal water supplies are 36% less than the crop water requirements. This shortage further increases to 56% if actual canal supplies (averaged over last ten years) are compared with the crop water requirement. The groundwater levels are depleting at the rate of 30 to 40 cm per year in most parts of the LBDC command and this tendency of lowering may increase in future due to further increase in crop water requirements. The analysis of data for the last seven years indicate that quality of groundwater in most parts of LBDC command is generally good (64% of the area) or marginally acceptable (28%) for irrigation use. However, declining trends in groundwater quality are visible and can create long term sustainability problems if proper remedial actions are not taken well in time.

Key Words: *Lower Bari Doab Canal; water shortages; groundwater; water quality; sustainability*

1. Introduction

Worldwide there is a renewed interest in local water allocation arrangements and their functioning. This interest is not only triggered by the steadily increasing demand for water and hence, the growing need for better and more legitimate water allocation decisions at the local level, but also by the comprehensive water sector reforms that have occurred in many countries since the 1990s (Mul, et al. 2010). In one of the ministerial level meeting at 4th World Water Forum, it was concluded that; *"The 'technology push' approach has proved to be ineffective. Local solution should be implemented and traditional experience should be taken into account and means of improving them found.*" (WWF, 2006). Such recommendations at highest level forum, requires that researchers must divert their efforts, and institutions must divert their resources towards finding local solutions for global issues. It will help using the large theoretical knowledge into practical and implement-able solutions. Water shortage is world wide problem, but its solutions need to be provided locally. This research has been carried out to look into local problems of water shortage for irrigation and its local impacts on water quality. Also local solutions and methods, evolved and adopted locally to confine the problems of water shortages, have been looked into.

When canal water allocation does not match with the requirements and pricing of alternate source of water (groundwater for example) motivates farmers to reduce water use. But it magnitudes the adverse effect on farm profitability. From a development perspective it is worrying that the smaller farms in terms of output (mainly the poorer farmers) are affected most and, at higher water prices, are not profitable anymore and would even quit production (Speelman, et al. 2009).

Hellegers et al. (2011) evaluate incentives to reduce groundwater consumption in Yemen and suggested that the range of possible incentives is although wide (water pricing, metering, water rights, water markets, taxes, subsidies, information, participatory management, etc.), but the range of potentially effective incentives in the Yemeni political context is more limited due to difficulties of implementing and enforcing change.

Whenever the demand for freshwater increases, a competition among municipal, industrial, and agricultural sectors often ends up in a decrease in the allocation of water to agriculture. This phenomenon is expected to continue leaving less and less freshwater for agricultural use; rather it is expected to intensify in less developed, arid region countries that already suffer from water, food, and health problems (Qadir, et al. 2003). Low canal releases impact on irrigated agriculture may result in a widespread shift from double to single cropping, during the deficit year; from a normal sowing paddy variety to a late sowing paddy variety and to rain-fed crops or fallow land (Gaur, et al. 2008).

Chronic low water supply may force the farmers to depend more on precipitation and local water sources than on the canal flows. However, water intensive crops are highly affected by shortages in canal water flow. Farmers develop alternative plans, like switching from water intensive crops to irrigated dry crops, and the development of shallow and deep tube wells. However, a better understanding of the surface-groundwater interaction is required, since groundwater levels are highly responsive to canal flows (Gaur, et al. 2008). Latif and Ahmed (2008) stated that groundwater salinity increases from head to tail reaches along all irrigation canals including main, secondary and tertiary canals in Pakistan.

This paper reviews the canal water availability compared with the water requirements for the LBDC system and evaluates its impact on groundwater. The LBDC system was selected for this study being one of the important systems which contributes significantly in the form of agriculture output (particularly wheat, cotton and sugarcane crops) of the Punjab province of Pakistan. Any concerns on the sustainability of this system can have wide ranging effects on the economy of the province, particularly on the ongoing poverty alleviation drives, as millions of people are dependent on the agricultural sector. The following section will describe the study area and main features of the canal command.

2. Study Area

The Lower Bari Doab Canal (LBDC) off-takes from the Ravi River at Balloki barrage and covers a gross command area of 0.728 million hectares with a culturable command area (CCA) of 0.676 million hectares along the left bank of the Ravi River. The command area of the Lower Bari Doab canal system is shown in Figure 1. The length of the canal is nearly 120 Km and full supply discharge at the head with a perennial water supply is 279 m^3/sec. Most of the water to the canal is supplied from the Chenab and Jhelum rivers by transfer through inter-river link canals. Some water from the Ravi River is also used during flood season. Ground surface slopes, generally in a south-westerly direction, are very mild. Part of the CCA is water logged where groundwater is not suitable, and soils are generally saline. However most of the canal command area is underlain by fresh groundwater, which is also used to supplement surface water supplies. The area lies in the cotton wheat zones, with cotton being the major crop in the Kharif (April to October) season and wheat in the Rabi season (October to April) (Shakir and Qureshi 2007).

