Land and Water Productivity

Trends Across Punjab Canal Commands

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ABSTRACT

As a consequence of green revolution in 1960s, though irrigated areas and agriculture production has increased considerably, yields are still less as compared to various countries of the world. Furthermore, huge spatial variation in cropping pattern and productivity of land and water within irrigated agriculture of Pakistan has become a chronic issue. There are various reasons causing low production. These include farmers' investment potential, physical environments, market mechanism and availability of water, which is the most precious input in farming. The role of irrigation water resources and its management is extremely important. The sustainability of agriculture can be largely insured through proper and better management of water resources. Indus Basin Irrigation System (IBIS) is basically supply-based by its design which means water is not supplied according to crop requirement. Low gross production is an inherent limitation of this supply-based system.

The research activity aims to see the spatial variation in production across canal commands using gross production indicators i.e. Gross Value of Production (GVP) per unit of land and GVP per unit of water. Given the data constraints, Punjab province is selected for the analysis, which consists of major network of 12, inter-linked and a total of 23 canals out of 45 canals of IBIS. The analysis is performed at the canal command level.

Secondary data gathered from government agencies are used. These data are available at different levels e.g. canal commands, administrative districts and meteorological stations. Geographic Information System is used to standardize the data at canal command level. Water availability responses to GVP are analyzed by using regression technique. By explaining GVP in two ways Inferences are made. First, by estimating GVP as a response of intensity and types of crops grown in a canal command, as both mainly rely on water. Second, by estimating direct relationship between GVP and water availability.

Huge variation in cropping intensities across Punjab canals is found which ranges from less than 60% to 160%, annually. GVP per hectare of command area varies with a ratio of about 1:5 (Rs. 3844 per hectare to Rs. 18326 per hectare). GVP per cubic meter of water varies with a ratio of 1:5 (Rs. 0.35 per cubic meter to Rs. 1.57 per cubic meter). Some canal commands produce less per unit of land and per unit of water in spite of higher canal supplies. Environmental degradation i.e. waterlogging/salinity is probably the reason for low production. Ground water is the major influence in certain canal command areas during Rabi season. Annual GVP and Kharif GVP are explained by canal water while Rabi GVP is explained by ground water.

ACKNOWLEDGMENTS

GLOSSARY

Abiana	=	Irrigation water charges.
ASP	=	Agriculture Statistics of Pakistan.
CA	=	Cropped Area.
CCA	=	Culturable Command Area of canal.
DEM	=	Directorate of Economic and Marketing of the Provincial Agriculture Department.
GCA	=	Gross Command Area of canal.
GDP	=	Gross Domestic Product.
GIS	=	Geographic Information System.
GVP	=	Gross Value of Production.
Kharif	=	Summer time, warm-wet season, officially mid-April to mid-October.
Patwari	=	Revenue and Irrigation department official responsible for keeping land records and assessing abiana, respectively.
PIPD	=	Provincial Irrigation and Power Department.
Rabi	=	Winter time, cool-dry season, officially mid-October to mid-April.
Tehsil	=	A sub-divisional administrative zone under a district administration.
Tehsildar	=	Revenue officer of tehsil.
WAPDA	=	Water and Power Development Authority.
Zilladar	=	Head of a section of irrigation sub-division who have several patwari under him. Usually an irrigation sub-division consists of 3-4 sections.

UNITS

1 Hectare	=	2.471 Acres
1 US $	=	30 Pak. Rupees (1993-94)

LAND AND WATER PRODUCTIVITY
TRENDS ACROSS PUNJAB CANAL COMMANDS

INTRODUCTION

Perspective

Pakistan is one of the foremost among the countries facing threat of rapidly increasing population with the growth rate of 2.7 percent. Its population was reported 138 million in 1998 (census 1998) and was projected to reach 208.06 million in year 2025 (PWP 2000). Food grain production in the country shows shortfall with respect to its requirement. A recent study shows that food grain requirement will increase from 26 million ton in year 2000 to 40 million ton in year 2025 (PWP 2000). Alongside the food grain, requirement for other products of agriculture sector will have to face momentous increase. Hitherto, agriculture is the backbone of country's economy having 1/4th share in its Gross Domestic Product (GDP). About 50 percent of the labor force relies on agriculture. The sector earns 70 percent of export revenue, directly or indirectly (World Bank 1994).

Out of 80 million hectares of Pakistan, 20 million hectares of land is cultivable and 75 percent of this consists of irrigated areas. The climatic conditions are suitable for double cropping. The summer cropping season which lies between mid April to mid October is called *Kharif* season while the rest (winter) is called *Rabi* season. Major crops of Kharif are Cotton and Rice while in Rabi season Wheat is the single major crop. Sugarcane is an annul crop, which takes almost whole year to mature. Fodder is sown in both seasons to fulfill the local livestock requirements.

The green revolution in 1960s brought more area under cultivation. Though the production of crops increased considerably, crop yields are lower than many other countries of the world (Mellor et al 1994) particularly wheat, which contributes more than 50% of per capita daily availability of calories and 85% of the total protein intakes (Alderman et al 1993).

The stagnant yields and huge disparity in average yields demand inquiry of its causes. There can be several causes of low production. Along with the socio-economic factors e.g. land tenure and land fragmentation, there are several physical factors as well for this low yield. Indus basin Irrigation system is basically supply-based by its design, which means water, is not supplied according to crop water requirements. Thus, the irrigation supplies do not meet the crop water needs for optimum yields. Adequacy and reliability are the two main issues. The volume of water supplied does not match with the time pattern of crop needs.

Being a precious input in farming, the role of irrigation water resources and its management is extremely important. The sustainability of agriculture can be largely insured through the proper and better management of water resources. There have been substantial changes in century old contiguous

system, which now consists of 3 major reservoirs, 15 barrages, 12 link canals and 45 mains canals (see annex 1 for a note of Indus Basin Irrigation System, IBIS).

The annual average water supply through this network is about 180 billion cubic meters and the command area is 14.3 million hectares. Before the development of present system of canals in 1817 by British Army engineers, a number of inundation canals existed on all rivers of the Indus Basin. They were constructed and managed by cultivators, local states or tribes. Building weirs, head works and remodeling of the canals by 1900 improved four old inundation canals of Punjab. Most of the existing irrigation channels of Punjab were constructed before 1930 and most of the projects in other provinces were completed before 1960.

Before 1960's, there were no reservoirs within the Basin. Water was diverted from rivers to canals through weirs. Water rights of the canals were fixed as perennial or non-perennial (Table 1.1). This classification was based on availability of river water at the specific location in winter, water use patterns of the inundation canals and political agreements between states and the British Government. Design cropping intensities and water duties were based upon the average values in the cultivated areas of that time. The management, operation and maintenance rules were designed on simplicity requiring minimum human interventions.

Since 1960's, there have been significant changes in the physical and management structure of the system. These include the construction of inter-river link canals and reservoirs as the result of Indus Basin Treaty of 1960 between India and Pakistan, which led to approximately 40% increase in water availability. Furthermore, groundwater became a major supplement to canal water. Resultantly, the cultivable area increased by 15-20 percent and cropping intensities doubled.

In spite of these changes, the official water allocation strategy has not been revised. Consequently, there is lack of coherence among water allocation rules that are in place. The Indus Basin Study of IWMI aims at developing coherent water allocation rules, which maximize agricultural production and minimize environmental degradation (Habib 1997). One major component of this study is to analyze the relationship between surface water supplies, ground water use, cropping pattern, environmental degradation and agriculture production through gross performance indicators. On production side, these Indicators include production per unit of land and production per unit of water. The estimation of these two indicators is the major concern of the report. Production is estimated in term of money values (section 2), which is called Gross Value of Production (hereafter GVP). The analysis provides an overview of money return per unit of area and per drop of surface water made available to different canal commands. The specific objectives of the current report are mentioned in the following section.

Objectives of the current report

Current report has four specific objectives;
▪ Discuss sources of secondary information which could be used to determine the spatial variation in gross value of production (GVP) per unit of land and per unit of water,

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- Identify methods to reconcile information available at different levels by canal command level,
- Find out the spatial distribution of GVP per unit of land and water;
- Estimate the effect of water available from different sources on GVP.

Study Area

Given the information constraint, canal commands of Punjab province are chosen for the analysis. The Punjab area consists of 23 canals (Figure 1.1) out of the total 45 canals of the Indus basin. Punjab is the biggest part of contiguous Indus Basin Irrigation System (IBIS), consisting of 12 inter-linked channels. It consists of the **25.8** percent of the land area of the country with **56.5** percent of total population (GWP 1999) and is a densely populated area. Table 1.1 presents the salient statistics of Punjab canals, which include year of operation, Gross Command Area (GCA), Culturable Command Area (CCA) and information on perennial and non-perennial systems.

Figure 1.1. Punjab canal commands.

Table 1.1. Command area statistics of Punjab canals.

Canals	Year of Operation	GCA	CCA	% Area Perennial
Upper Chenab	1912	618836	580147	60%
M.R.Link	1956	71002	63616	0%
C.B.D.C.	1859	284639	265700	100%
Depalpur (Upper)	1928	152223	141711	0%
Depalpur (Lower)	1928	263620	247718	0%
B.R.B.D.				0%
Lower Chenab (East)	1892	773321	647502	95%
Lower Chenab (West)	1892	724140	588614	95%
Upper Jehlum	1915	236625	220094	69%
Lower Jehlum	1901	662982	614488	86%
Thal	1947	950802	773843	100%
L.B.D.C.	1913	740374	675667	97%
Haveli	1939	457382	411711	36%
Mailsi	1928	303916	277956	32%
Pakpattan (Upper & Lower)	1927	570971	516233	60%
Fordwah	1927	188118	173111	15%
East Sadiqia	1926	497749	424850	98%
Abbasia	1929	120739	96139	48%
Bahawal	1927	365681	299776	47%
Qaim	1927	18320	17121	0%
Panjnad	1929	613172	551926	33%
D.G.Khan	1958	388706	368546	0%
Muzaffargarh	1958	383473	331764	0%
Rangpur	1939	144831	139769	0%

METHODOLOGY

Gross production indicators: the concept

Production is influenced by various factors which include exogenous variable i.e. infrastructure, climate, environment, water availability and prices of inputs and endogenous variables such as irrigation practices and quantities of different inputs applied. Analysis of all these at a large scale canal command level is a tedious task requiring huge information from reliable sources which is always a question in developing countries. However considering the commonalties of the irrigation systems e.g. land, water, and production, some indicators can be measured for comparison across irrigation systems. Various indicators are introduced by the scientists, which are reviewed by Rao 1993.

Perry 1996 presented a minimum set of indicators, which are tested for various systems by IWMI scientists. These indicators are not too data-intensive to discourage widespread application.

Given the data constraint, three basic production indicators, gross value of production (hereafter GVP) per cropped area; GVP per command area and GVP per unit of water are selected. The rationale behind considering VALUE of production instead of MASS production is obvious. Mass production is meaningful for comparison when only one crop is considered. But when different crops are aggregated, one has to translate production into value by considering its market prices, as 1 kg of a crop is not equal to 1 kg of another in terms of value. In the study, as the analysis is for the canal systems of the same region, therefore, local prices are used. Following is the description of these indicators.

