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Spatial Distribution of References and Potentia Evapotranspiration

A Study Across Indus Basin Irrigation Systems

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IWMI
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International Water Management Institute Lahore

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ABBREVIATIONS

bcm	Billion Cubic Meters
CCA	Culturable Command Area
CRBC	Chashma Right Bank Canal
CWD	Crop Water Demand
^{o}C	Degree Celsius
ET_o	Reference Evapotranspiration
FAO	Food and Agriculture Organization
GIS	Geographical Information System
GOP	Government of Pakistan
Ha	Hectare(s)
IBIS	Indus Basin Irrigation System
K_c	Crop Co-efficient
LAI	Leaf Area Index
LIP	Lower Indus Project
Mm^3	Million cubic meter
mm	Millimeter(s)
Mha	Million hectares
NWFP	North West Frontier Province
OFWM	On-Form Water Management
PARC	Pakistan Agriculture Research Council
PE	Potential Evapotranspiration
PID	Provincial Irrigation Department
PMD	Pakistan Meteorological Department
PPSGDPC	Punjab Private Sector Groundwater Development Project Consultants
PWP	Pakistan Water Partnership
RAP	Revised Action Program
WAPDA	Water And Power Development Authority

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ABSTRACT

Agriculture is the largest user of water in Pakistan. During the last fifty years, water used for irrigation has substantially increased due to increased cropping intensities. Spatial and temporal estimation of potential water requirements for agriculture will permit to assess the expected level of water stress. It will help in improved planning, allocation of water resources and sustainable groundwater management. The variation in climate at the regional scale effects the selection of crop and the evaporative needs of crops. Based on these variations of climate and crops with respect to their culture, intensity and patterns, Indus basin has been divided into three agro-ecological and seven agro-climatic zones. Some of agro-climatic zones exhibit different cropping pattern and crop periods within the zone. To accommodate significant variations in cropping pattern and periods within agro-climatic zones, this study divides all main canal commands of Indus into 11 groups.

The reference evapotranspiration is estimated at different stations by using Penman Montieth equation. The spatial variability of ET_o across the canal commands is accumulated using GIS. The upper and northeastern part of the basin has lower reference evapotranspiration (1200-1300 mm) because of mild climate, whereas, the lower part of the basin, Southern Punjab and Sindh have much higher ET_o values (1700-2100 mm). It has also been observed that ET_o is maximum in the month of June and minimum in December. The computation of TAM consultants for CRBC and IWMI using Penman are quite close though different climatic data sets are used for the calculations. A bigger difference is shown by Penman (IWMI 2000) with Delta II model (SPMP, 1988) and Priestley method (Bastiaanssen, 98), respectively 11 and 19 percent. The variation of reference evapotranspiration along with different land forms results in diversified agriculture with respect to cropping pattern and crop period. For developing crop co-efficient curve for different crops, periods of planting and harvesting, crop duration and crop growth stages are determined on the basis of primary and secondary information about cropping practices across the basin. For the major crops, planting and harvesting period extends for 2-4 weeks.

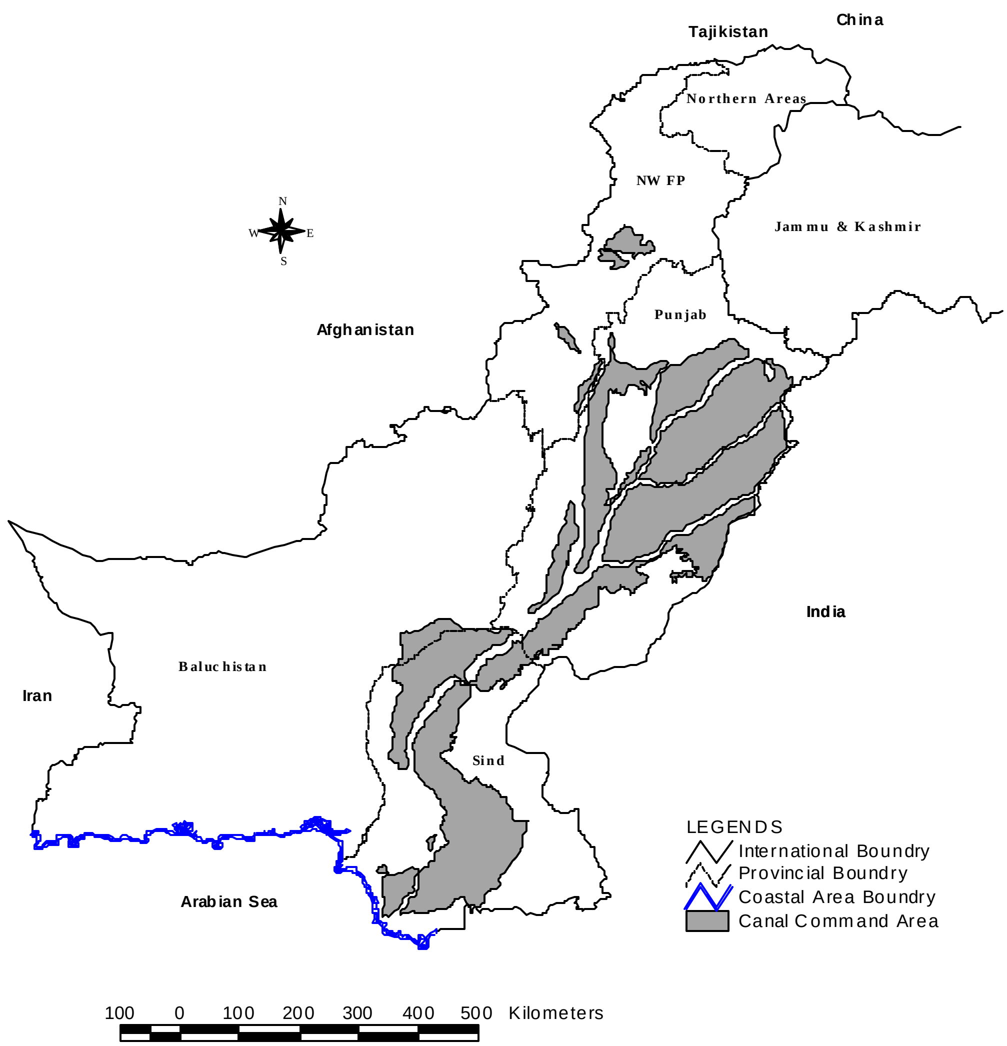
The potential water requirements of Rabi crops are in the same range of 240 mm to 462 mm. Whereas Kharif crops have quite variable requirements, 341 mm to 1004 mm. The spatial variation in potential evapotranspiration of different crops is from 14 to 50 percent in the basin The 10-daily water requirements of fully cultivated 1000 ha with existing cropping patterns show that water demand of lower Indus is about 50% higher than the upper Indus. Despite of a scatter in peak demand, the higher and lower water demand periods do not show a big shift across the Indus.

INTRODUCTION

Background

Agriculture is the largest (97%) user of water in Pakistan. The water consumed by crops is one of the important elements of the hydrological cycle. An estimation of potential water requirements for agriculture will permit improved planning and allocation of water resources among the municipal, industrial, environmental and agricultural sectors. The spatial variation of potential crop demand should also be known for sustainable groundwater management and water allocation. Out of 80 million ha of total area of Pakistan only 31.7 Mha is suitable for agriculture or forestry. Approximately 20.8 Mha is cultivated, of which 80% is irrigated as shown in Figure 1.1.

Figure 1.1. Indus Basin Irrigation System.



The Indus Basin comprises of five large and many small tributaries. The total average river diversion for irrigation is 128 bcm and extended by small flood irrigated packets on small streams and delay action dams. However, these surface water supplies are inadequate to fully satisfy the irrigation water requirement (PWP, 1999). To some extent this deficiency is fulfilled by groundwater, which has variable potential across the system in terms of quality and quantity.

During the last fifty years, water for irrigation has substantially increased due to increased cropping intensities. The need for improved water management for appropriate use of irrigation water was expressed at different forums. Almost all the canals in Pakistan were developed with an aim to bring large area under irrigation. Thus irrigation projects were designed to divert excessive supplies during high runoff season and share the misery with other co-sharers, during the low runoff season. This left no choice, but to determine irrigation water requirements for scientific development of agriculture in the canal command (WAPDA, 1979).

The irrigation supplies do not meet the crop needs for better crop yield. The volume of water supply is not matched with the time pattern of crop needs. The aggregate shortage of water is estimated to be about 40 percent of crop potential consumptive use (Ahmad, 1988).

This information is essential because in many canal systems, there is a mismatch of water supplies to crop water requirement at the farm level thereby negatively affecting agriculture production. Farmers increasingly complain of the inflexibility in this system and demand a more flexible water regime, which allows water trading (PWP, 1999).

In addition, this information is essential for official and unofficial water rights transfers from agriculture to other uses because such transfers are limited to historical crop water use and help in regional allocation of irrigation water (PPSGDPC, 1998).

Hence, the assessment of crop water needs is not only required for better distribution of canal supplies, but also to synchronize demand-supply gap at the command area level for sustainable management of water resources.

In this context, the report computes different components of potential crop water demand at the canal command level in Indus Basin. Major contribution is update of water demand based on several years of climate data, which improves the estimation of reference evapotranspiration for developing refined crop coefficients based on the latest cropping patterns. The water demands of major crop and fully developed standard unit for each canal command is presented for direct comparisons and adjustments, if required.

The report is part of Indus Basin performance study, which aims to identify the scope for integrated land and water management by evaluating current practices to propose sustainable alternatives.