3. Data Collection

The data required for this study was collected from a variety of sources as these data were not available with any one organization/ department. Like many other developing countries, there is no single mandated provincial body that systematically collects and records all relevant data regarding canal supplies, groundwater use, and rainfall and other meteorological data. These tasks are currently distributed amongst several different government organizations which are almost administratively independent from each other.

The groundwater data was collected from the Directorate of Land Reclamation (DLR) and recorded data of private tube wells in the LBDC system from individual records and Consultants reports submitted to the Irrigation and Power Department, Punjab. The rainfall and other meteorological data (temperature, humidity, sunshine hours etc.) were taken from reports of the Pakistan Meteorological Department (PMD), and canal water data was collected from the Punjab Irrigation and Power Department.

All the data were reviewed for their consistency and doubtful values if any were not considered for the analysis. The canal water supplies were converted into volume of water supplied on a seasonal basis for comparison with the allocated water supplies under the Water Apportionment Accord (WAA, 1991). The groundwater data was reviewed in the light of levels of groundwater tables to check trends of change in the elevation with time.

4. Crop Water Requirements

Crop water requirements for the LBDC system have been worked out using the Penman Montieth-2000 equation (Allen et al, 2005), which gives the values of evapo-transpiration. Shakir and Qureshi (2007) reported that this method has more likelihood of predicting relatively better values of reference evapo-transpiration (ET_o). The values of ET_o have been estimated for the LBDC command area on a monthly basis using the average of the daily data for

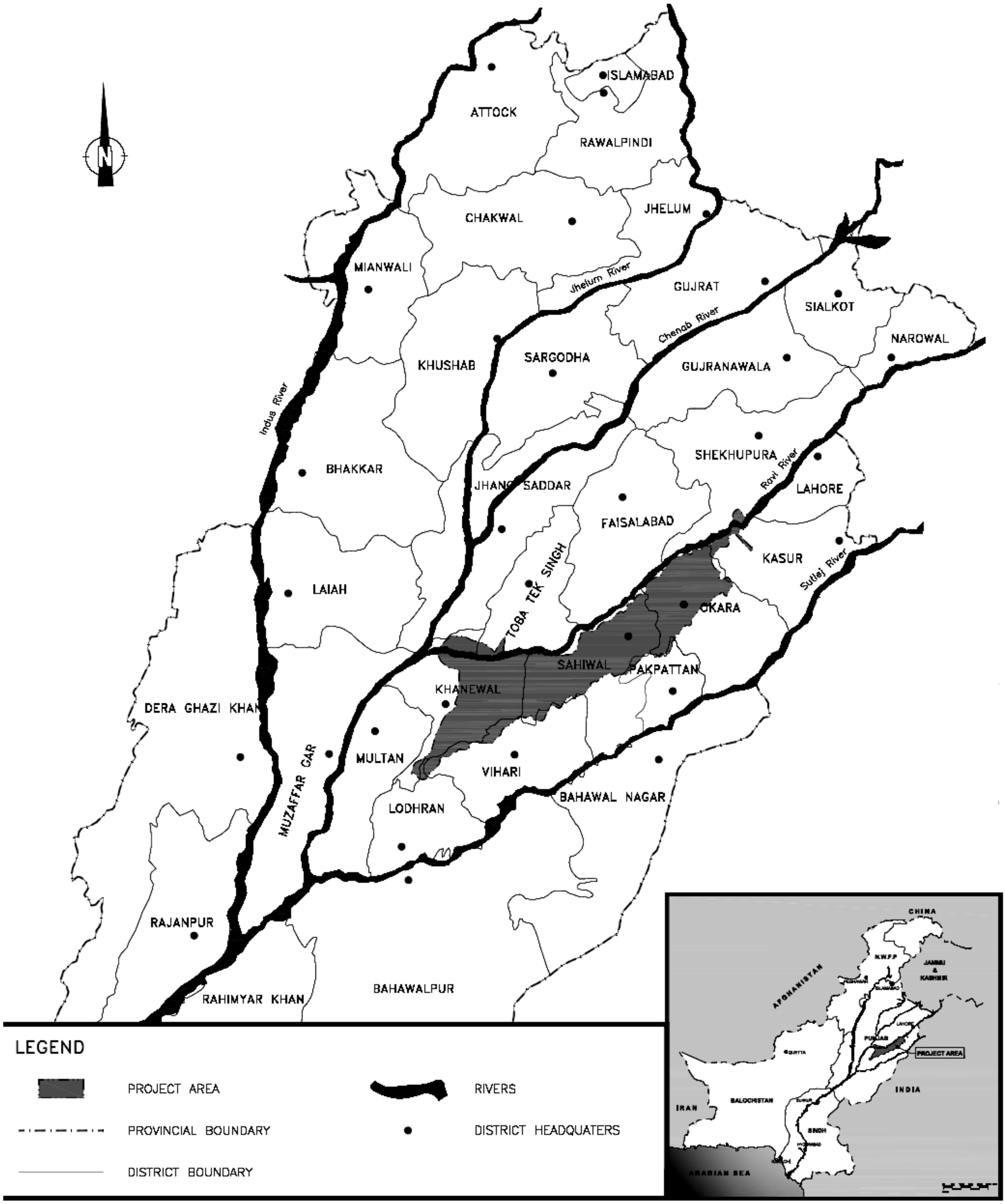


Figure 1: Location map of the LBDC Command area

each month. The effective monthly rainfall (P_e) was derived from the total monthly rainfall (P) using Equation (1) which is commonly used in Pakistan (Shakir et al. 2010). The monthly rainfall values were calculated from the rainfall data of three rain gauging stations located in the vicinity of the LBDC command using the Theissen Polygon Method.