Production per unit of cropped area (Rs./hectare)

$$GVP_i = \frac{\sum (c_j \times p_j)}{CA}$$

Where; GVP_i = Gross value of production in jth season, C_j = crop production of jth crop, P_j = market price of jth crop, and CA = Cropped area

Production per unit of command area (Rs./hectare)

$$GVP_i = \frac{\sum (c_j \times p_j)}{CCA}$$

Where; CCA means Culturable Command Area

Production per unit of water (Rs / m³)

$$GVP_i = \frac{\sum (c_j \times p_j)}{Water}$$

Where; Water = water available

GVP per unit of CA measures the response of land used for crops while GVP per unit of CCA measures the response of land available for crops. GVP per unit water measures the response of water available. Ideally, a 4th indicator GVP per unit of water used, should also be calculated. However, this is not included in the analysis due to non-availability of such information.

Explaining variation in GVP with special reference to water

Production of a particular crop can be increased in two ways. First, by increasing the area under that particular crop and second, by adopting yield enhancing inputs there. However, to increase the aggregate production (production sum of all crops in terms of money value), another important thing is, crop type.

Cash crops such as cotton and sugarcane give high returns. Therefore, three determinants of GVP appear cropping intensity, yields and cropping pattern. (Market prices also influence the gross value of production, however, this part is kept out of the analysis by assuming there is no variation in prices across canal commands as the agricultural markets are well integrated, Tahir et al. 1997).

Thus;

GVP = f(Cropping Intensity, Cropping Pattern, Yields)……………………………(1)

Though cropping intensity and cropping pattern are not solely determined by water and are influenced by other factors such as depth to water table and soil conditions, water availability is a major determinant among these. Similarly, yields of different crops also depend upon various endogenous factors i.e. use of better seeds, fertilizers, farm machinery, labour intensity and plant protection (pesticides and wedicides etc.), however, water availability has a major influence. Given the data constrains, relationship of water availability with cropping intensity and cropping pattern, is estimated.

By explaining GVP in two ways Inferences are made. First, by estimating equation 1 and second, by estimating direct relationship between GVP and water availability (Equation 2).

GVP = f(Water Availability)……………………………………………………(2)

GVP from CCA is used, as dependent variable in the Equation 2 where CCA refers to Culturable Command Area whish is worthy of canal water.

Functional form

Water availability response to GVP is analyzed by using regression technique. This technique provides the information needed in determining the resource use and output patterns. In studying agricultural relations, economists usually use linear, log, semi-log and quadratic equations. Most accepted procedure to choose the functional form is that which best explains the variation in dependent variable. The functional forms that provide the least residual sum of square and highest coefficient of determination (R^2) are used to select the best-fitted model (Maddala 1988). Following basic functional form is used to analyze the resource use efficiency.

$$Y_i = a + \sum_{j}^{n} b_j X_{ij} + e$$

Where

Y = gross value of production;
α = constant;
β = parameters to be estimated;
X = explanatory variable;
ε = random error term;
i = 1,2,3…..n canals
j = 1,2,3…..n explanatory variables.

INFORMATION AVAILABILITY AND ITS LIMITATIONS

Information on crop acreage, yields and commodity prices

To calculate GVP at canal command level, mainly three type of information is required (i) crop acreage (ii) crop yields, and (iii) output commodity prices. These data are collected by different government agencies at different scales. As these agencies have different objectives of monitoring, their methodology and time scale is not the same. For instance, Provincial Irrigation and Power Departments monitor and maintain the information on crop acreage at main canal command level and its secondary and tertiary levels. PIPD staff monitor crops from acre to acre to levy water charges, which vary from area to area and crop to crop. The variation in water charges is due to crop water requirement of different crops. Thus, PIPD groups different crops according to crop families such as oilseeds, vegetables and pulses etc.

The following paragraphs discuss the above three topics, separately.

Crop Acreage

Crop acreage data are gathered from two sources;
i)   Provincial Irrigation and Power Department (PIPD)
ii)   Directorate of Crop Reporting Service, Agriculture Department, Government of Punjab

Scale of data of above two sources is different. PIPD maintain their data at canal command level as they are directly concerned with canals while Crop Reporting Service keep up data at administrative unit level (districts). Crop Reporting Service has its sub-office at tehsil (district's lower administrative unit) level where they gather crop area data. The PIPD source is selected because data is available at canal command level while conversion from district to canal command is not straightforward.

As discussed above, the purpose of maintaining crop acreage data by the PIPD is basically the assessment of crop for water charges. Revenue department is involved with the irrigation department in recovering water charges. The process of assessment of crop acreage and recovery is:

In an irrigation sub-division (usually a canal command consists of several sub-divisions), number of *halqa*s on the basis of village located in the canal command, are established. One canal *patwari* (visiting clerk) is appointed per halqa. In the beginning of each season (*rabi / kharif*) a printed book[1] is given to canal patwari by the Divisional Canal Officer through Deputy Collector. Canal patwari conducts numerous visits from crop sowing to its maturity. After the maturity, canal patwari makes final measurement by visiting halqa. After that he moves to his *zilladar's* office[2] where he makes the final statement of assessment called *khatuni*. After the completion of khatunis, zilladar submits it to Divisional

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[1] Book is printed with machine numbered pages using indelible ink.

[2] Zilladar is the head of a section of irrigation sub-division who have several patwaris under him. Usually an irrigation sub-division consists of 3-4 sections.

Canal Officer where after final checking the khatunis are transferred to *tehsildar* (revenue department's officer for the administrative sub-division). Tehsildar hands over these khatunis to revenue patwaris who recover water charges (abiana) from the farmer through village *lamberdar*. Crop acreage statements that are organized at canal level are then send to PIPD head office.

Crop acreage statements do not expose all crops in detail. Usually, crops of same family or having the same revenue are aggregated in one group. For instance, different fodder crops sown in kharif season are aggregated and called *kharif fodder*.

PIPD reported following crops in kharif and rabi seasons.

Table 3.1. Crops reported in crop acreage data.

No.	Kharif Crops	Rabi Crops
1	Sugarcane	Wheat
2	Rice	Barley
3	Cotton	Grain
4	Maize	Grams
5	Jowar & Chari	Rabi Oilseeds
6	Bajra	Rabi Fodder
7	Kharif Oilseeds	Rabi Others
8	Kharif Fodder	Rabi Orchards
9	Kharif Others	
10	Kharif Orchards	

Crop Yields

Federal Ministry of Food and Agriculture publishes the average yields of different crops by administrative districts after every three years. Federal ministry collects this data from Crop Reporting Service. For instance, Directorate Crop Reporting Service of Agriculture Department, Government of Punjab, has 1010 sample village locations through out Punjab province where they monitor crop yield and then generalize it to district level.

Commodity Prices

Mainly, two type of information regarding prices with respect to sources, is available that are;

i)   Directorate of Economics and Marketing (hereafter DEM) of provincial agriculture departments, and

ii)   Agriculture Statistics of Pakistan (hereafter ASP), published by Federal Ministry of Agriculture, Food and Livestock.

Basic difference between the two sources is that ASP, mainly, presents the average annual prices on higher scale (at provincial level) and the support prices of the commodities offered by the government while DEM maintains the wholesale prices at the *mandi* (local market) level.

DEM source is adopted as it is more proximate to prices taken by farmers after produce and its scale is smaller and better representative of remote areas. Where the price of some specific commodities not available (usually, commodities that are not marketed), prices are taken from various studies based on field data collection i.e. Farm Management Handbook, published by University of Agriculture Faisalabad, in 1993.

DEM price data of different markets reveals that price differentials across area are very nominal. Usually major agriculture commodity markets are well integrated with each other and price shocks in one market are observed in other markets, instantly. Not only major markets are integrated; even small markets with off-road locations are also integrated (Tahir 1997). Where isolation of markets is observed, that is mainly due to government restrictions on the movement of a particular commodity from one area to another. Even in such cases (like wheat in Pakistan), government offers support and procurement prices, which work as price stabilizer, and prices remain the same in different market locations of the country. So with the finding of very nominal price differential across area, constant price of commodities during a certain year is used for all canal commands.

The discussion so far reveals that the data sets required for the estimation of gross value of production at canal command level are not homogenous at all, horizontally and vertically. This heterogeneity can be summarized as;

- Different data sets provide information at different levels while every data set is required at canal command level;
- In some data sets crops are grouped according to crop family while there is variation in yields and prices within group; and
- Prices of many perishable and non-marketable commodities are not available.

This situation requires standardization of these data sets using some systematic techniques.

Solution

The problem of data sets collected at different levels, is solved with the help of Geographic Information System (GIS). It is done in three steps. At first step two maps, map of districts falling in the Indus Basin (containing the yield data) and the map of canal commands is constructed. Secondly, canal command map is overlaid on the district map to draw out the district areas falling in the canal commands[3]. At the third step, using the district areas (falling in canal command) as weight, weighted average of crop yields is calculated. Thus, the yield data at the canal command level is produced[4].

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[3] See Annex 2 for percentage of districts areas falling in Punjab canal commands

[4] See Annex 3 for average yields of major crops at canal command level

The heterogeneity in crops in area and yield data sets was a big problem. In the yield data mostly the yield of each and every crop are reported while in the area data crops of same family are grouped under one name (e.g. oilseeds, pulses etc.). This causes the problem of associating yield to oilseeds in order to calculate the production, as it is not known that yield of which oilseed crop (either sunflower or mustard or whatever) is more appropriate for oilseed category in a particular canal command. This problem is resolved by literature survey. Studies conducted in different areas of Indus Basin reveal the crops grown in the area. Thus, the appropriate oilseed crop can be assessed in a particular canal command area. Further, taking a look at the cropping patterns, it is scrutinized that grouped crops mostly have minor area under them. So, even taking constant yield for all canal commands will not provide misleading results.

The unavailability of prices of many perishable and unmarketable commodities was another problem in calculating the gross value of production. Some assumptions are made while doing these calculations;

- Commodities are of the same quality,
- Prices are stable during the crop season,
- Market price is equal to farm gate price, and
- Markets in the canal commands are well-integrated.

Again, consulting the literature and studies, shadow prices are used for perishable, unmarketable and some time for grouped crops.

Information on water sources

Water supply from all three sources has been assessed on seasonal basis for each canal command. In 1993-94 the river inflows remained 10 percent below the average during *Kharif* (April-September), which includes the torrential rain of monsoon period, and 20 percent below average during *Rabi* (October-March). The rainfall in the canal command was also very low, ranging from 10 to 60 percent below average in the IBIS command areas. In sum, the year 1993-94 presents conservative figures. In following paragraphs, quantification process of canal, ground and rainwater is discussed, separately.

Canal Water

The 10-daily discharge data of the Provincial Irrigation and Power Department (PIPD) of the Punjab province were used to compute the surface water supplies. A detailed analysis of the river inflow hydrographs, reservoir operations, canal diversion and losses and gains has been carried out (Khan 1999) which takes 40 years' information for system inflow-outflow analysis and the last 10 years data for canal and reservoir operations. Figure 3.1 shows 10 daily averages for diversions to the canal system of Punjab. The diversions in *Rabi* are equivalent to about 40 percent of the diversions in *Kharif*.