Objective of the Report

The objective of the report is to assess potential crop consumptive use at the main canal level by improving the estimation of reference evapotranspiration and crop coefficients using the latest and most comprehensive sets of data available in the Indus basin.

Data and Information Used in the Study

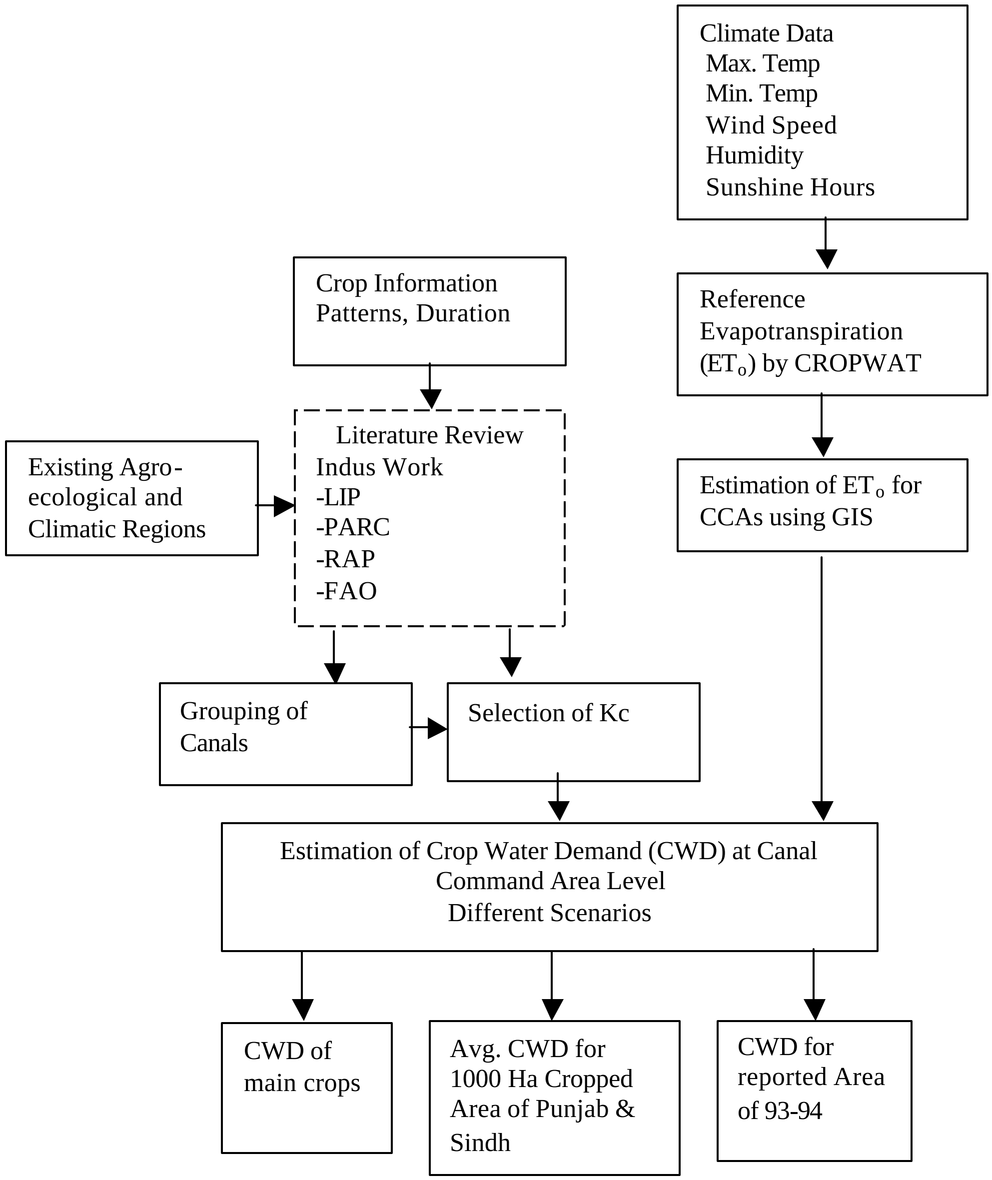
Crop data on the intensity and pattern during Rabi and Kharif at canal command level is collected from the provincial irrigation departments and processed for the computation of potential crop water demand.

Daily or weekly data of climatic variables is not available so mean monthly values for maximum and minimum temperature; wind speed, humidity and daily sunshine hours for a long period (20-25 years) were collected from Pakistan Meteorological Department (PMD). The crop duration, dates of planting and harvesting were determined on the basis of the agronomic character of different crops in Pakistan, IWMI's case studies and consultant studies in various locations of Pakistan.

The past work done by FAO, Pakistan Agriculture Research Council, Water and Power Development Authority (Lower Indus Project, Revised Action Program, Left Bank Outfall Drain and Chashma Right Bank Canal Irrigation Project), International Water Management Institute and different consultants have been reviewed for the selection of crop coefficient. The computational procedures are given in Figure 1.2. The analysis presented in the report is structured in the following order:

- *The presentation of spatio-temporal trends of climatic and crop data after reviewing agro-climatic zones in Pakistan and organizing canals into groups for further computations.*
- *Computation of reference evapotranspiration at canal command level and comparison with other studies to improve its estimation.*
- *Selection of crop coefficients and cropping periods based on the review of literature.*
- *Computation of potential crop water demand for different scenarios considering: I) major crops, II) actual cultivated area and III) fully cultivated 1000 ha. A comparison of these scenarios for different canal commands was made.*
- *Conclusions were drawn based on the above-mentioned activities.*

Figure 1.2. Flow Chart for the Computation of Crop Water Demand.



AGRO-ECOLOGICAL AND AGRO-CLIMATIC CHARACTERISTICS OF THE INDUS BASIN

Many factors influence water demand by plants and it may differ with locality and fluctuate from year to year. Mostly water demand is related to the natural influences of the environment and to the growth characteristics of the plants. More important natural influences are climate, water supply, crop culture, soils and topography. Indus basin extends from north to south and diversity of terrain, results in a diversity of climatic variables. Seasonal differences in climatic variables are also substantial. Based on variation in climate, water supply and crop culture, the Indus basin was divided into different ecological and agro-climatic zones, which are discussed in this chapter.

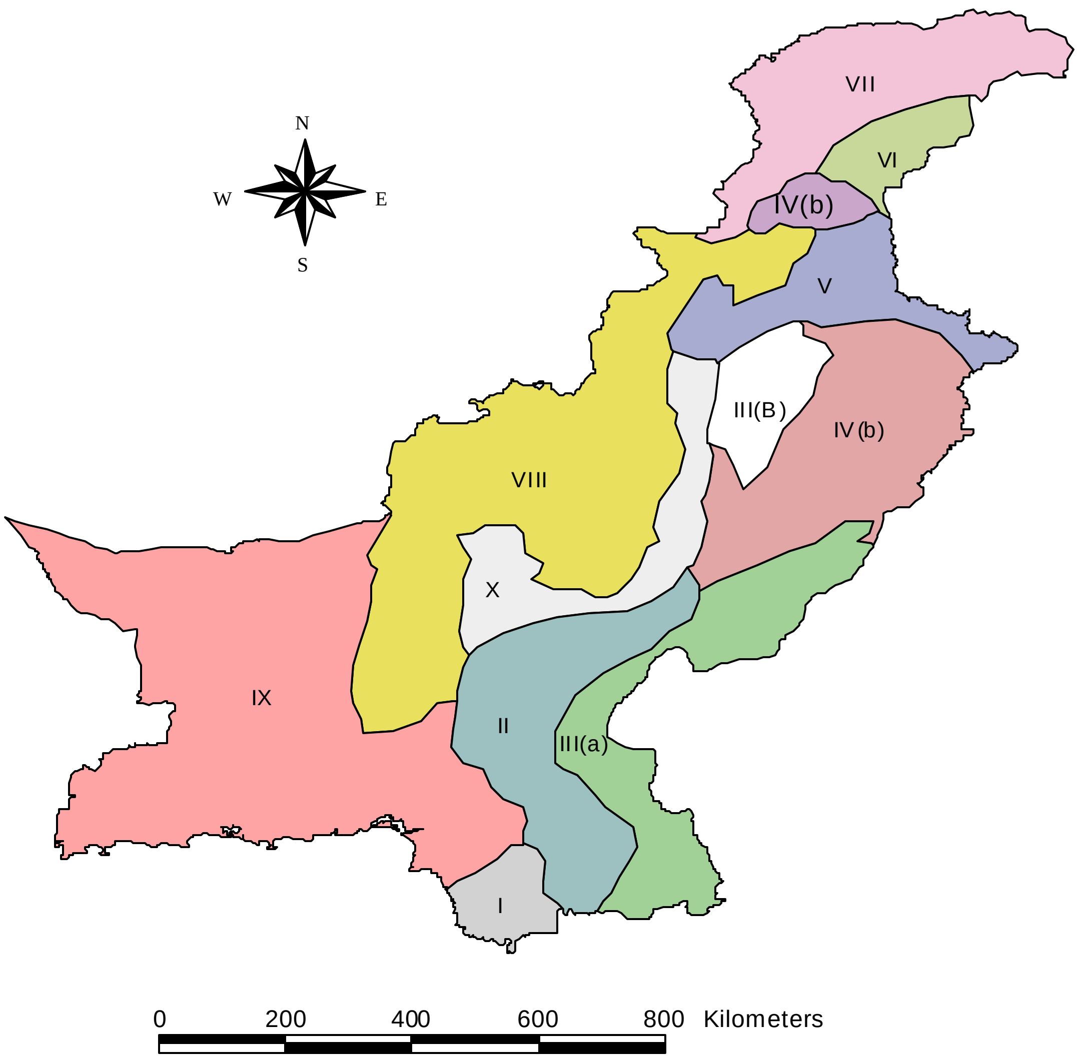
Agro-Ecological Zones of Pakistan

The use of land is governed by several interacting factors, which are physical, biological, social and economic in nature. A clear vision of these factors is essential for increased agricultural production in any given region. The Pakistan Agricultural Research Council in 1980 divided Pakistan in ten Agro-Ecological zones, based on a survey carried out by FAO and review of the available literature on physiography, climate, soils, land use and other factors affecting agriculture production, as shown in Figure 2.1 (OFWM, 1997). Details of these regions are given in Table A of Appendix I. It provides a basis for evolving crops varieties, cultural practices, type of animals and farm machinery, which would be most suitable to the conditions in any given agro-ecological zone. The information of agro-ecology also provides a basis for developing crop zoning for farming system. Zones VII, VIII and IX, which cover more than one-third area of Pakistan, consist of dry mountains and Plateau. The whole Indus Basin comprises of three agro-ecological zones (I, II, III).