$$\text{Effective Rainfall } (P_e) = 0.8\,P - 0.001\,P^2 \qquad (1)$$

The estimated values of ET_o and effective rainfall for the LBDC system are shown in Figure 2. Based on the monthly evapo-transpiration values and crop coefficients for each crop, crop evapo-transpiration was worked out. Using the average cropping intensities for ten years (1993-2002), in the canal system crop consumptive use was calculated. The irrigation water requirements for the LBDC system have been worked out from the estimated monthly values for the consumptive use less effective rain fall taking an overall irrigation efficiency of 40%. This overall irrigation efficiency is estimated considering water losses that occur in the system i.e. (conveyance losses in the main canal and distributory canals, water course losses and field losses). For the purpose of this study, conveyance losses are taken as 15%, water course losses as 20% and field losses as 25% of the actual water supplied at each level (Shakir and Qureshi, 2007). The annual irrigation water requirement for the LBDC system are worked out as 8.02 BCM compared with the allocated canal water supplies as 5.9 BCM at the head of the canal

5. Comparison of Canal Water Availability and Requirements

The canals are generally designed in Punjab including the LBDC for providing a pre-determined seasonally fixed water allocation. The system cannot meet the needs based on a demand supply model. The system does not have the capacity and water resources to accommodate variable demand supply models. The farmers are at liberty to plan for what they want to cultivate on their lands based on their socio-economic requirements and water availability. The government some times influences the cropping pattern in the country by giving specific incentives to grow certain crops as the need arises. Water allocations in Pakistan are made for each canal command area according to the Water Apportionment Accord (WAA, 1991). Following the WAA (1991), the LBDC has an annual water allocation of 5.9 BCM with 3.2 billion cubic meter (BCM) for the Kharif and 2.7 BCM for the Rabi season. However, the actual water availability to the LBDC system varies from year to year depending upon the overall water availability in the Indus River System. The canal water data for the last ten years (2000-2009) indicate that there has been a shortage of 5 to 35 % in different years (at an average of about 20%) compared with the allocated supplies for the LBDC System as per WAA (1991).

The comparison of allocated, actual water availability and irrigation water requirements for the

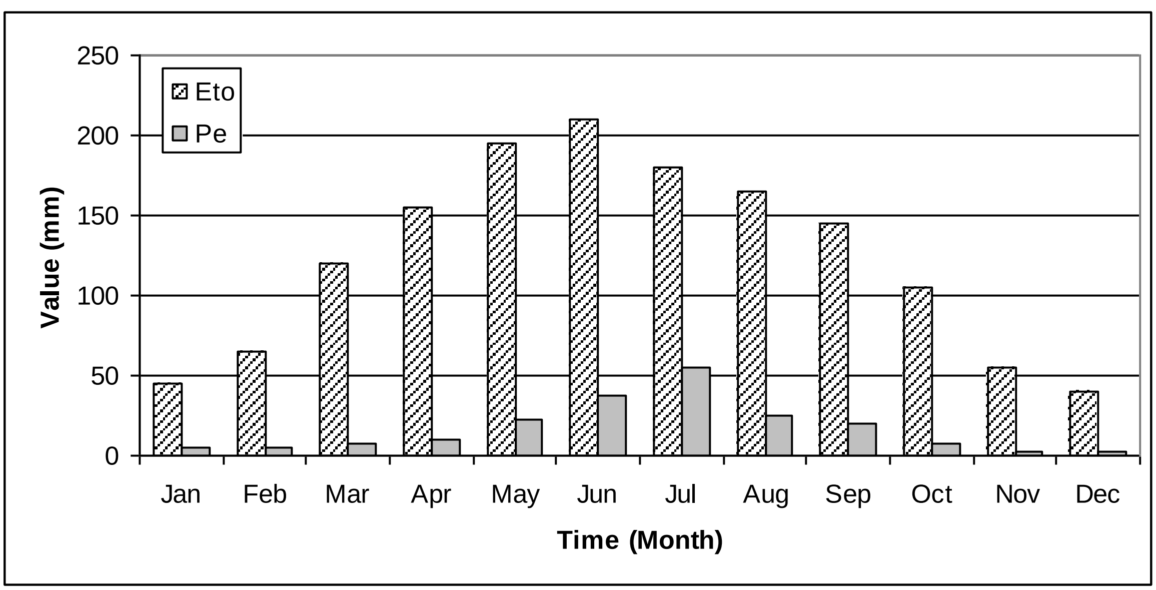


Figure 2 Reference evapo-transpiration (ET_o) and effective rainfall (P_e) for LBDC system