The conveyance losses of the primary and secondary systems are computed according to the criterion developed by WAPDA (RAP 1979, WSIPS 1990). The formula includes the variability of flows, soil texture and canal lengths; modifications are introduced in the coefficients adopted for flows higher than

80 percent. The loss coefficients vary from 13 percent to 34 percent for the main canals. The losses are computed for every 10-daily period and accumulated for the season.

Figure 3.1. Diversions to Punjab canal system in the crop year of 1993-94.
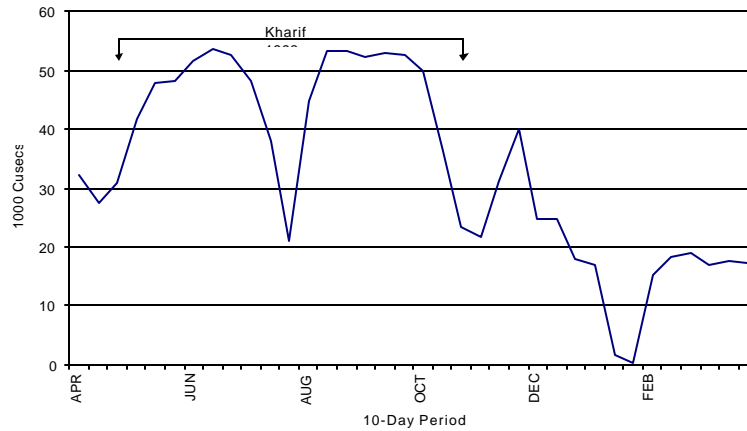
Rain Water

The rain data of 37 metrology stations are processed to compute the monthly and seasonal rainfall. This data was used to prepare Isohyetal Maps (Linsley, et al, 1992) using Geographic information system. These maps are superimposed with the canal command maps to compute the rainfall volume for each canal command area. The spatial and seasonal variation of rainfall in Pakistan (command areas indicated) for 1993-94 is shown in Figure 3.2 and 3.3.

Figure 3.2. Distribution of rain across the Punjab during Kharif 1993.

Figure 3.3. Distribution of rain across the Punjab during Rabi 1993-94.

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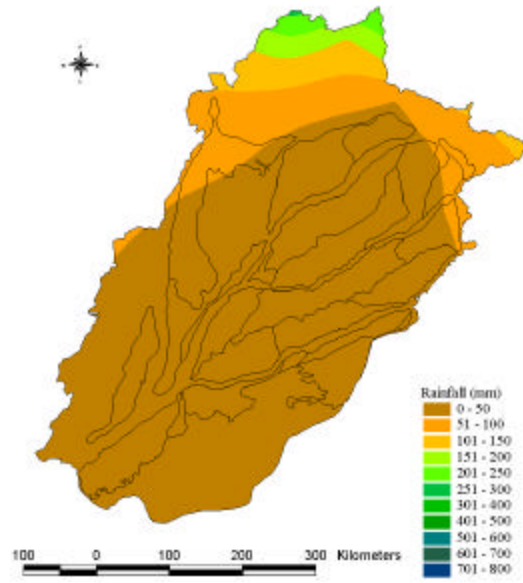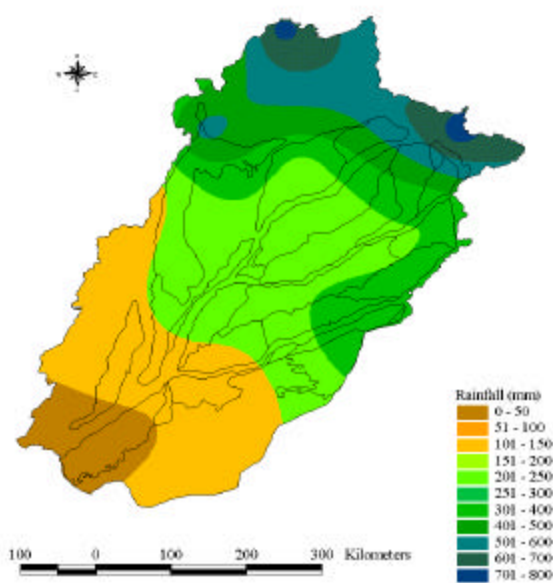
Ground Water

For the estimation of ground water, tubewell density data collected at the district level (Agriculture Machinery Census 1994) and the utilization coefficients established by WAPDA are used. The data are transformed to the canal command level by overlaying the district and CCA maps (Habib et al. 1999). The estimated total ground water mining for the CCAs is 65 bcm from private and 6.8 bcm from public wells. The growth rate of tubewells and pumpage between 1986 and 1994 was 70 percent and 47 percent, respectively.

Following figures present the amount of water available from all three sources discussed above, for Kharif and Rabi seasons separately.

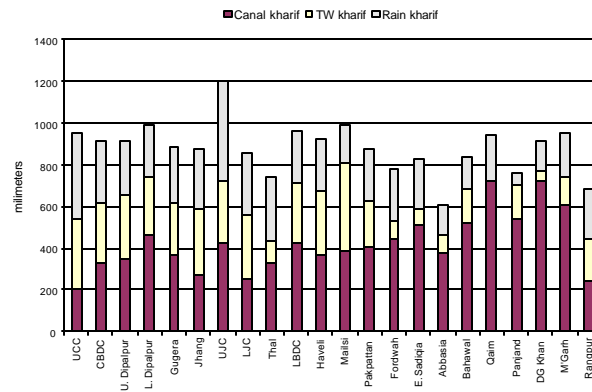Figure 3.4. Water availability in Punjab canal commands during Kharif 1993.

Figure 3.5. Water availability in Punjab canal commands during Rabi 1993-94.
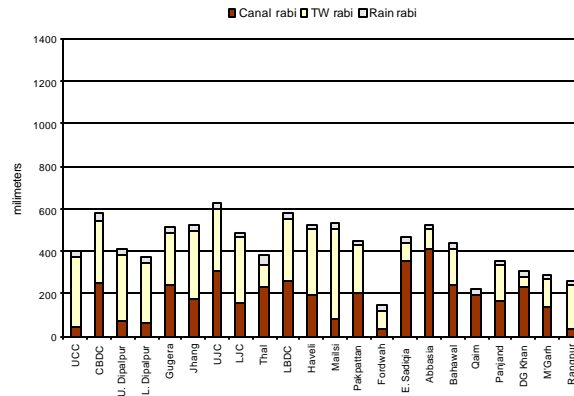
Table 3.2. Water availability in Punjab canal commands (all figures are in millimeters).

Canal Command	Kharif Season				Rabi Season			
	Canal water	Tubewell water	Rain	Total water	Canal water	Tubewell water	Rain	Total water
UCC	208	335	410	953	41	335	26	402
CBDC	327	294	295	916	249	294	36	580
Upper Dipalpur	349	311	255	915	71	311	25	407
Lower Dipalpur	464	280	250	994	64	280	25	369
LCC East (Gugera)	372	242	270	883	244	242	25	510
LCC West (Jhang)	273	316	284	872	179	316	25	520
Upper Jehlam	429	294	480	1203	309	294	25	627
Lower Jehlam	252	304	305	861	159	304	25	488
Thal	324	107	310	742	230	107	44	380
LBDC	426	292	250	968	262	292	25	579
Haveli	370	307	250	926	194	307	25	526
Mailsi	389	422	183	993	83	422	25	530
Pakpattan	402	222	250	874	205	222	25	451
Fordwah	444	82	250	776	38	82	25	145
Eastern Sadiqia	508	83	240	831	357	83	25	465
Abbasia	375	89	145	609	411	89	25	525
Bahawal	520	167	150	837	243	167	25	436
Qaim	718	0	224	942	199	0	25	224
Panjand	536	163	65	764	168	163	25	357
DG Khan	727	48	138	913	233	48	25	306
Muzzafargarh	609	133	206	949	134	133	25	292
Rangpur	238	205	237	680	33	205	25	263

VARIATION IN GVP ACROSS CANAL COMMANDS

Estimation of Gross production Indicators

This section presents the estimated gross value of production per unit of land and water for crop seasons, Kharif and Rabi, separately. Aggregation of seasons leading to annual GVP per unit of land and water is, then, presented.

GVP per unit of land in Kharif and Rabi

Estimation of GVP per hectare of Culturable Command Area (CCA) and Cropped Area (CA) for Kharif season indicates that;

GVP per unit of CCA varies with a ratio of 1:10 (Rs. 1,451 per hectare to Rs. 13,836 per hectare), and

GVP per unit of CA varies with a ratio of about 1:4 (Rs. 4,368 per hectare to Rs. 15,649 per hectare).

Figure 4.1 reveals two inferences in this regard. (i) Canal commands are terribly heterogeneous regarding land productivity in Kharif season. This leads to scrutinize the relationship between GVP per unit land and water availability in this season. (ii) Big difference between GVP per hectare of CCA and GVP per hectare of CA indicates under utilization of land in some canal command. It leads to analyze the relationship between land use (cropping intensity) and availability of water in these canal commands.

Figure 4.1.   GVP per unit of land in Kharif season.
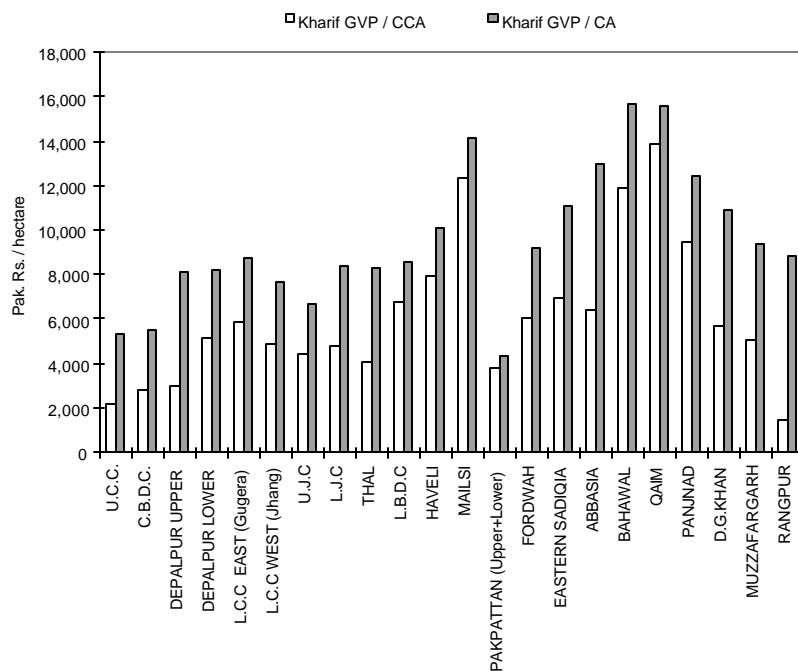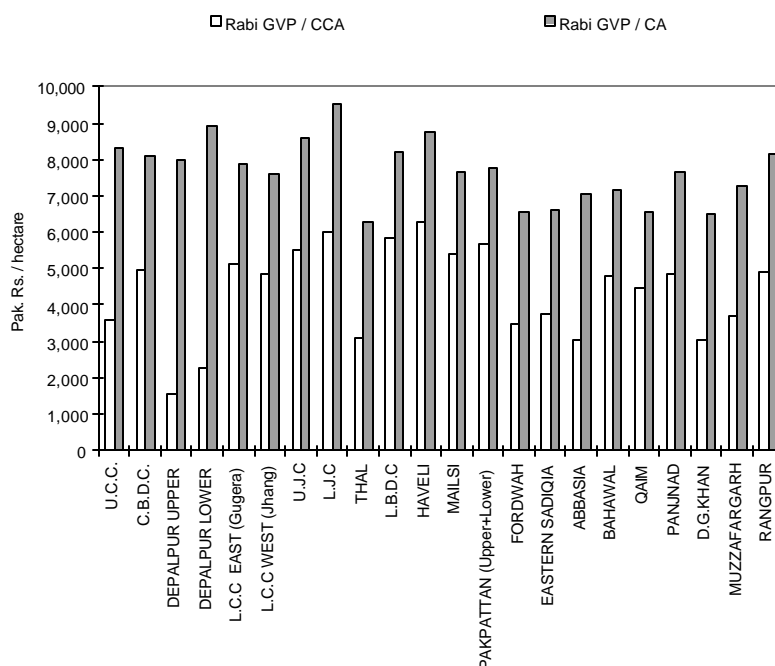