Agro-Climatic Zones of the Indus Basin

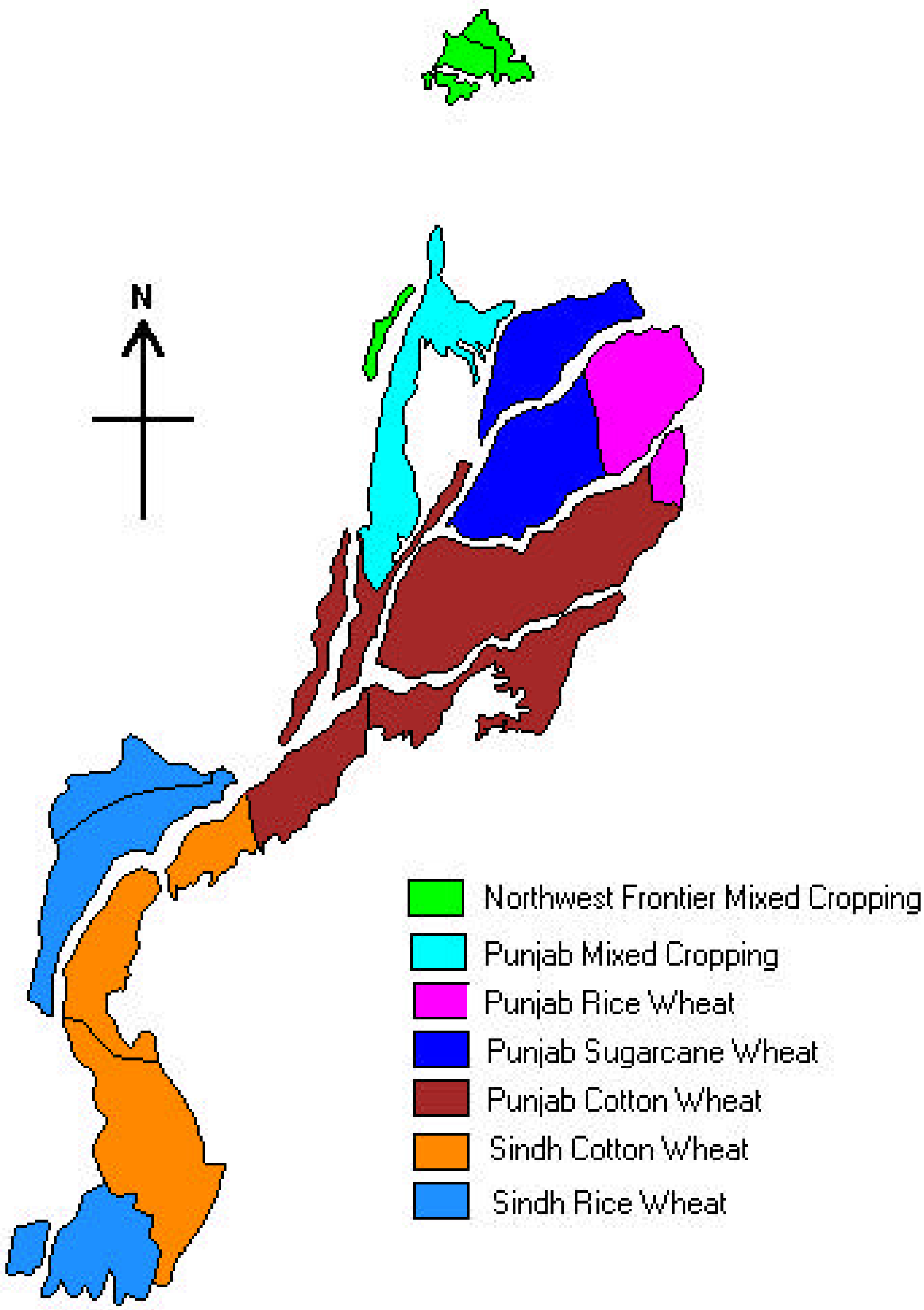
In 1979 WAPDA conducted a study for agricultural planning. In this study the irrigated areas of Indus Basin irrigation system were subdivided into seven agro-climatic zones taking into consideration the canal command boundaries, geographic location, climate and cropping pattern as shown in Figure 2.2. Some later study by WAPDA (1990) divided the Indus Basin into 9 agro-climatic regions. The characteristics of these regions are described in Box 2.1 of Appendix I.

Figure 2.1. Agro-Ecological Zones of Pakistan.



* For details see Appendix I.

Figure 2.2. Agro-Climatic Zones of Pakistan.



Climatic Variations in the Indus Basin

The variation in climate at regional scale effects the selection of crop and the evaporative needs of crops. The key climatic parameters used for the estimation of crop evapotranspiration demand are:

- *Temperature*
- *Humidity*
- *Wind Speed*
- *Sunshine Hours*

These parameters vary considerably from north to south of the Indus Plains. The climatic stations of Pakistan Meteorological Department (PMD) are spread all over the country. PMD is responsible for the operation and maintenance of all these stations. The climatic data from these stations is processed at PMD offices at Lahore and Karachi. The meteorological stations were selected with the objective of delineating spatial distribution of climatic parameters over the canal command area of the Indus Basin Irrigation System (IBIS). For computation purposes, monthly climatic data (maximum temperature, minimum temperature, humidity, wind speed, sunshine hours) from the selected seventeen stations was used. The spatial layout of these stations is shown in Figure 2.3.

Almost all-climatic parameters are available within the Indus Basin on long-term basis (20 to 30 years from 1960-1990). The data for different climatic factors is processed differently to meet the model requirement.

Temperature

Temperature plays an important role in the estimation of reference evapotranspiration. The variation in the maximum and minimum temperature in any area affects the vapor pressure of the atmosphere, which ultimately influences the reference evapotranspiration. It influences more than any other climatic parameter.

Temperatures are the highest, in May and June; over 45 C. Somewhat moderate temperatures extend from early July to mid-September. In fact, Indus Plain has two distinct summers, extremely hot and dry, and hot and humid. Temperatures are the lowest in December and January. The high summer temperature especially in May and June leads to high crop water demand.

Mean annual temperatures based on mean monthly values for selected stations in the Indus Plain are shown in Figure 2.4. It shows that Peshawar (Long, 71.32^{o}E and Lat, 34^{o}N) has minimum mean annual temperature and Hyderabad (Long, 68.22^{o}E and Lat, 25.23^{o}N) has maximum mean annual temperature. The mean annual temperature increases from north to south. Khan (1993) reported the following reasons for such variation:

- *Latitudinal extent of Pakistan*
- *Variation of mountain terrain in the northern and western parts of Pakistan*
- *Ameliorating effects of sea in the south and irrigation network in the plain*

Figure 2.3. Location of Canal Command of IBIS with Meteorological Stations.