Rabi and Kharif seasons for the last ten years (2000-2009) in the LBDC system is shown in Figure 3. However, it may be useful to mention that the LDBC also provides 0.80 BCM of water to the MP Link canal in the Kharif season for supplementing the shortage of water in the Pakpattan Canal. This water supplied to the MP Link has been adjusted from the Kharif supplies of LBDC at the canal head for making a realistic comparison exclusively for the LBDC System. As shown in Figure 3, the major deficit in water supplies is in the Rabi season ranging from 14 to 54% in different years. However, in the Kharif season the water availability is relatively better with supplies almost equal to allocation in some years and a deficit of up to 22% in the driest year. As shown in Figure 3 the overall allocated canal water supplies are 36% less than the irrigation water requirements on an annual basis. This shortage amounts to 14% in the Rabi season and 53% in the Kharif season compared with the crop water requirements. This gap between availability and requirements increases to 56% when compared with average actual water supplied into the canal in the last ten years (2000-09). On a seasonal basis this shortage is 48% in Rabi and 64% in Kharif. This deficiency of canal water is normally met by the pumping of groundwater through private tube wells by the farmers.

6. Ground Water Use

To estimate the variations in groundwater table a network of observation wells is established by the Directorate of Land Reclamation Punjab (DLR, 2009). The wells monitor the groundwater table depths below natural surface level. The observations are taken twice a year i.e. before and after the monsoon rains. It is understandable that most of the deficiency in canal water supplies compared with irrigation water requirements is met by groundwater abstractions, largely by private tube wells which can have a significant impact on the sustainability of the groundwater resources. This is also supported by the groundwater level observations in most parts of the LBDC command area indicating a continuous lowering of the groundwater table (i.e. increase in water table depths). Figure 4 shows the levels of the groundwater tables in the three districts of LBDC command area namely: Okara, Sahiwal, and Khanewal..The data indicate that groundwater tables are lowered in Sahiwal, and Khanewal districts of the LBDC command area while it have shown upward trend in Okara district. The data further revealed that groundwater tables lowered at an average rate of 30 to 40 cm per year mainly in the Sahiwal and Khanewal Divisions of the LBDC command area.

The lowering of groundwater tables indicates that abstractions are more than the recharge in most parts of the canal command. This tendency of lowering the groundwater tables is expected to accelerate keeping in view stagnant canal water supplies and increase in cultivation intensities in future due to the immense pressure of an increasing population in the country.

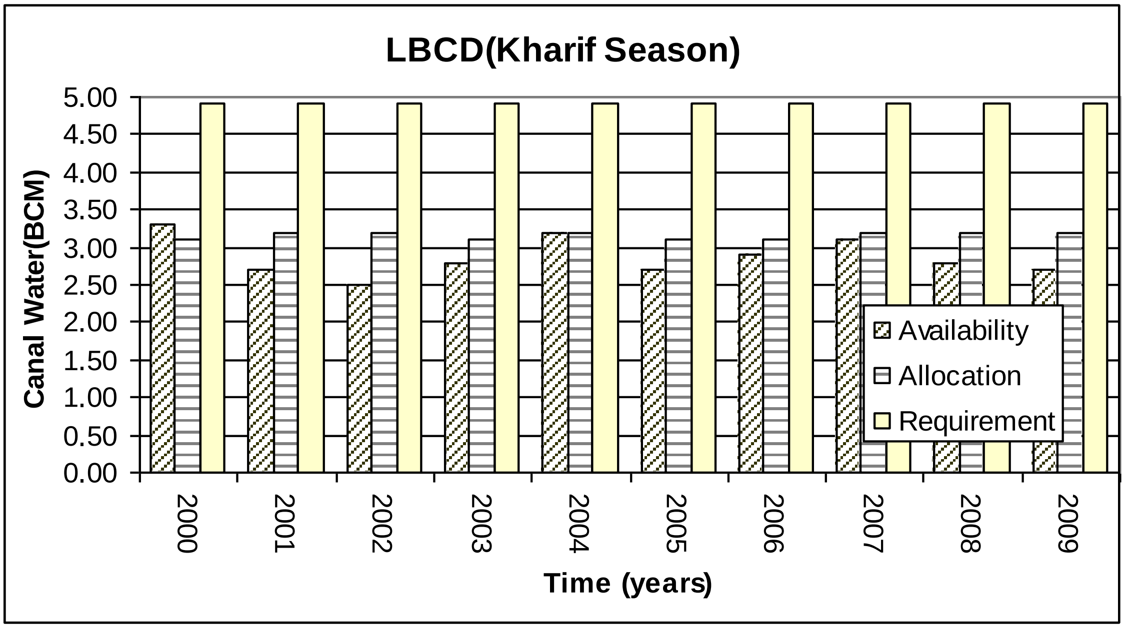
Halcrow (2006) also suggested that the overall recharge in the LBDC command area is less than the abstractions indicated by the water table which lowers every year. They estimated the average annual recharge as 4.41 BCM and average annual abstractions for irrigation as 4.78 BCM. Considering the domestic use and regional inflows/outflows they estimated the depletion of groundwater storage as more than 0.37 BCM/year in the LBDC command area.