In Rabi season;
GVP per unit of CCA varies with a ratio of 1:4 (Rs. 1,566 per hectare to Rs. 6,258 per hectare), and

GVP per unit of CA varies with a ratio of about 1:2 (Rs. 6,251 per hectare to Rs. 9,503 per hectare). See figure 4.2. In case of Rabi, differences between GVP per hectare of CCA and CA are even greater. It indicates that large parcels of culturable land are kept fallow in Rabi season.

Uniformity of canal commands for GVP per hectare of CA in Rabi leads to analyze its relationship with cropping pattern. Rabi season accommodates one major crop, which is wheat supported by

controlled pricing policy of the government. While Kharif season comprises on various cash crops, their values drastically different from each other. This analysis is presented in section 4.2.

Figure 4.2.   GVP per unit of land in Rabi season.

GVP per unit of water in Kharif and Rabi

Estimations of GVP per cubic meter of water available from all sources for Kharif and Rabi seasons, separately, provide interesting information;

- In Kharif season; GVP per unit of water varies with a ratio of 1:6 (Rs. 0.21 per cubic meter to Rs. 1.47 per cubic meter), and

- In Rabi season; GVP per unit of water varies with a ratio of 1:6 (Rs. 0.39 per cubic meter to Rs. 2.41 per cubic meter). See figure 4.3.

It infers that productivity of water is higher in Rabi season as compared to Kharif season. This is contrary to productivity of land. As indicated above, productivity of land is higher is Kharif season than Rabi.

Aggregate figures for Punjab province also strengthen this finding.

|	
Total land available in Punjab canal commands (CCA)	8.43 Mha
Total water available at watercourse head from all sources in kharif	76 bcm
Total water available at watercourse head from all sources in rabi	39 bcm
Total GVP in kharif	49 billion rupees
Total GVP in rabi	39 billion rupees
Per hectare GVP in kharif	5,752 rupees
Per hectare GVP in rabi	4,564 rupees
Per cubic meter GVP in kharif	0.64 rupee
Per cubic meter GVP in rabi	1.00 rupee

Figure 4.3. GVP per unit of water in Kharif and Rabi seasons.

Kharif GVP / Total Water   **Rabi GVP / Total Water**
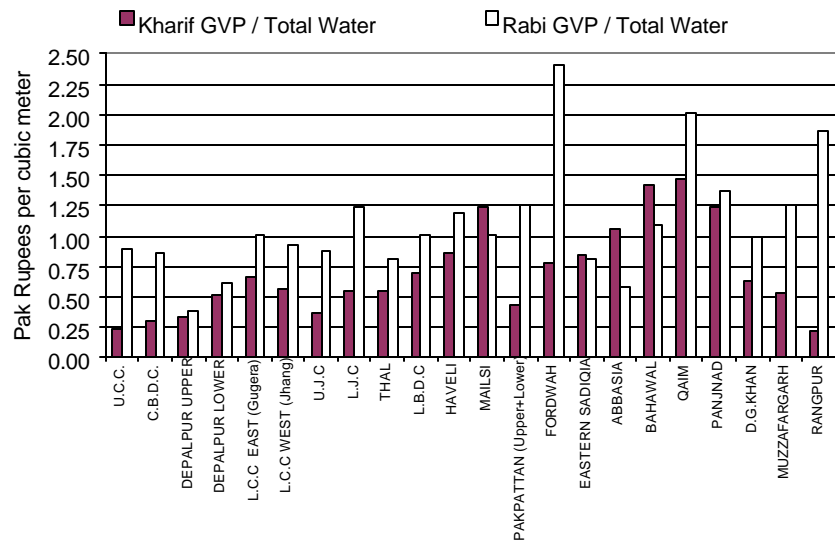
Annual GVP per unit of land and water

Figure 4.4 shows that GVP per unit of CCA among 23 canal of Punjab varies with a ratio of about 1:5 (Rs. 3,844 per hectare to Rs. 18,326 per hectare). GVP per unit of water available varies with a ratio of 1:5 (Rs. 0.35 per cubic meter to Rs. 1.57 per cubic meter).

Figure 4.4. Annual GVP per unit land and water in Punjab, year 1993-94.

GVP / CCA   GVP / Total Water
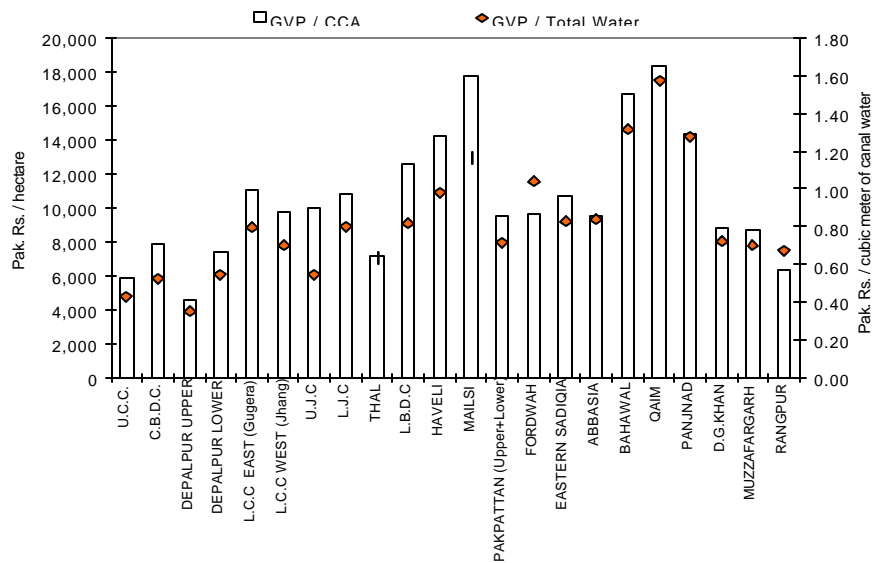
GVP, Cropping intensity and cropping pattern

Cropping intensity, water availability and GVP

Cropping intensity represents the utilization of land, which could be influenced by water availability and land quality. One can see huge variation in cropping intensities across canal commands (figure 4.5). It ranges from less than 60% to 160%, annually. The lower cropping intensities in Rabi as compared to Kharif support the factor, as Rabi is substantially dry with respect to rain and river water availability. In the arid to semi-arid climatic conditions of the Punjab, availability of fresh water is a critical determinant.

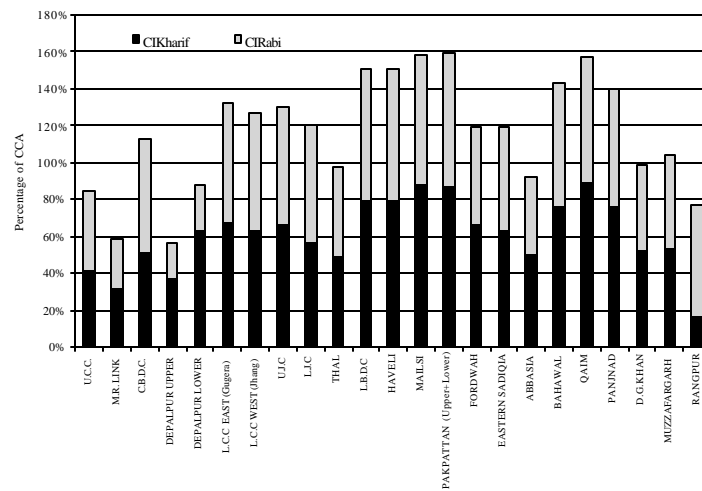Figure 4.5. Cropping intensity across Punjab.

Figure 4.6 shows that canal supplies influence cropping intensity. A positive relationship is found but scatter leads toward constant return at more than 700 mm canal water supplies. The influence is Abbasia, Muzaffargarh and Eastern Sadiqia canal commands. Although receiving extra canal water supplies, cropping intensity is significantly lower than others, which ultimately leads to low productivity of land and water.

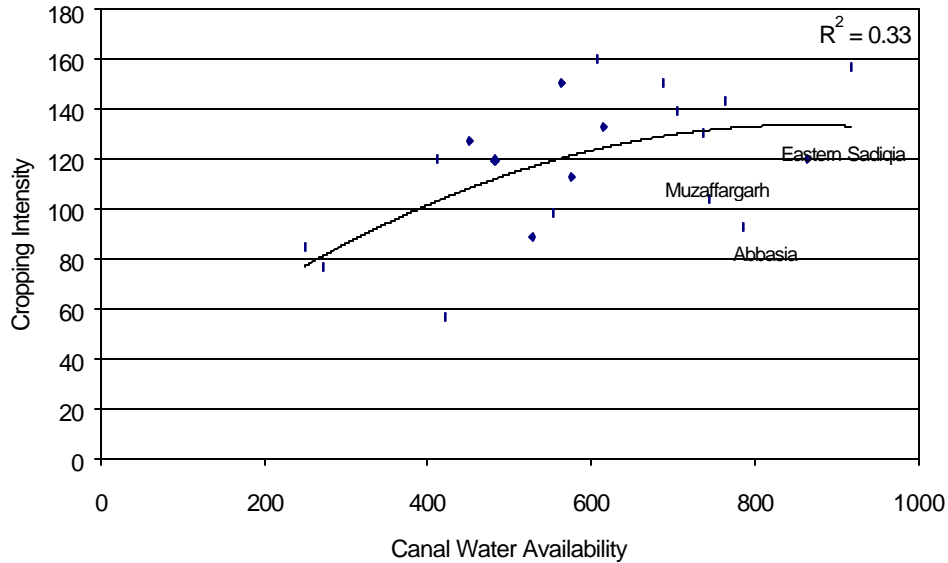Figure 4.6. Cropping intensity Vs Canal Water Availability.