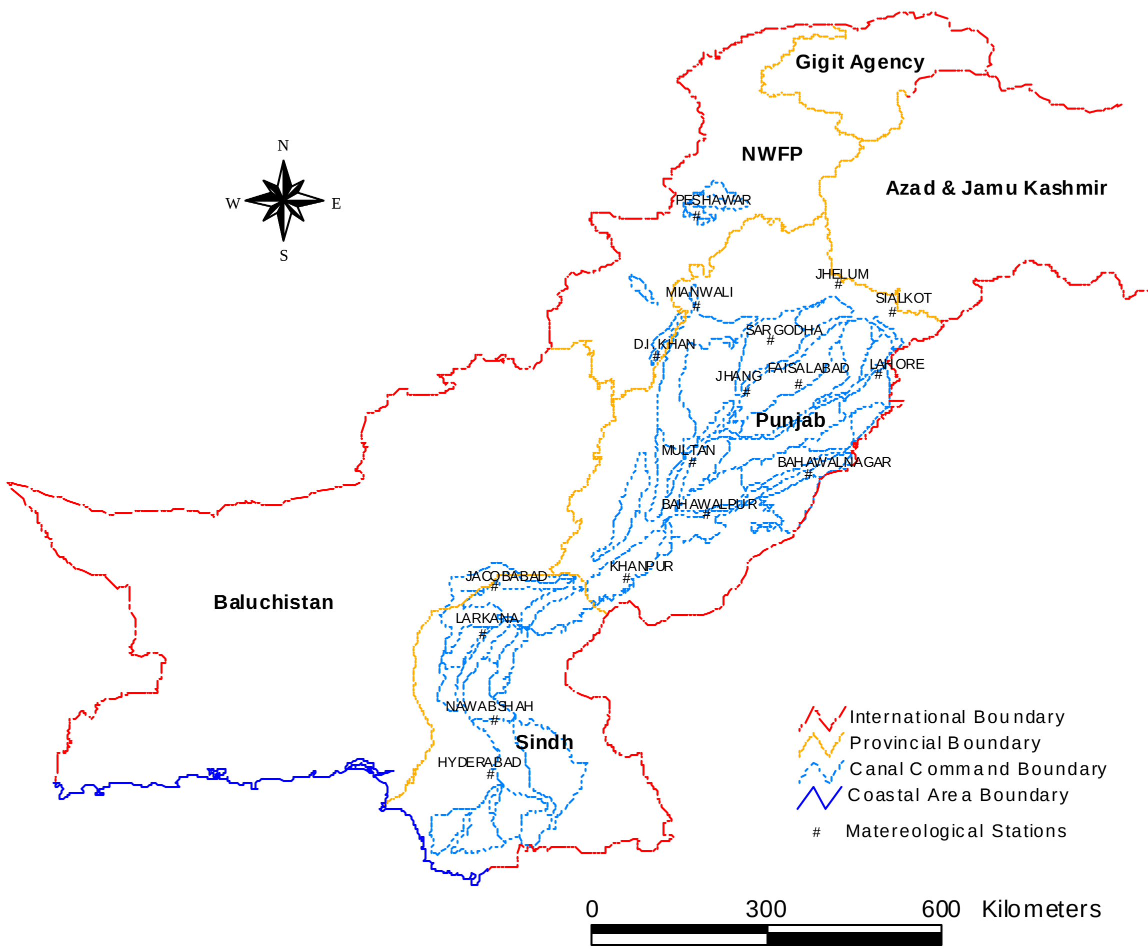
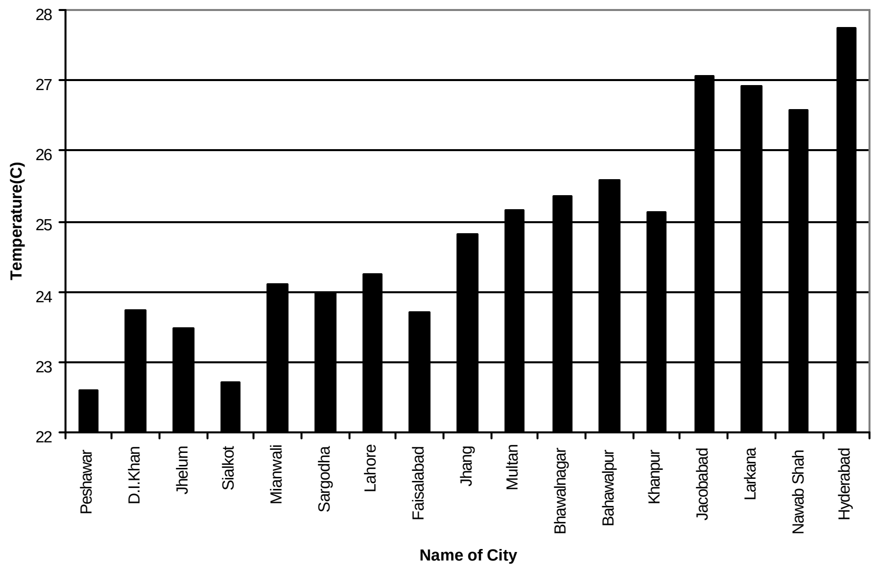


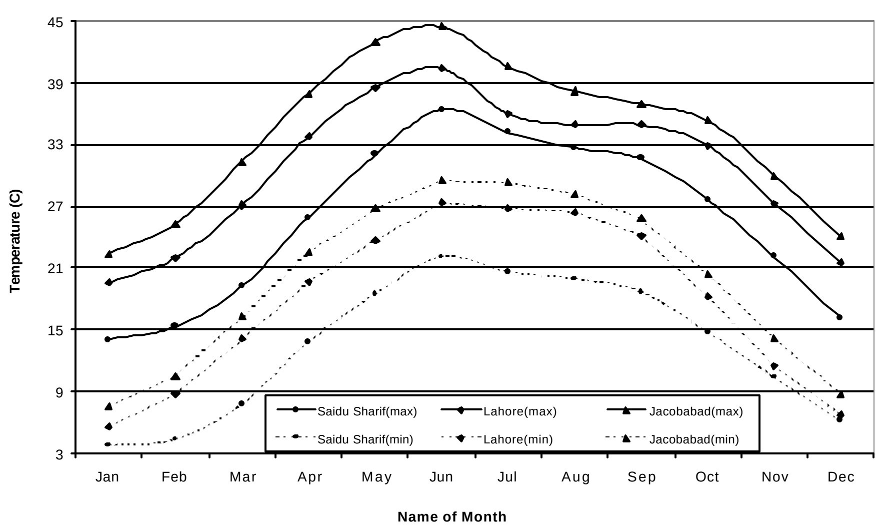
Figure 2.4. Mean Annual Temperatures of Various Stations within the Indus Basin.



The mean minimum and maximum temperature (Table B & C, Appendix I) also increases from north to south in a similar pattern as mean annual temperature. Figure 2.5 indicates that the mean monthly maximum temperature gradually increases from January to June and then sharply decreases in July due to the monsoon effect. From August to October it remains nearly constant and then goes on decreasing for the remaining months of the year.

On the other hand the mean minimum temperature increases more sharply from January to June than it decreases from July to December. Figure 2.5 also indicates the ranges between mean monthly maximum and minimum temperatures.

Figure 2.5. Mean Monthly Maximum and Minimum Temperatures of Some of the Stations within the Indus Basin.



Humidity

Water content of the air can be expressed in several ways. For this study mean relative humidity is used for computation. As the data from PMD contains relative humidity measured at 5:00 AM, 8:00 AM and 5:00 PM. The mean relative humidity used for analysis was obtained by taking mean of relative humidity measured at 5:00 AM and 5:00 PM because it is maximum and minimum at this time and is presented in Table D in Appendix I.

Humidity and temperature have reverse relationship. During summer it is lowest in months of May and June and increases substantially during summer monsoon, which extends from early July to around mid-September. Humidity is low in October and November and moderates for remaining winter. It however remains higher throughout the year in the areas near the coast. In the Northern areas, and north Punjab average humidity during Rabi is higher than Kharif and this condition gets reversed in Sindh. From Sukkur down to Karachi, the average humidity during Kharif is higher as compared to Rabi.

Wind Speed

The process of vapor removal depends to a large extent on wind and air turbulence, which transfers large quantities of air over the evaporating surface. Wind speed measured at 2-m height above ground surface is recommended for the estimation of ETo. But the instrument used to measure the wind speed is installed either on the airports or on the roof of PMD offices. For computation, the mean monthly wind speed is multiplied with a factor of .83 (suggested by FAO) as height of instrument is approximately 6m. The adjusted wind speed at selected stations is given in Table E in Appendix I.

The Table E of Appendix I show that maximum wind speed occurs during the month of June. In June, the land becomes heated and a low-pressure area is developed which causes high wind speed.

Sunshine Hours

Solar radiation is the largest energy source and is able to change large quantities of liquid water into water vapor. To estimate net radiation the value of mean monthly daily sunshine hours has been used. The maximum daylight hours are observed in May and minimum in December and January for Northern part and July and August for southern part of the Indus basin. The detail is given in the Table F in Appendix I.

Grouping of Canals Used in this Report

The conventional three agro-ecological and seven agro-climatic zones of Indus basin irrigation system are discussed in previous section. Some of agro-climatic zones exhibit different cropping pattern and crop-periods within the zone i.e. Sindh Rice-Wheat zone consists of upper Sindh right bank canals and lower Sindh canals which have different cropping period but are placed in the same zone. Therefore, crop coefficient for same crop varies depending on the crop calendar. The purpose of grouping is limited here, related to crop culture. The canals having more or less same Kc and crop duration are grouped together. To accommodate significant variations in cropping pattern and period within the same agro-climatic region, all canal commands of IBIS are divided into 11 groups as reported in Table 2.1.

The value of crop coefficient for a particular crop remains constant for all canals lying in a particular group.

Table 2.1. Main Canals Group Having Uniform Cropping Pattern And Characteristics.

Group No.	Name of Province	Name of Canal
	NWFP	
1		Upper Swat, Lower Swat, Warsak, Kabul River Canal
	PUNJAB	
2		a) BRBD (Raya), Upper Chenab, Marala - Ravi, b) Upper Dipalpur, Central Bari Doab Canal
3		Upper Jhelum, Lower Jhelum, Lower Chenab Canal (Jhang + Gugera)
4		Lower Bari Doab, Lower Dipalpur Canal
5		Pakpattan, Haveli, Sidhnai, Mailsi
6		Rangpur, Thal, Muzafargarh, D. G Khan, CRBC
7		a) Fordwah, Eastern Sadiqia b) Bahawal, Panjnad, Abbassia
	SINDH/BALOCHISTAN	
8		Desert, Pat (Sindh/Baloch'n), Begari Feeder, North West, Rice, Dadu
9		Ghotki, Khairpur East, Khairpur West
10		Nara, Rohri
11		Kalri, Lined Channel, Fuleli, Pinyari

REFERENCE EVAPOTRANSPIRATION FOR DIFFERENT CANAL COMMANDS

Background

The evapotranspiration is a combination of two separate processes, water lost from the soil surface by evaporation and from the crop by transpiration.