7. Ground Water Quality

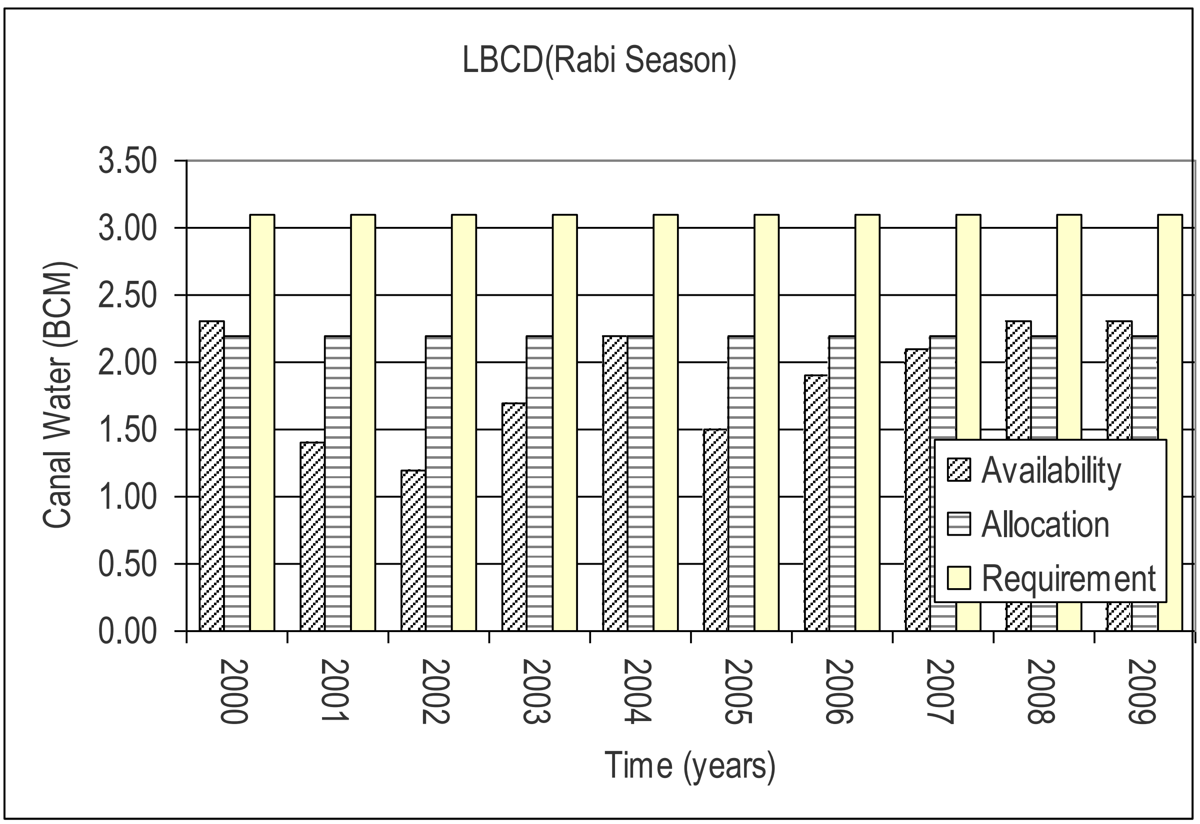
A significant amount of groundwater (about 4.78 BCM annually) is used for supplementing canal water supplies for irrigation in the LBDC system. The quality of groundwater plays an important role for crop yield predictions, which may vary from crop to crop. An attempt is made to analyze the water quality of the subsurface water in the LBDC system and the ill effects if any on the irrigated agriculture in this command area. The Irrigation and Power Department, Government of the Punjab uses water quality criteria for irrigation purposes as shown in Table 1 (DLR, 2009). The criteria are based on recommendations of several international organizations and due consideration of the local needs and environment.

Table 1: Irrigation Water Quality Criteria (DLR, 2009).

	Electrical Conductivity (EC) ds/m	**Sodium Adsorption Ratio (SAR)**	**Residual Sodium Carbonate (RSC) me/l**
Permissible Level	≤1.5	≤10	≤2.5
Unfit Level	>1.5**	>10	>2.5



(a)



(b)

Figure 3: Comparison of canal water allocation, actual water availability and irrigation water requirements (a) Kharif Season (b) Rabi Season

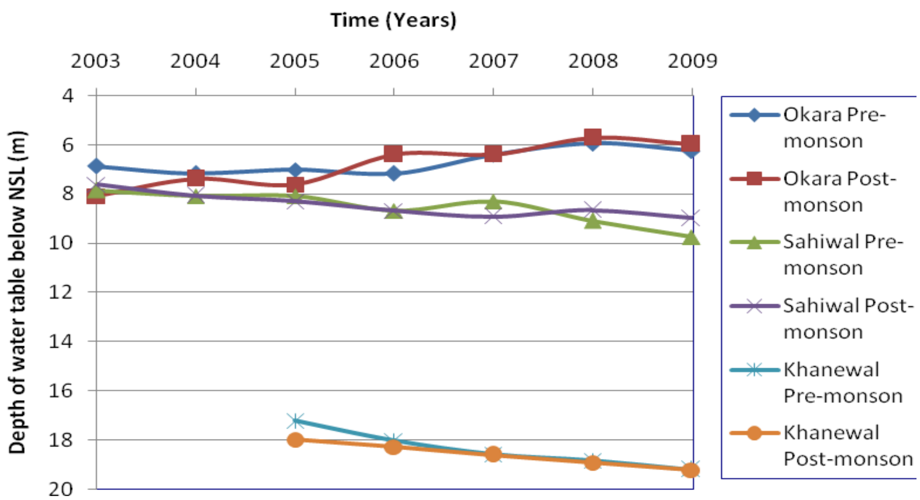


Figure 4: Average depth of water table below Natural Surface Level in LBDC command