Figure (4.7) shows the relationship between GVP and cropping intensity. The quadratic formed with zero intercepts considering the fact that GVP will be zero with zero cropping intensity. The equation concludes that 1- percent increase in cropping intensity contributes 66 rupees to GVP per hectare. More importantly, as the cropping intensity increases, GVP increases with a higher ratio, which is equal to 0.16 rupees. The equation explains around 68% variation in GVP (R-square = 68%).

Figure 4.7. GVP versus cropping intensity.
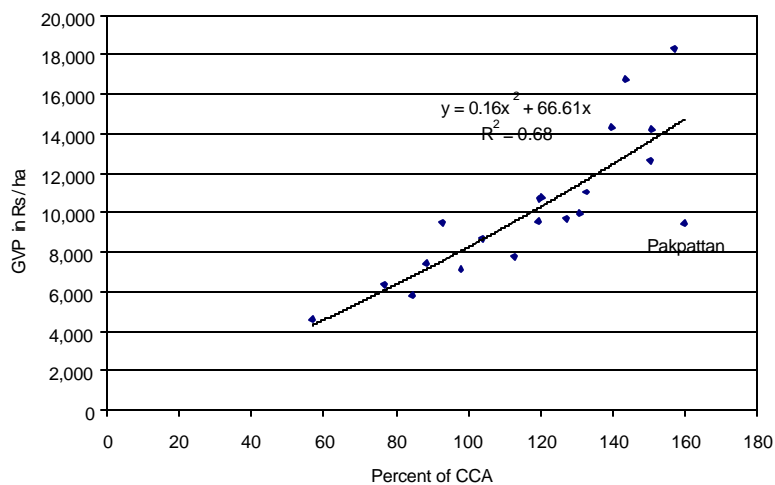
Cropping Pattern, water availability and GVP

In Punjab variety of crops are grown as mentioned in section 2 whose market values vary widely therefore causing variation in gross value of production. Wheat is the single major crop of Rabi season (table 4.1) while in Kharif there are only three crops i.e. rice, cotton and sugarcane (table 4.1). There are

certain areas, which traditionally grow cotton while some areas are specialized in rice due to agro-climatic conditions. Table 4.1 distinguishes these areas very evidently. Canal commands in southern Punjab are mainly cotton grown areas while northern and central part of the province is producing rice and sugarcane. Some area of the central Punjab such as Thal canal has mixed cropping pattern.

Table 4.1. Cropping Pattern in Punjab Canal Commands.

Canals	Sugarcane	Rice	Cotton	Kharif Others	Wheat	Rabi Others
U.C.C.	3%	58%	0%	39%	40%	60%
M.R. Link	2%	90%	0%	9%	24%	76%
C.B.D.C.	11%	17%	7%	65%	71%	29%
Depalpur Upper	12%	27%	12%	50%	75%	25%
Depalpur Lower	3%	14%	35%	48%	56%	44%
L.C.C East (Gugera)	18%	12%	12%	58%	68%	32%
L.C.C West (Jhang)	20%	15%	8%	58%	68%	32%
U.J.C	15%	36%	2%	47%	65%	35%
L.J.C	15%	10%	5%	71%	58%	42%
Thal	8%	4%	8%	80%	68%	32%
L.B.D.C	7%	8%	36%	49%	66%	34%
Haveli	2%	6%	49%	42%	65%	35%
Mailsi	1%	2%	82%	15%	80%	20%
Pakpattan (Upper+Lower)	4%	7%	63%	26%	80%	20%
Fordwah	5%	27%	36%	32%	77%	23%
Eastern Sadiqia	9%	6%	56%	28%	71%	29%
Abbasia	12%	3%	52%	33%	65%	35%
Bahawal	6%	5%	62%	27%	81%	19%
Qaim	2%	14%	69%	15%	83%	17%
Panjnad	6%	4%	61%	28%	72%	28%
D.G.Khan	2%	19%	53%	26%	82%	18%
Muzzafargarh	6%	9%	42%	43%	72%	28%
Rangpur	1%	12%	17%	70%	64%	36%

Study by WAPDA in 1979 (RAP 1979) divided Indus basin in 7 agro-climatic zones and Punjab into 4 zones i.e. Rice-Wheat, Sugarcane-Wheat, Cotton-Wheat and Mixed-Wheat. Table 4.1 reflects these zones. Canal commands without any major Kharif crop such as Thal and LJC represent Mixed-Wheat Zone.

As discussed before, though cropping pattern is not solely determined by water availability, water is one of the major determinants. Percentage of area under different crops in different canal commands is regressed on availability of canal water. The case of cotton is presented in figure 4.8. Higher canal water availability reflects higher area under cotton in Punjab.

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Figure 4.8. Area under cotton Vs canal water available in respective season (Kharif).
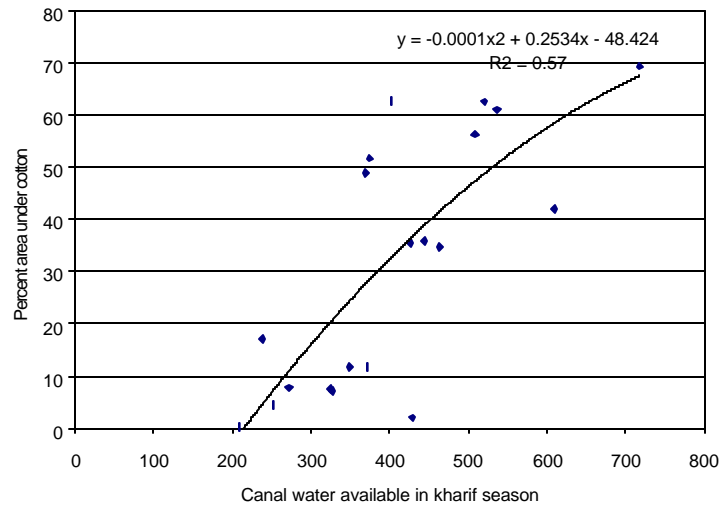
The influence of cropping pattern on GVP is explained in two ways. First, by comparing cotton and rice as substitute crops in Kharif season (figure 4.9). Second, by considering sugarcane as similar cash crop to cotton (figure 4.10). Graph shows strong positive influence of percent area under cotton on GVP. Higher areas under cotton crop reflect higher GVP while in case of rice this influence is negative. Rice growing canal commands reflect lower GVP.   Higher percent area under cash crops (cotton + sugarcane) shows higher GVP (figure 4.10).

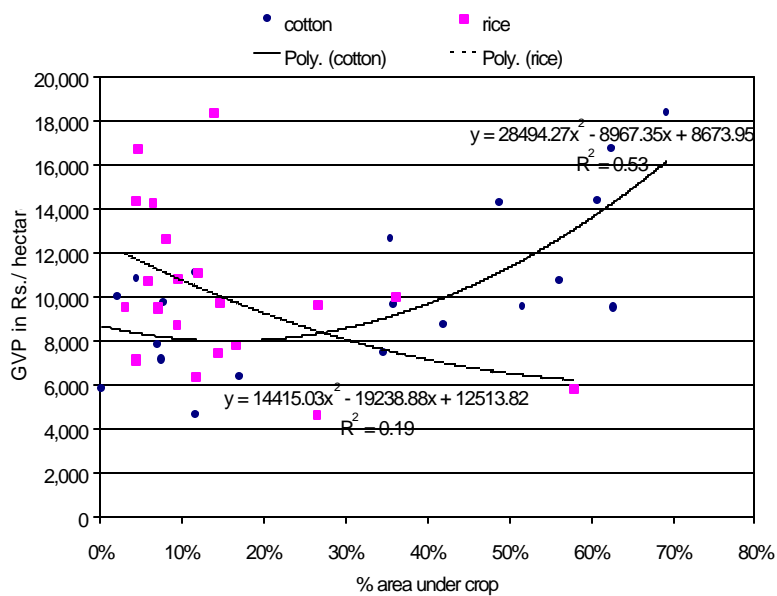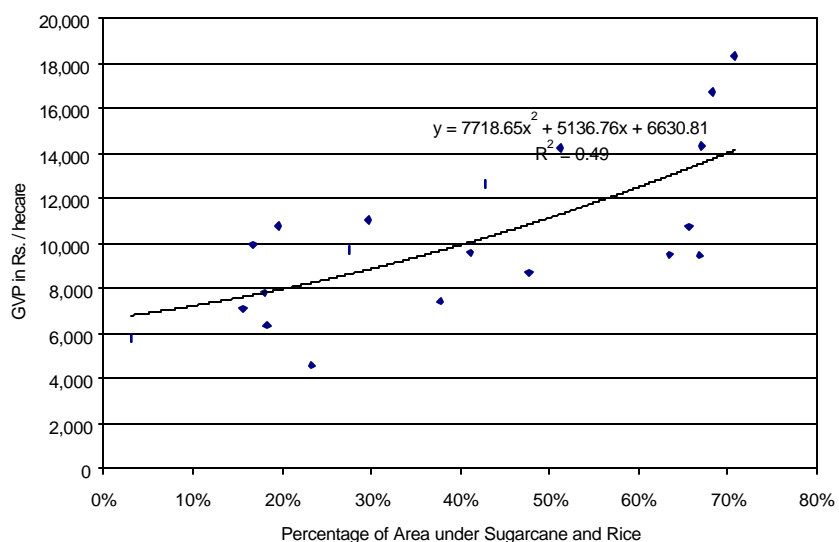Figure 4.9. GVP versus percentage area under cotton and rice.

Figure 4.10. GVP versus percent area under cash crops (cotton + sugarcane).

Chart: y-axis "GVP in Rs. / hecare" (0 to 20,000); x-axis "Percentage of Area under Sugarcane and Rice" (0% to 80%).

$$y = 7718.65x^2 + 5136.76x + 6630.81$$
$$R^2 = 0.49$$

GVP as a function of cropping intensity and cropping pattern

Multiple regression is also performed to see the combined effect of cropping intensity and cropping pattern. Regression model produced the following equation.

*GVP = -1269.57 + 78.22 * Cropping Intensity + 56.88 * Area Under Cash Crops*

Where cash crops are cotton and sugarcane. R-square statistics of the model is 0.73 and both variables are found at 95% level of significance. Equation shows that 1- percent increase in cropping intensity reflects 78 rupees of GVP per hectare. Further 1- percent increase in area under cotton and sugarcane augments 57 rupees from a hectare of CCA.

GVP and water availability

This section is split up into two subsections
GVP per unit of land and different sources of water
GVP per unit of water and different sources of water

GVP per unit of land and different sources of water

The water response to GVP is analyzed through the equation 2 (section 2). The quadratic model is found to be the best fit (higher R-Square and minimum sum of the squared residuals) for testing the relationship between gross production and water. Generally, surface water, ground water and rain are presumed as major explanatory variables for production. However, these variables are not independent of each other. Strong correlation exists among three sources of water (table 4.2 and figure 4.11).

Table 4.2. Correlation between water sources.