Evaporation is the process whereby liquid water is converted to water vapor and removed from the evaporating surface. The difference between the water vapor pressure at the evaporating surface and that of the surrounding atmosphere is the main driving force to remove water vapor from the evaporating surface. As evaporation continues, the surrounding air becomes gradually saturated and the process slows down and might stop if the wet air is not transferred to the atmosphere.

The process of vaporization of liquid water contained in plant tissues and to the atmosphere is called transpiration. The water is taken up by the roots and transported through the plant leaves to the atmosphere. Almost all water taken up is lost by transpiration and only a very small part is consumed within the plant.

The concept of reference surface was introduced to define the unique evaporation parameters for each crop and stage of growth. Evapotranspiration rates of various crops are related to the evapotranspiration rate from the reference surface by means of crop coefficients.

The FAO Expert Consultation on Revision of FAO Methodologies for crop water Requirements accepted the following unambiguous definition for the reference surface:

A hypothetical reference crop with an assumed crop height of 0.12m, a fixed surface resistance of 70 s/m and an albedo of 0.23.

The reference surface closely resembles an extensive surface of green grass of uniform height, actively growing, completely shading the ground and with adequate water.

Methods of Estimating Reference Evapotranspiration

Several methods are available for estimation:

- *Penman-Monteith*
- *Blaney-Criddle*
- *Radiation*
- *Modified Penman*
- *Pan Evaporation*
- *Priestley and Taylor*
- *Hargreaves*

Penman-Monteith method has strong likelihood of correctly predicting ET_o in a wide range of locations and climates and has a provision for application in data short situation (FAO, 1998). Some other studies carried out in the Indus basin have recommended Penman method. A comparison of several techniques used in the Indus basin is given in the last section of this chapter. Based on this information, CROPWAT model based on Penman-Monteith equation for the estimation of reference evapotranspiration is selected.

For estimating ET_o by Penman-Monteith method the basic equation is as follows:

$$ET_o = \frac{0.408\Delta(Rn-G)+g\frac{900}{T+273}u_2(e_s-e_a)}{\Delta+g(1+0.34u_2)} \qquad (3.1)$$

Where

ET_0	reference evapotranspiration (mm/day)
R_n	net radiation at the crop surface ($MJ/m^2 day$)
G	soil heat flux density ($MJ/m^2 day$)
T	mean daily temperature at 2 m height (^oC)
U_2	wind speed at 2 m height (m/sec)
e_s	saturation vapor pressure (Kpa)
e_a	actual vapor pressure (Kpa)
e_s-e_a	saturation vapour pressure deficit (Kpa)
Δ	slop vapor pressure curve (Kpa/ ^oC)
γ	psychrometric constant(Kpa/ ^oC)

The equation 2.1 determines the evapotranspiration from the hypothetical grass reference surface.

Estimation of Reference Evapotranspiration for Indus Basin

Monthly reference evapotranspiration for all selected meteorological stations was computed. These estimations were then apportioned to show spatial variability, using GIS in all canal commands.

Estimation of ET_o at Meteorological Station

The computed values of monthly reference evapotranspiration for all the selected meteorological stations are given in Table 3.1. These values vary from 1210 to 2112mm/year from north to south. The factors influencing range are temperature, humidity, and wind speed, sunshine hours, location and altitude. Computation indicates that Sialkot (Long, 74.53^{o}E and Lat, 32.52^{o}N), the extreme North East of the Indus Basin has the minimum value of reference evapotranspiration 1210 mm/year. The highest value of evapotranspiration was found 2112 mm/year at Jacobabad (Long, 68.46^{o}Eand Lat, 28.28^{o}N). The value of evapotranspiration decreases down of Jacobabad and goes on decreasing due to the coastal effect.

Table 3.1. Reference Evapotranspiration of Various Climatic Stations in the Indus Basin.

Name of Station		ET_o in mm/day											ET_o mm
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Peshawar	1.4	2.0	3.1	4.4	5.7	6.3	5.2	4.9	4.2	2.8	1.7	1.2	1303
D.I.Khan	1.6	2.4	3.8	5.0	6.4	6.9	6.0	5.5	4.8	3.3	2.0	1.5	1497
Jhelum	1.4	2.1	3.4	4.8	5.9	6.2	4.7	4.0	4.5	4.0	2.9	1.8	1390
Sialkot	1.2	1.9	3.1	4.4	5.4	5.8	4.4	4.3	3.8	2.7	1.6	1.1	1210
Mianwali	1.4	2.0	3.3	4.6	6.2	6.5	5.6	5.0	4.6	3.1	1.8	1.2	1379
Sargodha	1.7	2.5	4.0	5.6	7.2	7.6	6.1	5.3	5.1	3.8	2.3	1.7	1612
Lahore	1.4	2.2	3.6	5.0	6.3	6.5	5.2	4.7	4.5	3.2	1.8	1.3	1396
Faisalabad	1.4	2.2	3.5	4.8	6.2	6.5	5.4	4.9	4.7	3.3	1.9	1.3	1405
Jhang	1.6	2.5	3.9	5.5	7.2	7.8	6.5	5.8	5.0	3.6	2.2	1.5	1622
Multan	1.5	2.5	4.1	5.2	6.4	7.6	6.2	5.9	5.2	3.4	2.0	1.5	1565
Bahawalnagar	2.0	3.0	4.5	6.5	8.3	9.0	6.6	6.3	5.7	4.4	2.8	1.9	1853
Bahawalpur	1.8	2.8	4.1	5.5	6.8	7.7	6.2	6.0	5.3	3.9	2.5	1.7	1652
Khanpur	2.0	3.0	4.5	6.0	7.2	8.0	6.6	6.2	5.2	4.0	2.6	1.9	1738
Jaccobabad	2.6	3.5	5.6	7.5	9.3	10.2	7.9	6.9	6.0	4.7	3.0	2.2	2112
Larkana	2.4	3.4	5.3	7.0	9.0	9.8	7.4	6.4	6.1	4.4	3.1	2.3	2026
Nawabshah	2.8	3.7	5.1	6.7	8.7	9.5	7.2	6.2	6.1	4.9	3.3	2.7	2036
Hyderabad	2.8	3.7	5.1	6.9	8.6	7.9	6.2	5.6	6.1	4.9	3.3	2.8	1946

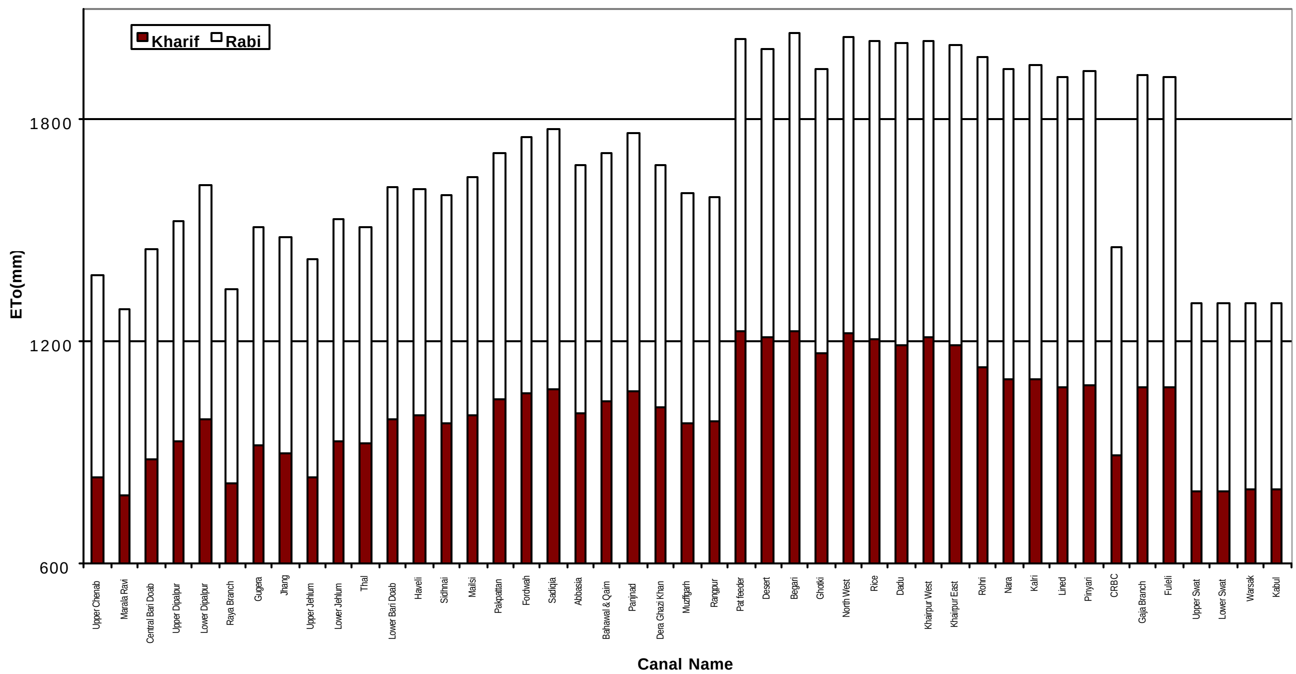
Spatial Variability of ET_o for Canal Commands Using GIS

The spatial variability of ET_o across the canal commands is estimated by using GIS techniques. Computer software Surfer, Arcinfo and Arcview are used for the spatial analysis and visual representation of reference evapotranspiration in the canal commands of the Indus basin. This involves the following process:

- *Contours of equal ET_o were drawn by interpolation between stations by using kriging method in SURFER on monthly basis. The kriging is superior because it allows the calculation of the error associated with the estimates, namely the variance of the error distribution and tries to minimize this variance. It considers all surrounded values of the variable around the interpolated points by applying the weighed coefficients to them.*
- *The canal command map was then superimposed over contour maps to obtain the monthly reference evapotranspiration for each canal command.*

The estimated ET_o for all canal commands of Indus Basin is given in Table A of Appendix II. Seasonal variation of ET_o as shown in Figure 3.1 indicates that upper and northeastern part of the basin has lower reference evapotranspiration (1200-1300 mm), whereas, the lower part of the basin, Southern Punjab and Sindh have much higher ET_o values (1700-2100 mm). It has also been observed that ET_o is the maximum in the month of June. In Sindh, Guddu Barrage Canals have the highest ET_o in the Indus Basin irrigation System. The monthly evapotranspiration is generally maximum in June except Kotri Barrage canals (Indus delta) where maximum values occur in May due to sea effects.