EC = Electrical Conductivity in ds/m (deci-siemens/m)

SAR = Sodium Adsorption Ratio

RSC = Residual Sodium Carbonate in me/l (milli equivalents of solute per liter of solvent)

** The water having EC values between 1.5 and 3 ds/m is accepted as marginal quality water for use in acute shortages.

Groundwater quality data was obtained from the Directorate of Land Reclamation (DLR, 2009) for the period 2003-2009 for the LBDC command area. The Groundwater Monitoring Cell in the DLR which started functioning in 2003, measures water quality data at 208 stations throughout the canal command. The samples are taken twice a year at these points in the pre and post monsoon seasons and estimates of EC, SAR and RSC values for each sample are made. Out of 208 measuring stations in the LBDC system, the electrical conductivity (EC) values were within acceptable limits (as per DLR criteria) at 137 stations in the year 2003 which decreased to 131 stations in the year 2009. If marginal water quality (EC values up to 3 ds/m) is considered for use due to pressing demand then data for only 11 stations in 2003 showed EC values above the limits indicating unusable water. The number of stations showing unacceptable water increased to 15 in the year 2009. The overall water quality based on the EC values in the canal system area for the year 2009 is shown in Figure 5 which shows that only 8% of the data indicates unusable groundwater conditions. Out of the remaining 93%, 64% is of good quality and another 28% is of marginal groundwater quality. The SAR values at 170 out of the total of 203 stations were within acceptable limits in the year 2003, but the number decreased to 160 stations in the year 2009. The RSC values at 154 out of 203 stations were within acceptable limits, but also decreased to 152 stations in the year 2009. The groundwater quality assessment based on SAR and RSC criteria in the LBDC Command area for the year 2009 are shown in Figure 6 and Figure 7 respectively. Comparison of water qulity data of year 2003 and 2009 is presented in Figure 8. A detailed look at these data indicates that most of the points showing good values for the EC, SAR and RSC lie in the Okara District (Figure 9). The observation wells with acceptable values of EC are 74%, 60% and 60 % in Okara, Sahiwal and Khanewal districts, respectively.

The analysis of these data indicates that water quality in most parts of the LBDC command area is generally good or at least acceptable when compared with the standards indicated in Table 1. However, few measuring points show higher values of these indicators compared with minimum permissible values.

This analysis shows that a well planned strategy for the use of surface and groundwater need to be evolved with a mechanism to ensure its implementation to save this system from future damages. The strategy need to be optimized for various distributory canals and minors on a case to