	R	P-Value
Canal water Vs Ground water	-0.65	0.0013
Canal water Vs Rain	-0.44	0.0460
Ground water Vs Rain	0.53	0.0136

Figure 4.11. Canal water availability versus ground water exploitation and rain.
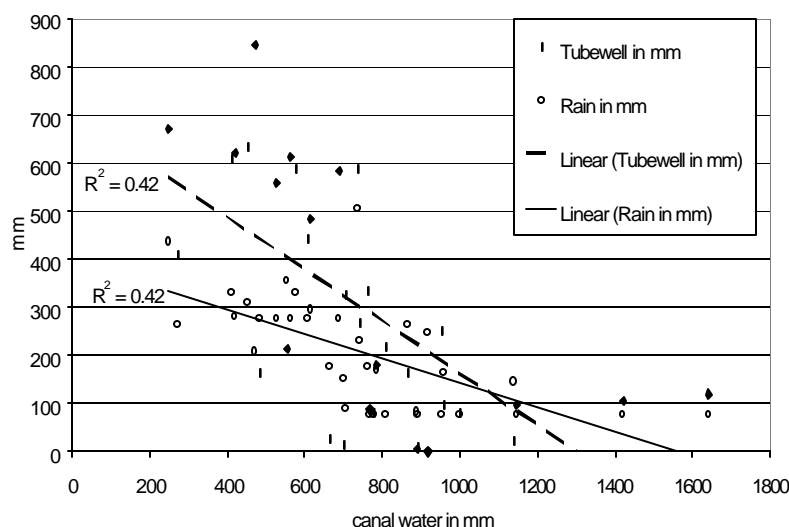
Since, the variables representing three waters are inter-linked, according to econometric criteria, these cannot be used in a single equation as independent variables. Therefore, simple regression equation is estimated.   Following matrix of relationships is constructed and estimated.   Only significant relationships are presented (95% level of significance). The matrix is followed by graphical presentation of significant relationships.

Table 4.3. Matrix of relationship between GVP per hectare of land and water.

	Canal Water	Ground Water	Rain
Annual GVP	$y = 0.01x^2 + 4.70x + 4705$ $R^2 = 0.44$	X	X
Kharif GVP	$y = -0.02x^2 + 35.07x - 4092$ $R^2 = 0.36$	X	X
Rabi GVP	X	$y = -0.02x^2 + 17.16x + 2395$ $R^2 = 0.71$	X

Matrix concludes that canal supplies mainly influence GVP per hectare in Kharif season while in Rabi season the same is explained by ground water.

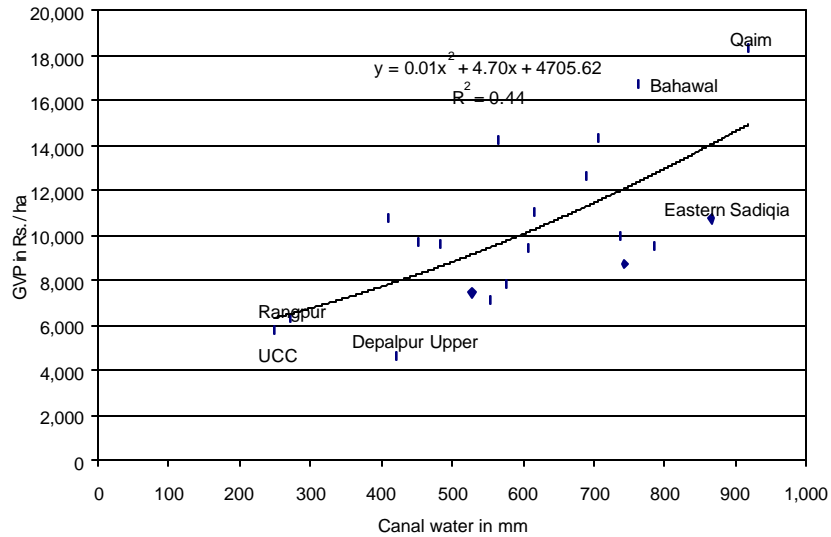Figure 4.12. GVP vs. canal water availability in Punjab, year 1993-94.

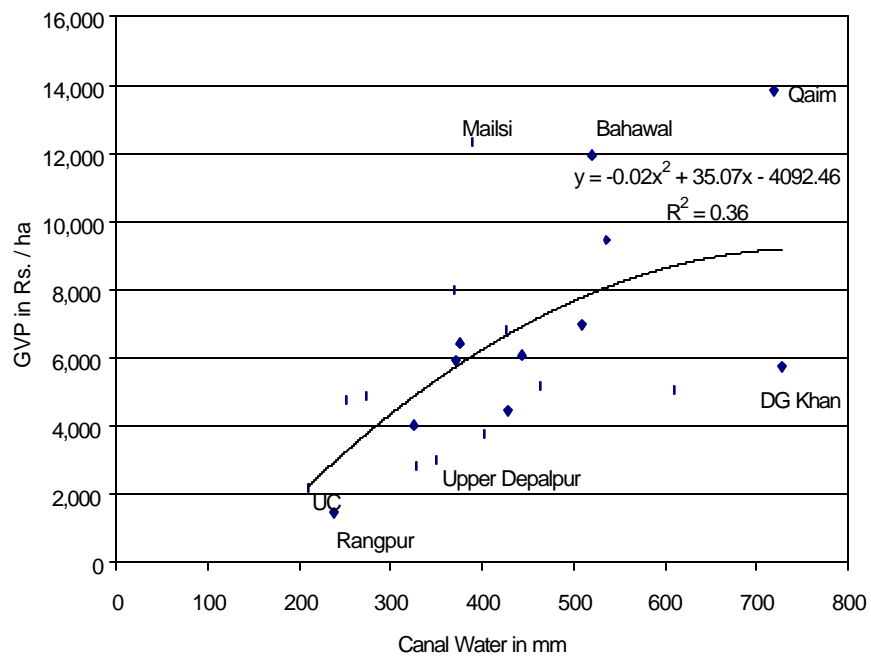Figure 4.13. GVP vs. Canal water availability in Punjab, Kharif season.

Figure 4.14. GVP vs. groundwater pumpage in Punjab, Rabi season.

$$y = -0.02x^2 + 17.16x + 2395.47$$
$$R^2 = 0.71$$
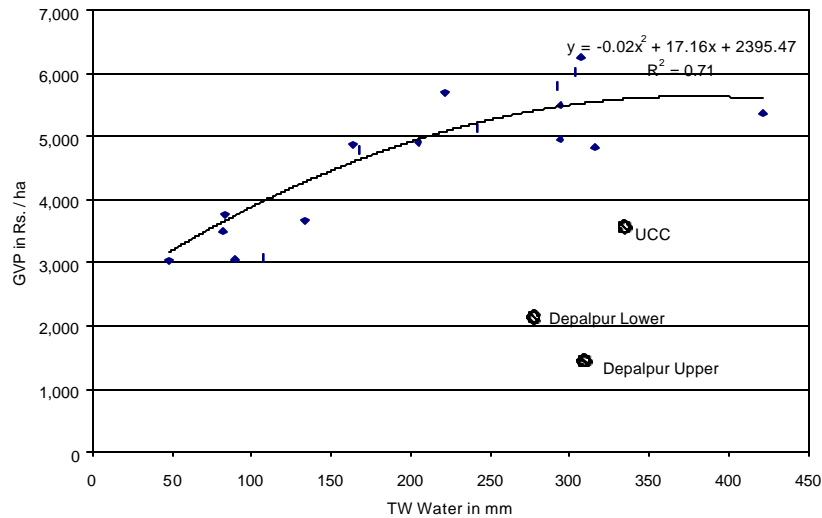
GVP per unit of water and different sources of water

To examine the share of different water sources in productivity of water, GVP per unit water is plotted against percent share of each water source. Figure 4.15 to figure 4.17 present this analysis. Kharif GVP as well as annual GVP of water is influenced by canal-water. Ground water in Kharif does not appear to have influential share in GVP. In case of Rabi season, rainfall appears to have influential share in gross production.

Figure 4.15. Kharif GVP per cubic meter of water versus share of canal water in total water availability.

Figure 4.16. Rabi GVP per cubic meter of water versus share of rain water in total water availability.
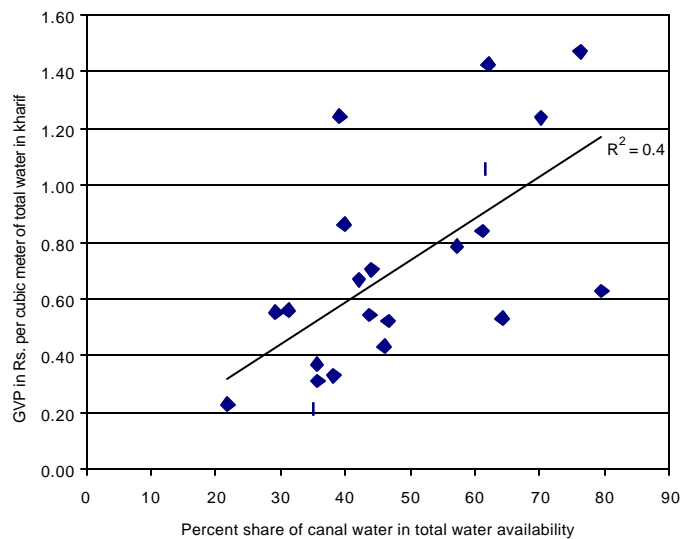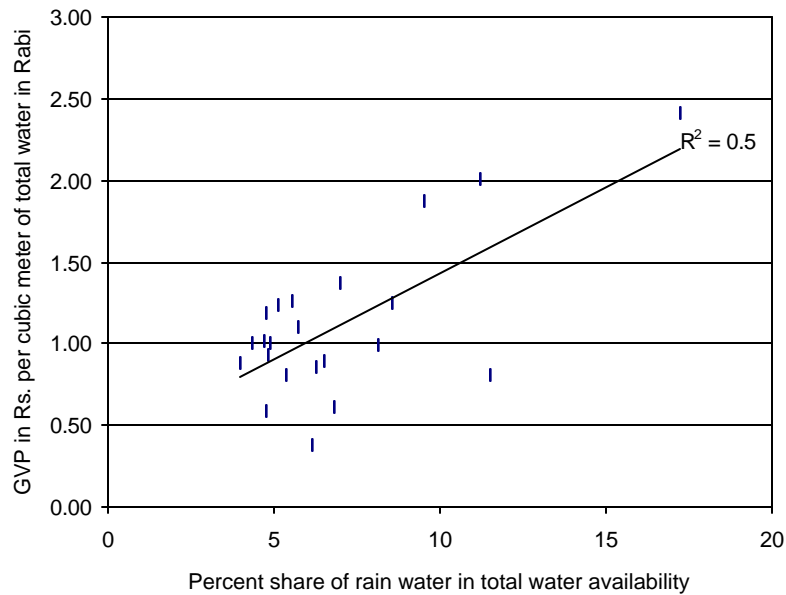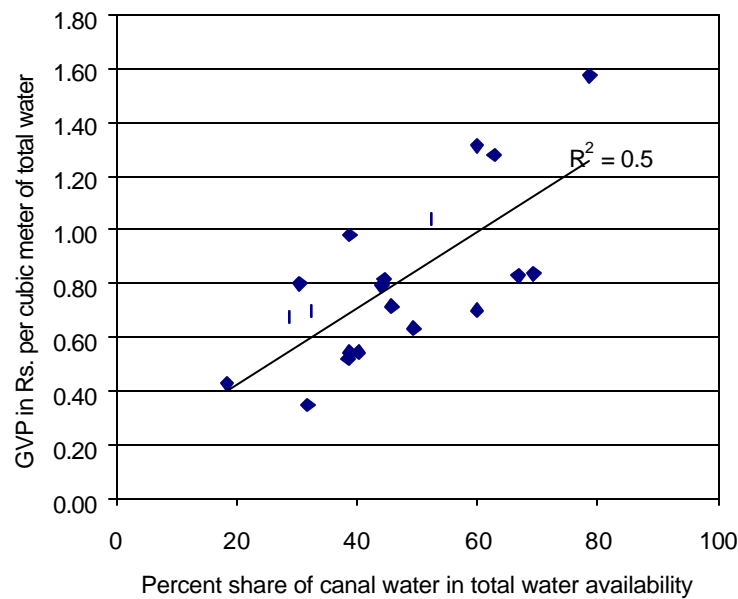

Figure 4.17. Annual GVP per cubic meter of water versus share of canal water in total water availability.