Figure 3.1. Reference Evapotranspiration of canals of Indus Basin Irrigation System.



Figures 3.2a & b represent the spatial variability of ET_{o}, which generally increases from North to South during both Kharif and Rabi seasons over the entire Indus Basin.

Extreme variability of ET_o within the year

Figures 3.3 a & b indicate that during June the reference evapotranspiration varies spatially from 180 to 310 mm and in December from 30 to 90mm. The spatial north-south variability of ET_o during June and December has same trend as shown by seasonal averages

Figure 3.2a.   Spatial Variability of Reference Evapotranspiration during Kharif in IBIS.

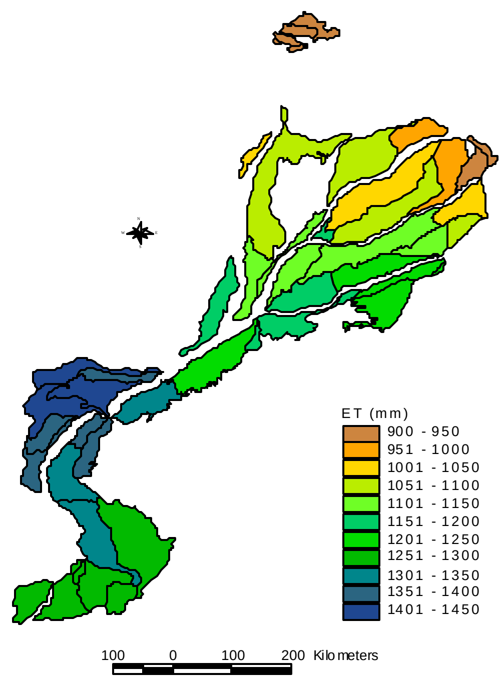


Figure 3.2b.   Spatial Variability of Reference Evapotranspiration during Rabi in IBIS.

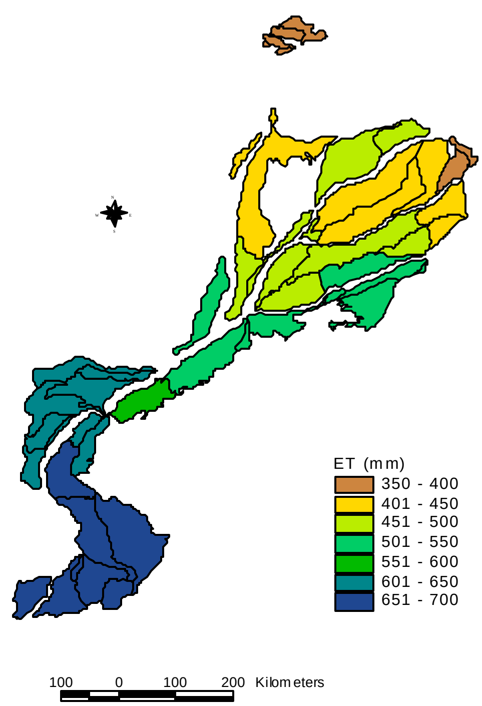


Figure 3.3a. Spatial Variability of Reference Evapotranspiration during June in IBIS.

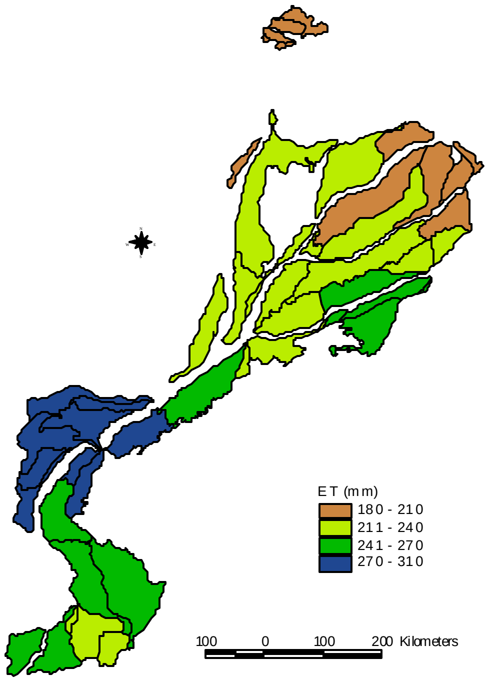
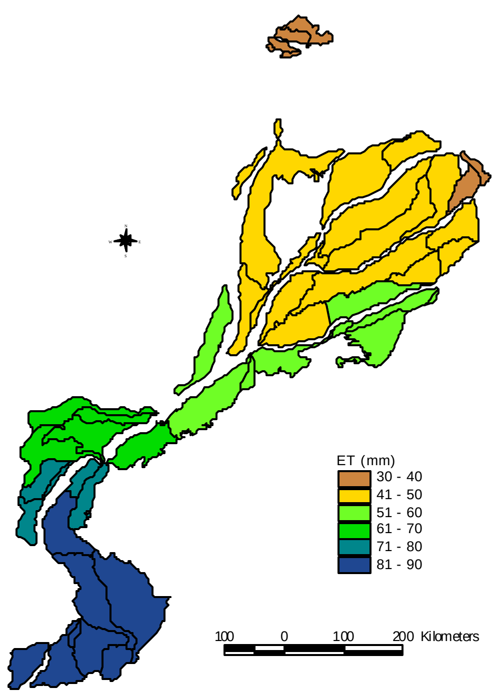


Figure 3.3b. Spatial Variability of Reference Evapotranspiration during December in IBIS.



Comparison of computed ET_o with Other Studies

Many scientists debated the precision level in the estimation of ET_o (Bastiaanssen, 99). All assessment methods use empirically derived coefficients influenced by the nature and location of the experiment. The field-testing of evapotranspiration could not be done directly. The estimation methods have the influence of selected parameters and the range of their variability. However, a comparison of current computations with previous studies conducted in Indus Basin could be useful to have an idea of difference caused by the selection of method and data.

The following section briefly describes:

- *ET_o estimations for Chashma Right Bank Canal by different methods over a period of fifteen years; and*
- *ET_o for extreme conditions by Penman (CROPWAT 98) and Hargreaves*

Different Computations of ET_o for CRBC

The Chashma Right Bank Canal Project in NWFP provides an example to compare different computations for reference evapotranspiration and crop water requirements. CRBC is a big crop-based irrigation scheme with head diversions of 138 cubic meters per second. The 10-daily water allocations and diversions to CRBC are based on crop-water requirements for the proposed cropping patterns and determine the canal capacity. However, different studies indicate a difference in the estimation of ET_o and crop water requirements.

The several different sets of reference ET_o for CRBC are given in Table 3.2.and Figure 3.4 Three of these are computed during the project planning and implementation, while remaining sets are computed by this study, using three different methods.

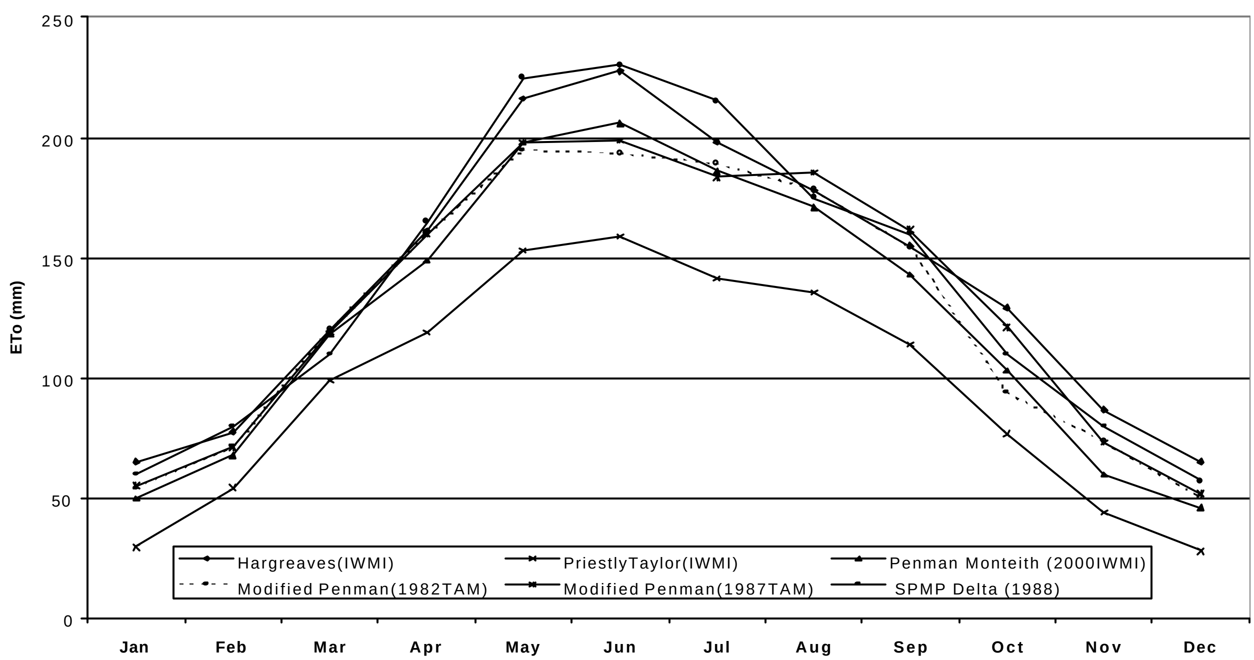
Table 3.2. Comparison of Monthly ET_o Estimates of different Studies with IIMI.