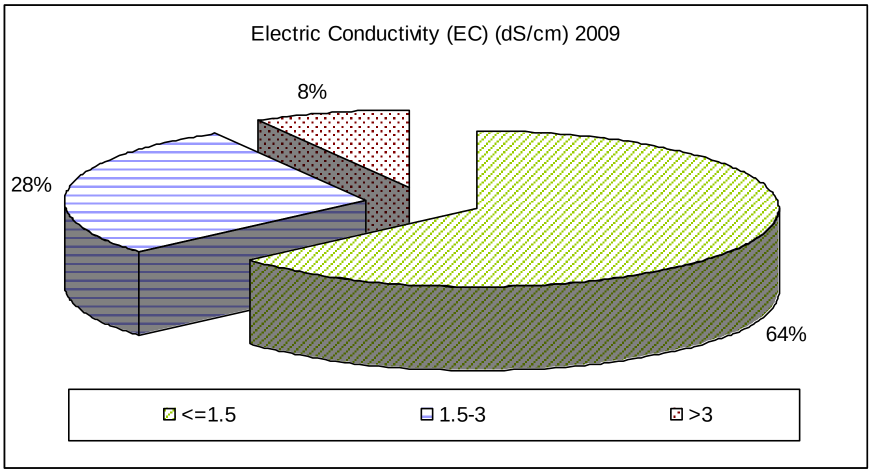


Figure 5: Distribution of Groundwater EC in study area during the year 2009

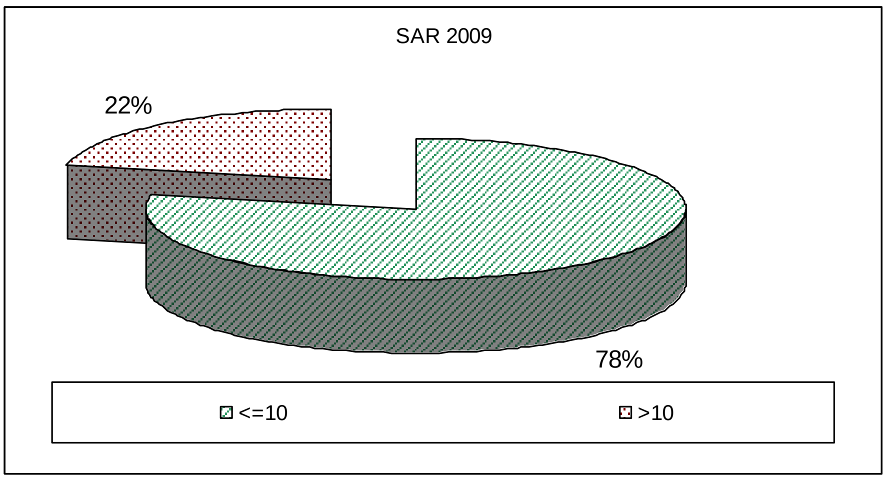


Figure 6: Distribution of Groundwater SAR in study area during the year 2009

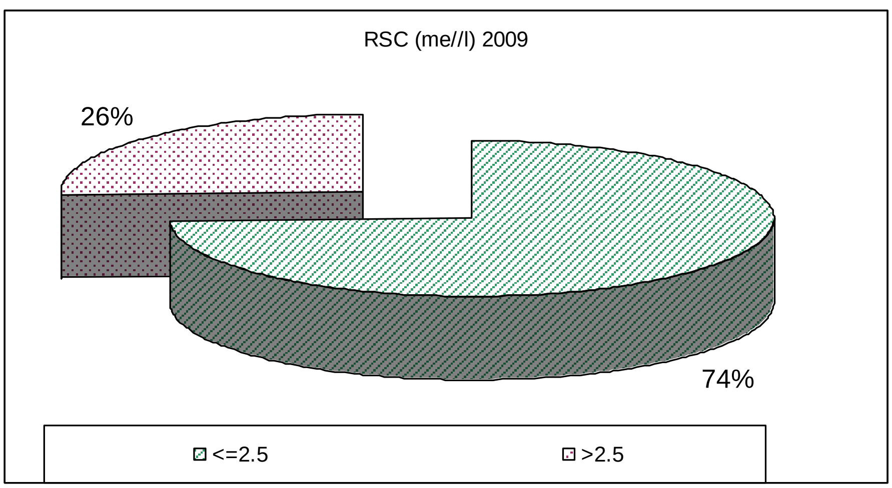


Figure 7: Distribution of Groundwater RSC in study area during the year 2009

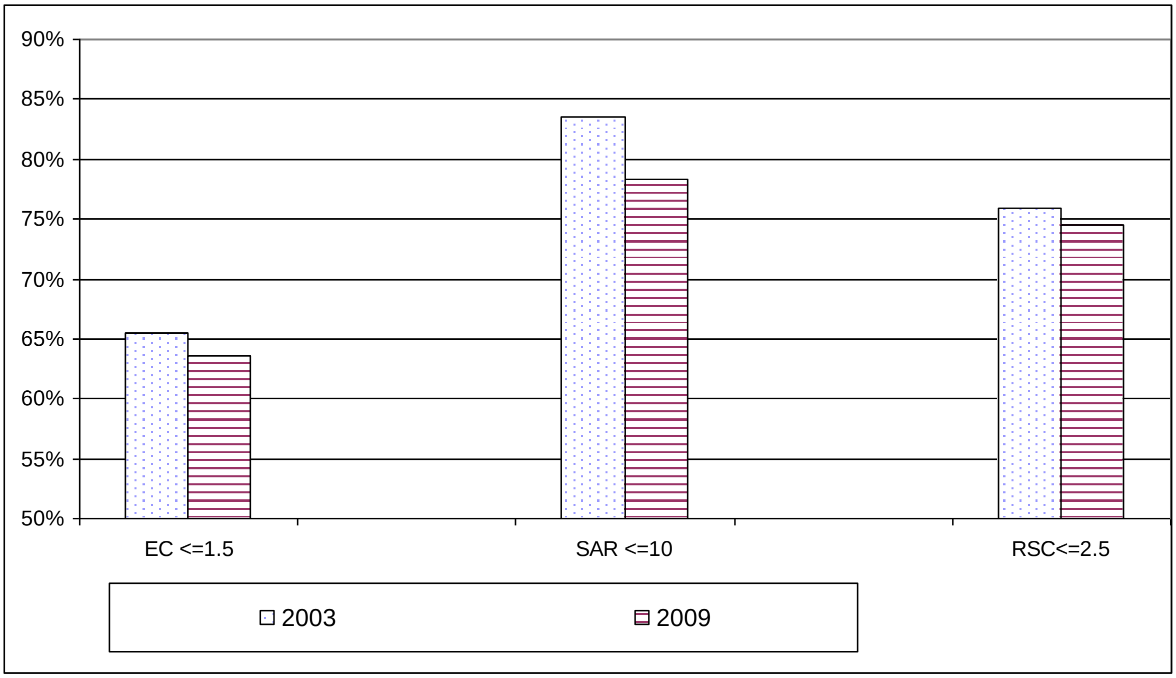


Figure 8: Comparison of Groundwater Quality Parameters for years 2003 and 2009 for study area.