   To distinguish the canal systems having agriculture production based on canal water only from the canal systems with substantial contribution of ground water and rain, comparison of GVP per unit of total water and GVP per unit of canal water is made.

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Notice that for estimation of GVP per unit of canal water all the GVP is assigned to canal water. It is assumed that there is only canal water and total GVP is the response of canal water only. Figure 4.18 presents this comparison.

Figure 4.18. GVP per unit of total water and canal water.
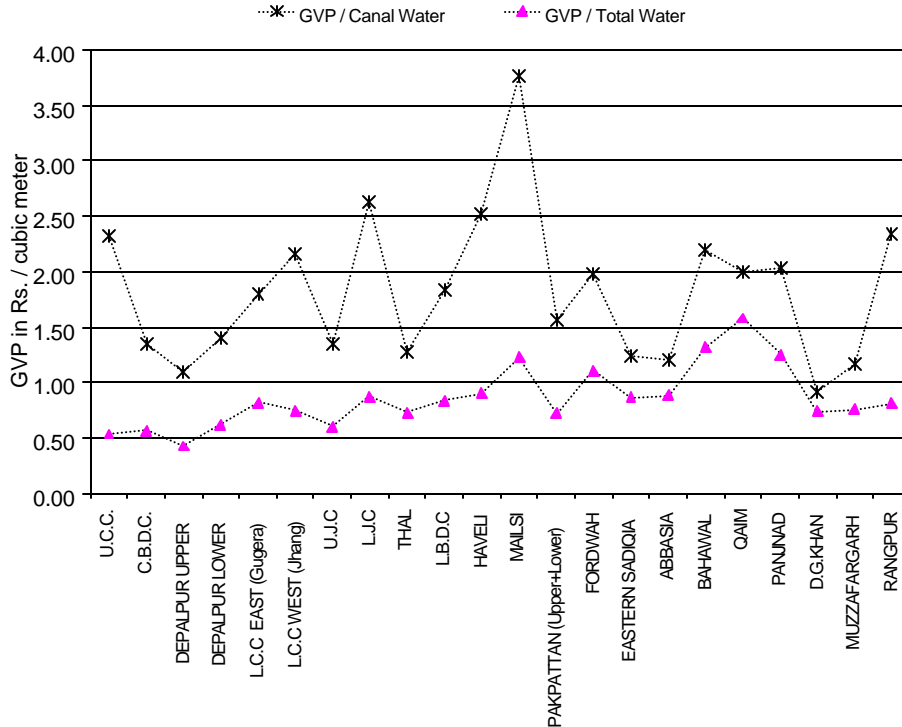
Canal commands like Thal, Eastern Sadiqia, Abbasia, DG Khan and Muzaffargarh show little gap between the GVP per unit of canal water and GVP per unit of total water, which implies the little use of ground water. Productivity of water, in general, is also on lower side in these systems, which is mainly the low productivity of canal water. It implies that either (i) these canals have extra canal water supplies, which are not used efficiently, or (ii) environmental problems, perhaps high depth to water table and poor ground water quality or both.

SUMMARY AND CONCLUSIONS

Summary of findings

Spatial variation in land and water productivity across canal commands is analyzed through gross production indicators (gross value of production per unit of land and water) by using secondary information. Secondary data was available at different levels e.g. canal commands, administrative districts and meteorological stations that was standardized at canal command level by using Geographic Information System. Relationship between cropping intensity, cropping pattern, gross value of production and water availability from different sources was estimated. Following are the major findings:

(i)   During this analysis, GIS application was developed and validated to convert district level (administrative unit) information into canal command (hydraulic unit) level. Punjab Province has 35 districts and 23 main canals (section 3.1.4 & Annex 2).

(ii)   A big variation in cropping intensities across Punjab canals is shown by the secondary data, ranging from less than 60% to 160%, annually.

(iii)   In Kharif season, GVP per unit of CCA varies with a ratio of 1:10 (Rs. 1,451 per hectare to Rs. 13,836 per hectare), and GVP per unit of CA varies with a ratio of about 1:4 (Rs. 4,368 per hectare to Rs. 15,649 per hectare).

(iv)   In Rabi season, GVP per unit of CCA varies with a ratio of 1:4 (Rs. 1,566 per hectare to Rs. 6,258 per hectare), and GVP per unit of CA varies with a ratio of about 1:2 (Rs. 6,251 per hectare to Rs. 9,503 per hectare).

(v)   In Kharif season, GVP per unit of water varies with a ratio of 1:6 (Rs. 0.21 per cubic meter to Rs. 1.47 per cubic meter).

(vi)   In Rabi season, GVP per unit of water varies with a ratio of 1:6 (Rs. 0.39 per cubic meter to Rs. 2.41 per cubic meter).

(vii)   Annual GVP per unit of CCA among 23 canal of Punjab varies with a ratio of about 1:5 (Rs. 3,844 per hectare to Rs. 18,326 per hectare).

(viii) Annual GVP per unit of water available varies with a ratio of 1:5 (Rs. 0.35 per cubic meter to Rs. 1.57 per cubic meter).

Values of GVP per unit land and water from secondary data are 15% different than indicated in Fordwah Canal command analysis using primary information (Habib et al. 2001). This is due to reporting constraints. However, secondary information could be used for comparison purpose.

(ix)   The Difference between GVP per culturable command area (CCA) and GVP per cropped area (CA) shows that large parcels of land are kept fallow in certain canal commands (mostly rice based). Productivity of water is also lower in these canal commands.

Cropping intensity and cropping pattern are two main contributors of gross value of production in canal commands. Areas growing sugarcane and cotton give higher GVP than areas of rice and other crops.

Ground water is the major source of water in certain canal command areas during Rabi season. Annual and Kharif GVP per unit of land are explained by canal water while annual and Rabi GVP are explained by ground water.

The quadratics equation shows that GVP increases at a higher rate with an increase in canal water. It indicates the importance of canal water supplies for agricultural production as a whole.

The production per unit of water in canal systems is lower than the expected values, though they have significant canal supplies. All of these canals have higher percentage of waterlogged areas.

Analysis does not find any relationship between gross value of production and perennial/non-perennial systems. Some perennial canal commands produce less than some non-perennial commands or vice versa.

Ground water exploitation has inverse relationship with canal water supplies and direct relationship with rainfall. It implies that more ground water is mined in those areas where canal water supplies are lower and where rainfall is high.

(x)   Some non-perennial canals e.g. Qaim, DG Khan and Muzaffargarh receive handsome amount of water from canal during Rabi season. Amount of water received is even higher than in some of the perennial canals.

Conclusions

(i)   Secondary information required for calculating GVP per unit of land and water is available at the office of different government agencies. However, this information is maintained at different scales. GIS tools can be used to reconcile this information efficiently.

(ii)   Though the GVP estimates from secondary information are relatively lower to estimates from primary information, however, secondary information could be used for comparison purpose.

(iii)   Production per unit of water and production per unit of land are generally low and quite diverse among canal systems. From the cropping system, cropping intensities and patterns are the main determining factors of gross production.

(iv)   Productivity of land is higher is Kharif season as compared to Rabi. However, in case of water productivity, the results are opposite. The efficient use of water is in Rabi season.

(v)   The analysis shows the importance of canal water as a primary source of water. The marginal productivity of canal water is higher in certain canal commands and increased supply to these canals augments the aggregate production.

(vi)   Analysis also shows the importance of secondary water source. The influence of ground water supplies is decisive in Rabi season. The ground water supply is the main factor determining the GVP in Rabi season. In fact, all sources of water, canal, ground and rain are integrated to a great extent. For instance, it is found that an extra amount of canal water will increase GVP but at the

same time it will reduce the exploitation of ground water. This may reduce the productivity of incremental water.

(vii)   Two indicators GVP per unit of land and GVP per unit of water provide overview of production as a response of resource use and may be used in defining reallocation strategy. However, any criteria developed for water reallocation requires the understanding of relationship between cropping pattern and physical environment, more precisely depth to water table and also the relationship between physical environment and GVP. Furthermore, inter-linked water sources need to be studied in a conjunctive way.

(viii)   An integrated utilization of canal and rain inflows and ground water extraction is taking place. A formal integrated water management is required, especially in view of excess canal supplies to some canal commands.

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ANNEX 1: THE INDUS BASIN IRRIGATION SYSTEM[5]

The Indus River System in Pakistan serves the world's largest contiguous irrigation network (16 mHa). The system comprises six major rivers, namely Kabul, the Indus, Jhelum, Chenab, Ravi and Sutlej. The Indus River is the largest of all these rivers and carries almost two-thirds of the annual river-flow in the system. Most of the river runoff occurs in the summer months of May-August. Nearly 80% of this runoff comes from snow and glacial melt. During August and September, the upper catchments of these rivers (mainly Jhelum, Chenab, Ravi and Sutlej) are hit by the *Monsoons,* bringing in lots of rain that may result in heavy floods.

The mean annual river runoff available in the system is 172 bcm, 83% of which is available during the six months April-to-September period. There are three major reservoirs in the system having a combined live storage capacity equal to 10% of the mean annual river-flow. There are 15 barrages and 45 main canals with discharge capacities ranging from 15 m^3/sec to 425 m^3/sec. In addition, there is a network of 14 inter-river link canals, having discharge capacities ranging from 142 to 624 m^3/sec, for transferring water from one river to another. The annual canal withdrawals in the system average 130 bcm with almost 65% of river water diverted during the *Kharif* season (April *thru* September) and the rest in the *Rabi* season (October *thru* March).

This complex irrigation network is mainly managed by three public sector organizations. At the national level, the Indus River System Authority (IRSA) looks after provincial interests by ensuring that each province gets its share of water in the light of the Water Apportionment Accord (WAA) of 1991. The Pakistan Water and Power Development Authority (WAPDA) is responsible for the operation of reservoirs for irrigation water supply, hydropower generation and flood mitigation. The Provincial Irrigation Departments (PIDs) regulate and distribute the water diverted from the rivers to agricultural farms through a network of canals. The early *Kharif* period (April-June) is the most critical period when irrigation water demands to sow of *Kharif* crop are high; the reservoirs nearly empty after providing for the winter crop, and the spring freshet has yet to commence. This is the period when conflicts regarding the sharing of irrigation water arise between the provinces.