Month	Reference Evapotranspiration (mm)					
	Modified Penman (1982 TAM)	Modified Penman (1987 TAM)	1988 Delta SPMP	Penman Monteith (2000, IWMI)	Hargreaves (IWMI)	Priestley &Taylor (IWMI)
Jan	54.3	55.3	60	50	65	33
Feb	71.4	71.2	80	68	78	54
Mar	120.0	119.0	110	118	120	110
Apr	160.0	159.8	165	149	161	127
May	194.8	198.0	225	198	216	165
Jun	193.5	198.7	230	206	228	170
Jul	189.2	183.4	215	186	198	157
Aug	178.3	185.5	175	171	178	150
Sep	154.2	161.7	160	143	155	122
Oct	94	121.2	110	103	129	85
Nov	73.5	73.4	80	60	87	47
Dec	50.1	51.9	57	46	65	31
Annual	1534	1579	1667	1497	1680	1252

The selection of method and climatic data:

- *The TAM studies in 1982 and 1987 used FAO approach. The average climatic data of three stations was used in 1982 and of five stations in 1987. Two of these stations are located in the command area and others in vicinity of the area. The number of years vary for different parameters;*
- *The ET_o that was calculated by SPMP (1988) used data set of D. I. Khan for climatic variable and Pan Evaporation measurements. Delta 2 module of Indus Basin Model was used to compute ET_o.*
- *IWMI estimated ET_o using three empirical methods; Penman Monteith, Priestley & Taylor and the simple temperature based equation of Hargreaves. Thirty years (1962-1991) average monthly data of D. I. Khan is used for these calculations.*

Figure 3.4. Reference Evapotranspiration for CRBC by different Methods.



The computation of TAM and IWMI using Penman are very close though different climatic data sets are used for the calculations. It approves the efforts of TAM to strengthen the data set of D. I. Khan with other measuring stations in the range, which was of small duration with scarce information for sunshine hours.

The SPMP based on Delta model and Hargreaves computations are fairly close. A small difference could be due to data. The mathematical relations used by Delta are not given in CRBC documents but mentioned as temperature based only. So, it seems that delta is using the same equation. The estimation is higher than Penman Monteith. A bigger difference is shown by Priestley & Tailor method, where the estimations of ET_o are substantially low.

Summarizing

- *Four methods (Penman, Delta SPMP, Priestley & Tailor and Hargreaves) used in Indus basin estimate in different ranges; Hargreaves and Delta are about 10% higher and Priestley & Tailor is about 20% lower than the Penman Monteith.*
- *The influence of data sets used for CRBC is in the range of 5%.*

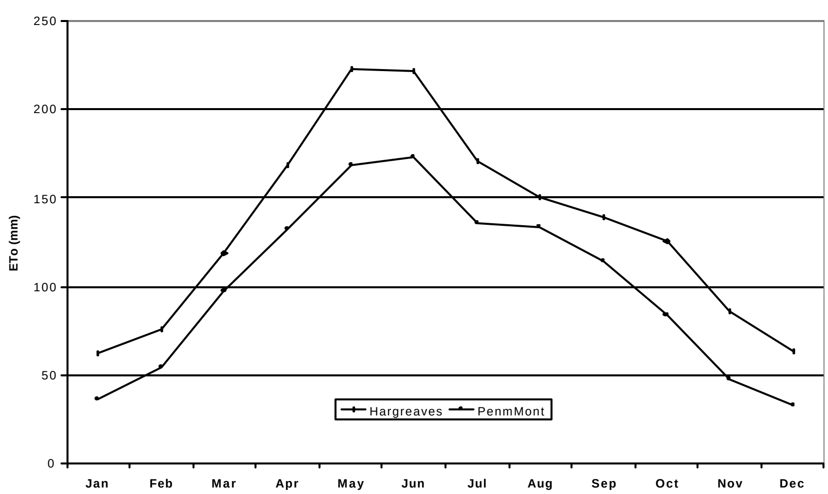
Comparison of Penman with Temperature Based Method Hargreaves

The ET_o computed by Hargreaves and Penman Monteith (FAO 1998) for two stations with extreme climatic conditions is given in Figures 3.5a & b. Sialkot is towards north-east of Indus basin while Jaccobabad in the Southern region, the hottest station of Pakistan. The temperature of Jaccobabad is about 20% higher than Sialkot and wind speed more than double. Sialkot is in semi-arid while Jaccobabad in strongly arid zone. Hargreaves computes 20% higher ET_o for Jaccobabad than Sialkot while Penman 75% higher. In the calculation of individual stations, Hargreaves is 10% lower for Jacobabad and 32% higher for Sialkot.

The difference comes from two types of factors:

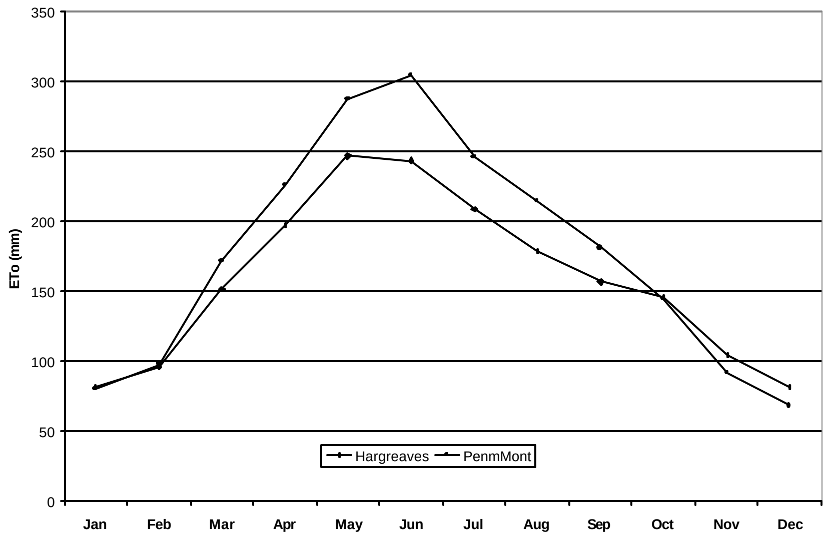
- *Hargreaves[1] is based on temperature, which changes slowly across Indus Basin.*
- *Three additional climatic parameters, humidity, wind-speed and sunshine hours are used by Penman. The wind speed has a big and other two substantial variations across the semi-arid to the arid and desert zones of Indus.*

Figure 3.5a. Reference Evapotranspiration for Sialkot by Penman Monteith and Hargreaves Method.



[1] Hargreaves equation: $ET_o = 0.0023(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5} R_a$

Figure 3.5b. Reference Evapotranspiration for Jacobabad by Penman Monteith and Hargreaves Method.



CROP COEFFICIENT

Selection of Crop Coefficient

The crop coefficient, Kc, is basically the ratio of actual crop evapotranspiration to reference evapotranspiration. Not to the level of ET_o, crop coefficient also posses' distinct spatial character. The coefficients (Kc) are influenced by crop type, soil evaporation, climatic conditions and crop growth stages. Many field experiments have been conducted by different researchers and implementing agencies to measure the actual evapotranspiration and the Kc of different crops. The Kc values computed and selected by different agencies vary in a wide range, especially their distribution over 10-daily period. In this study Kc is selected based on a comprehensive literature review and an assessment of crop periods based on latest agronomic information.

The ground cover, crop height and the leaf area changes with the development of crop and thus, Kc for a given crop vary accordingly. In this study, crop growth stages are divided into the following four categories over the growing period (FAO, 98).

- *Initial Stage*
- *Crop Development Stage*
- *Mid Season Stage*
- *Late Season Stage*

Initial Stage

The length of initial period is highly dependent on the crop, the crop variety, the planting date and the climate. The initial stage is determined by period between the planting date and the time when approximately 10% of the ground surface is covered by green vegetation. As the Indus basin spreads over a large area from North to South and planting date is not the same even within the canal command, so the planting of each crop is distributed for a month or more.

Crop Development Stage

The crop development stage starts from 10 % ground cover to effective full cover. This effective full cover varies for different crops. Another way to estimate the occurrence of effective full cover is when the leaf area index ("LAI" average total area of leaves per unit area of ground surface) reaches three.

Mid Season Stage

The mid season stage starts from attainment of effective full ground cover to time of start of maturing as indicated by discoloring of leaves or leaves falling off. For some crops this may extend very near to harvest unless irrigation is not applied at late season and reduction ET (crop) is induced to increase yield. The mid season stage is the longest stage for perennials and for many annuals, but it may be relatively short for vegetable crops that are harvested fresh for their green vegetation. The Kc value reaches its maximum in mid season stage and remains relatively constant for most growing and cultural conditions.