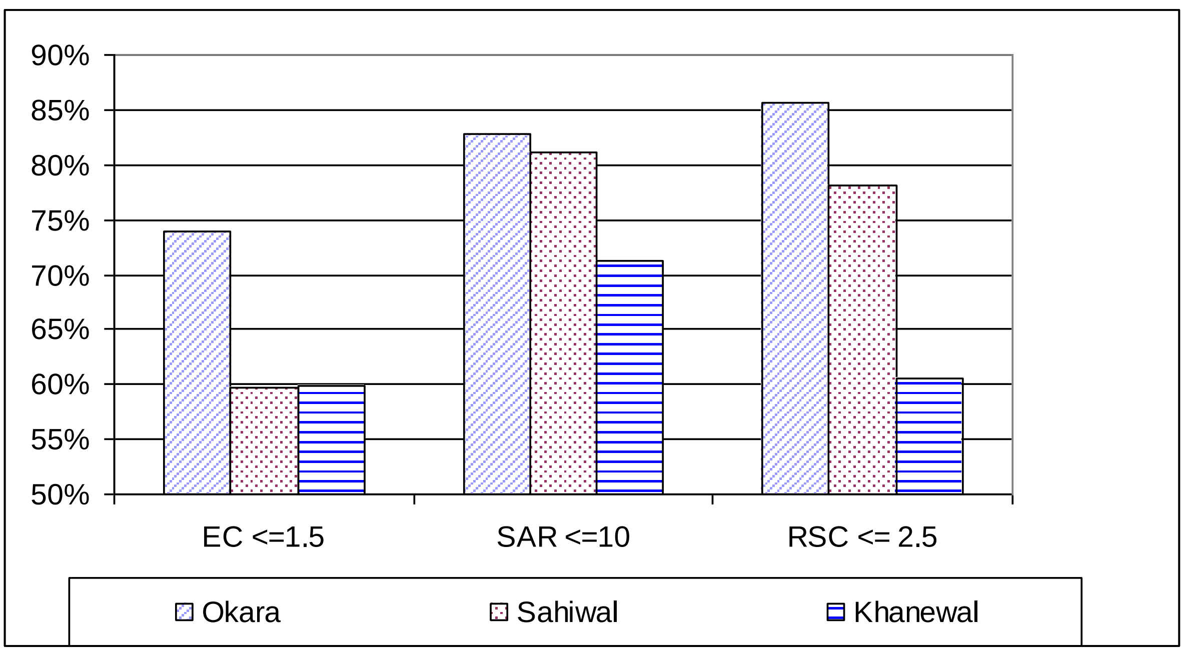


Figure 9: District-wise Comparison of Groundwater Quality Parameters for years 2009

case basis and any general solution at the canal command level may not be very helpful due to varying impact of water shortages in the canal command area. It is recommended that a detailed study should be carried out to prepare a long term plan for future surface and groundwater use for this canal system.

8. Water Management Options

The Indus Basin Irrigation System (IBIS) part of which is the LBDC command area brings highly seasonal flows (larger share in the summer and very small shares in the winter of the total annual flows). The surplus amount of water in the summer goes to Arabian Sea and can partly be utilized by the construction of new storages. The other management options may include but are not limited to:

- Water conservation by the lining of canals
- Demand management
- Water efficient agricultural practices including laser leveling of lands
- Properly designed conjunctive use of canal and groundwater (at the distributory canal and/or minor level) to minimize the negative effects of excessive use of marginal quality groundwater.
- Proper regulatory framework for groundwater exploitation for long term sustainability.

There is an urgent need to initiate studies and dialogue with the stake holders for the development of a new model for water allocation at the distributory level within a canal command. This can be worked out keeping in view the canal water availability and groundwater conditions in each area by optimizing the use of surface and groundwater based on the requirements and to mitigate ill effects on soil salinity which heavily limits crop production.

9. Conclusions and Recommendations

There is a 36% shortfall of canal water allocated for the LBDC system compared with crop water requirements, which increases to 56% when compared with actual water supplied for the last ten years.

The shortage is normally met through the pumping of groundwater by private tube wells which is causing a lowering of groundwater tables at a rate of 30 to 40 cm per year in most parts of the LBDC command area and which is expected to accelerate in the future.

The quality of the groundwater in most parts of the LBDC command area is generally good or acceptable for use when compared with the irrigation water standards. However, there seems to be a gradual declining tendency in groundwater quality causing long term sustainability concerns.

It is recommended that a detailed study be carried out to formulate a plan of conjunctive canal and groundwater use at the distributory canal level or even lower (tertiary) levels (as the case may be) to save this system from negative effects of water shortages and marginal groundwater quality on the irrigated agriculture in this canal command area. It is further recommended to explore the possibility of a water distribution model having variable water allocations in the sub components of a canal command area based on availability of canal water and groundwater conditions.

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