Rainfall and groundwater are also important contributors towards irrigation in the Indus Basin Irrigation System (IBIS). The rainfall in Pakistan is markedly variable in magnitude, time of occurrence and in its areal distribution. However, most of the rainfall (almost two-thirds) is concentrated in the three summer months of July−September. The mean annual precipitation ranges from less than 100 mm in parts of the Lower Indus Plain (Sind Province) to over 800 mm in the Upper Indus Plain near the foothills. There are two major sources of rainfall in Pakistan, the Monsoon Winds (July *thru* September) and the Western Disturbances (December *thru* March). The Indus Plains receive most of their rainfall from the Monsoons. In the last 25−30 years, ground water has become a major supplement to canal supplies especially in the Upper Indus Plain (Punjab Province) where ground water quality is good. Groundwater

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[5] Khan 1999

resources of Pakistan existing in the Indus Plains, extending from the Himalayan foothills to the Arabian Sea, are stored in the alluvial deposits. Major part of groundwater abstraction for irrigation is within the canal commands or in the flood plains of the rivers. The groundwater pumpage for the Indus Basin canal commands is estimated to be over 50 bcm.

ANNEX 2: PERCENTAGE OF DISTRICT AREAS FALLING IN PUNJAB CANALS

Distt. ID	District Name	Canal ID	Canal Name	District Area in Canal (sq. meters)l	Total District Area (sq. meters)	District area percentage in CC
2.00	Gujranwala	1	Upper Chenab Canal	2134339000	3433773000	62.16
3.00	Hafizabad	1	Upper Chenab Canal	51528060	2367511000	2.18
4.00	Sheikhupura	1	Upper Chenab Canal	2027630000	6115865000	33.15
1.00	Sialkot	2	Marala Ravi Canal	524410300	3702319000	14.16
4.00	Sheikhupura	2	Marala Ravi Canal	118798100	6115865000	1.94
6.00	Lahore	3	Central Bari Doab Canal	1046336000	1457728000	71.78
21.00	Kasur	3	Central Bari Doab Canal	2074052000	4410471000	47.03
21.00	Kasur	4	Upper Dipalpur Canal	1331660000	4410471000	30.19
22.00	Okara	4	Upper Dipalpur Canal	375419000	4167336000	9.01
22.00	Okara	5	Lower Dipalpur Canal	1600235000	4167336000	38.40
23.00	Sahiwal	5	Lower Dipalpur Canal	291257100	5623143000	5.18
26.00	Pakpattan	5	Lower Dipalpur Canal	556463200	1013199000	54.92
1.00	Sialkot	6	Raya Branch (BRBD Inetranl)	119816900	3702319000	3.24
2.00	Gujranwala	6	Raya Branch (BRBD Inetranl)	295098400	3433773000	8.59
4.00	Sheikhupura	6	Raya Branch (BRBD Inetranl)	1352154000	6115865000	22.11
3.00	Hafizabad	7	Gugera	173246500	2367511000	7.32
4.00	Sheikhupura	7	Gugera	1533336000	6115865000	25.07
7.00	Faisalabad	7	Gugera	3264439000	5252541000	62.15
8.00	T.T. Singh	7	Gugera	2057898000	3160077000	65.12
2.00	Gujranwala	8	Jhang	137997400	3433773000	4.02
3.00	Hafizabad	8	Jhang	1439103000	2367511000	60.79
4.00	Sheikhupura	8	Jhang	633103600	6115865000	10.35
7.00	Faisalabad	8	Jhang	1932489000	5252541000	36.79
8.00	T.T. Singh	8	Jhang	1053882000	3160077000	33.35
9.00	Jhang	8	Jhang	2855436000	8916454000	32.02
2.00	Gujranwala	9	Upper Jehlum Canal	83489810	3433773000	2.43
10.00	Gujrat	9	Upper Jehlum Canal	283733000	2740865000	10.35
11.00	Sargodha	9	Upper Jehlum Canal	124228600	5912901000	2.10
12.00	M.B. Din	9	Upper Jehlum Canal	2156162000	2943098000	73.26
9.00	Jhang	10	Lower Jehlum Canal	1664667000	8916454000	18.67
11.00	Sargodha	10	Lower Jehlum Canal	5067048000	5912901000	85.69
12.00	M.B. Din	10	Lower Jehlum Canal	230437500	2943098000	7.83
13.00	Mianwali	11	Thal Canal	1606651000	5573883000	28.82
14.00	M.Garh	11	Thal Canal	1399381000	8266734000	16.93
15.00	Layyah	11	Thal Canal	2896975000	5709921000	50.74
16.00	Khushab	11	Thal Canal	1776902000	6639989000	26.76

Distt. ID	District Name	Canal ID	Canal Name	District Area in Canal (sq. meters)l	Total District Area (sq. meters)	District area percentage in CC
17.00	Bhakkar	11	Thal Canal	3105628000	7976002000	38.94
21.00	Kasur	13	Lower Bari Doab Canal	174617300	4410471000	3.96
22.00	Okara	13	Lower Bari Doab Canal	1759900000	4167336000	42.23
23.00	Sahiwal	13	Lower Bari Doab Canal	2886596000	5623143000	51.33
26.00	Pakpattan	13	Lower Bari Doab Canal	123883600	1013199000	12.23
27.00	Khanewal	13	Lower Bari Doab Canal	2493558000	4252671000	58.64
28.00	Vehari	13	Lower Bari Doab Canal	80008480	3486164000	2.30
28.00	Vehari	13	Lower Bari Doab Canal	37206860	3486164000	1.07
9.00	Jhang	14	Haveli Canal	415471200	8916454000	4.66
27.00	Khanewal	14	Haveli Canal	149462400	4252671000	3.51
24.00	Multan	15	Mailsi Canal (Lower Mailsi+Lower Pakpattan)	968038600	3935249000	24.60
25.00	Lodhran	15	Mailsi Canal (Lower Mailsi+Lower Pakpattan)	2301898000	2390247000	96.30
28.00	Vehari	15	Mailsi Canal (Lower Mailsi+Lower Pakpattan)	956406100	3486164000	27.43
22.00	Okara	16	Pakpattan Canal (UP+UB+UM)	140640100	4167336000	3.37
23.00	Sahiwal	16	Pakpattan Canal (UP+UB+UM)	1674480000	5623143000	29.78
26.00	Pakpattan	16	Pakpattan Canal (UP+UB+UM)	272928800	1013199000	26.94
27.00	Khanewal	16	Pakpattan Canal (UP+UB+UM)	65334530	4252671000	1.54
28.00	Vehari	16	Pakpattan Canal (UP+UB+UM)	2219128000	3486164000	63.66
20.00	B-Nagar	17	Fordwah	1963040000	8463031000	23.20
20.00	B-Nagar	18	Sadiqia Canal	147661300	8463031000	1.74
20.00	B-Nagar	18	Sadiqia Canal	3710224000	8463031000	43.84
29.00	Bahawalpur	18	Sadiqia Canal	745924300	25815350000	2.89
29.00	Bahawalpur	19	Abbasia Canal	264104000	25815350000	1.02
30.00	R. Y. Khan	19	Abbasia Canal	382130800	11712210000	3.26
29.00	Bahawalpur	20	Bahawal Canal	3250886000	25815350000	12.59
29.00	Bahawalpur	21	Qaim Canal	434778100	25815350000	1.68
30.00	R. Y. Khan	22	Panjnad Canal	5767079000	11712210000	49.24
18.00	D. G. Khan	23	Dera Ghazi Khan Canal	1532170000	11037450000	13.88
19.00	Rajanpur	23	Dera Ghazi Khan Canal	2461103000	12240520000	20.11
14.00	M.Garh	24	Muzffgarh Canal	3115875000	8266734000	37.69
9.00	Jhang	25	Rangpur Canal	754068800	8916454000	8.46
14.00	M.Garh	25	Rangpur Canal	693270900	8266734000	8.39
15.00	Layyah	25	Rangpur Canal	125473800	5709921000	2.20
24.00	Multan	26	Sidhnai Canal	2338101000	3935249000	59.41
27.00	Khanewal	26	Sidhnai Canal	1085016000	4252671000	25.51

ANNEX 3: YIELD OF MAJOR CROPS

Average yields of four major crops are presented in the following figures. Although there is variation in yields for each crop, in case of cotton crop variation is huge. Canal command areas of southern Punjab (known as cotton-belt) have higher crop yield.
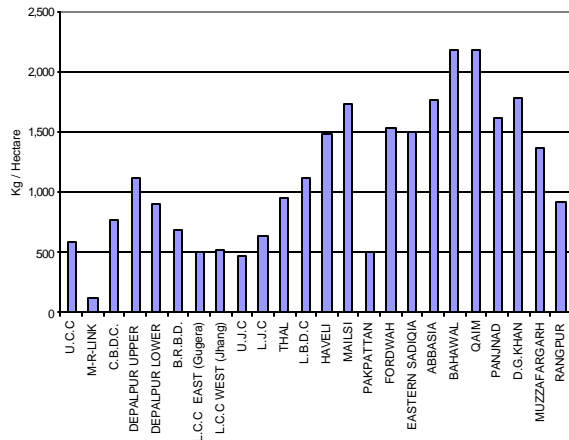
Figure A3. Cotton yield across Punjab.

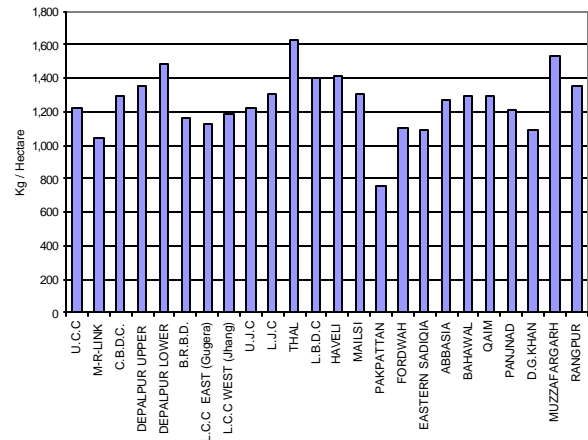Figure A3.2. Rice yield across Punjab.
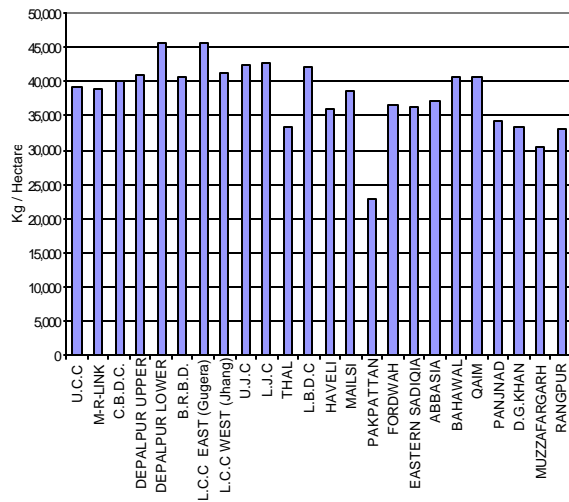

Figure A3.3. Sugarcane yield across Punjab.

Figure A3.4. Wheat yield across Punjab.

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