Late Season Stage

This stage runs from the start of maturity to harvest. For crops grown year round the date of termination may be taken same as the date of planting. The crop and water management practices play an important role in the selection of Kc value at the end of late season stage. If the crop is frequently irrigated until harvested fresh the Kc end value will be high and low in case when crop is dried out in the field before harvesting. Like planting and harvesting is not done at the same time. The spread of harvesting time is also considered in selection of Kc for that stage in Indus basin irrigation system

Crop Coefficient for Canals of Indus Basin

The reference evapotranspiration generally increases from North to South in Indus Basin. This variation of reference evapotranspiration along with different land forms results in diversified agriculture with respect to crop calendar and period. The selection of crop coefficient involves the following steps:

- *Selection of crop period*
- *Development of k_c curves for major crops*

Selection of Crop Period

The cropping seasons vary for individual crops but are generally defined as “Rabi” and “Kharif”. Rabi crops are sown after the rainy season in October and November, and harvested in spring in April and May. They include wheat, pulses, oil-seeds and fodder. These crops require lower temperatures and rainfall than Kharif crops, which are sown between April and June and harvested in October and November. Kharif crops include cotton, rice, maize, sorghum, vegetables and fodder. The crop duration of major seasonal crops varies from 3 to 6 months. Sugarcane is an annual crop, and has two different crop calendars within the basin.

The planting and harvesting dates vary from region to region due to climate and cropping patterns while within canal command due to irrigation practices (harvesting of the previous season’s crop, land preparation) crop variety and the availability of water. The periods of planting and harvesting, crop duration and crop growth stages for different groups of canals have been determined on basis of primary and secondary information about cropping practices across the basin. (WAPDA 1979, IIMI 1996, GOP 1997, PARC 1980, PPSGDP 1998, Lower Indus Report 1966, FAO, 1977 and FAO 1998). For most of the crops, the planting and harvesting period is extended over a couple of weeks. The selected calendars are indicated in the selection of Kc.

A comparison of Kc curves selected by the above-mentioned studies and the current selection for the major crops is discussed below

Ten-Daily Crop Coefficients for the Major Crops

The Kc curves are developed for eight individuals and a few group of crops, wheat, cotton, rice, sugarcane, maize, sorghum, oilseeds, pulses and minor crops for Kharif and Rabi.

Wheat

The wheat is grown all over Pakistan, in irrigated and non-irrigated areas, during winter as the main food-grain. Its best-producing region is the upper and central part of the Indus basin plain where cool and dry climate prevails during the growing season. Wheat is sown in Punjab from end of October to December, while it is recommended for sowing in November by Agriculture Extension Department. The harvesting of the Kharif crops delay planting of wheat, especially in the cotton belt of southern Punjab. In Sindh, it is mostly sown in October. The crop duration varies from 150-180 days.

The crop coefficient curves developed by different studies are shown in Figure 4.1a & b for Punjab and Sindh. The curve of PARC (Pakistan Agriculture Research Council) is based on the experiments conducted during 1976- 1980 under controlled soil moisture conditions (termed as optimum management conditions PARC, 1980). Curve developed by using guidelines of FAO considers one-month sowing period and coefficients of four growth periods recommended for the Central India. Harza (RAP, 1979) developed the WAPDA curves. Four different curves are recommended by the study, having different duration, but the same initial and development stages. The maximum coefficients by WAPDA are towards higher side, probably influenced by the data collected from the South. The curve by the current study is selected (IWMI-Punjab) by considering a scatter in sowing and harvesting dates, keeping the total Kc equal to PARC and taking maximum coefficient as recommended by FAO. Keeping in view PARC and WAPDA curves a spatial variation for different zones of Punjab is incorporated.

Figure 4.1a. K_c for Wheat in Punjab Assessed by Different Sources.

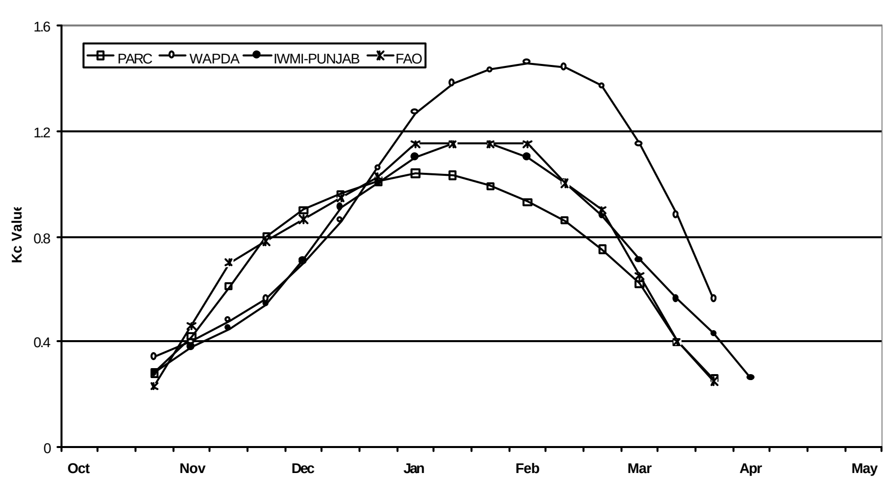
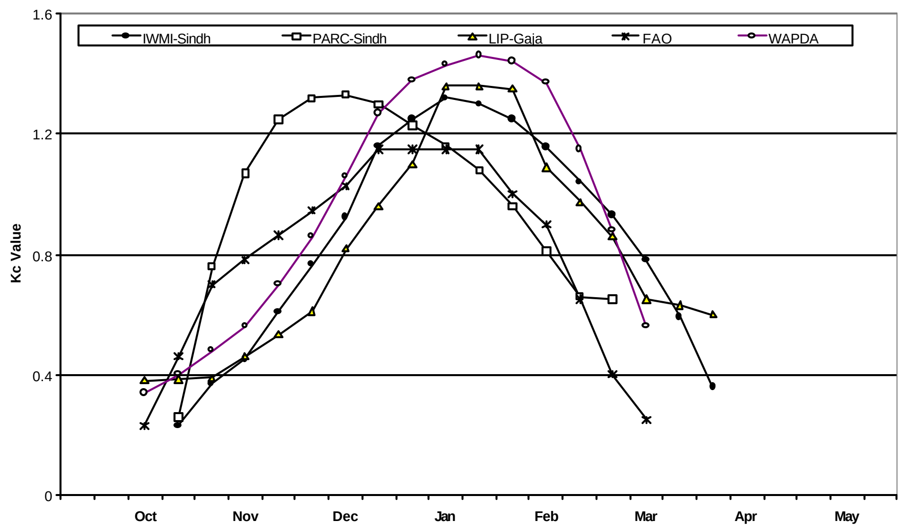


Figure 4.1b. K_c for Wheat in Sindh Assessed by Different Sources.



For Sindh, field experiments conducted by another study in 1964-66 are available. The recommended curve is shown in Figure 4.1b, along with Kc by other sources. The PARC curve is different, especially for the initial and the crop development stages. The main reason is that the other curves are accumulated for canal command area (and take into account about two to three weeks scatter in plantation period) while PARC curve is for one crop field. Nevertheless, the initial and crop-growth periods are shorter in PARC experiment. To address the gross characteristics, the selected curve is closer to LIP-curve, 10-daily distributions are computed again to adjust the sowing & harvesting practices and are presented in Table A of Appendix III.

Cotton

The southern irrigated plain of Sindh and the southern part of the northern irrigated plain are favorite areas of cotton growing. Figure 4.2a shows that in-group 3 the cotton is planted much earlier as compared to other groups. The local (Desi) variety of Cotton is planted in this group of canals, which takes longer time as compared to American cotton.

The crop-coefficient recommended by different sources for cotton shows less divergence as compared to wheat. The 10-daily values by LIP and WAPDA are almost the same (Figure4.2a & b). For Punjab, PARC reports almost the same value, while for Sindh their curve is very low. Considering sowing and planting dates generates the IWMI curves. The values recommended by WAPDA & LIP study are given in the Table B of Appendix III. An allowance for the soil moisture is provided in Sindh and the dry zones of Punjab.

Figure 4.2a. K_c for Cotton in Punjab Assessed by Different Sources.

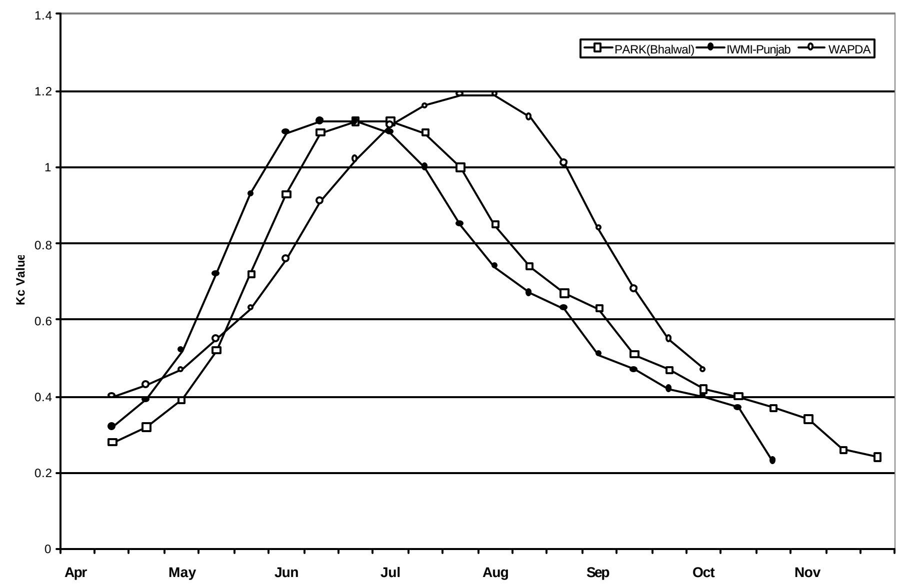
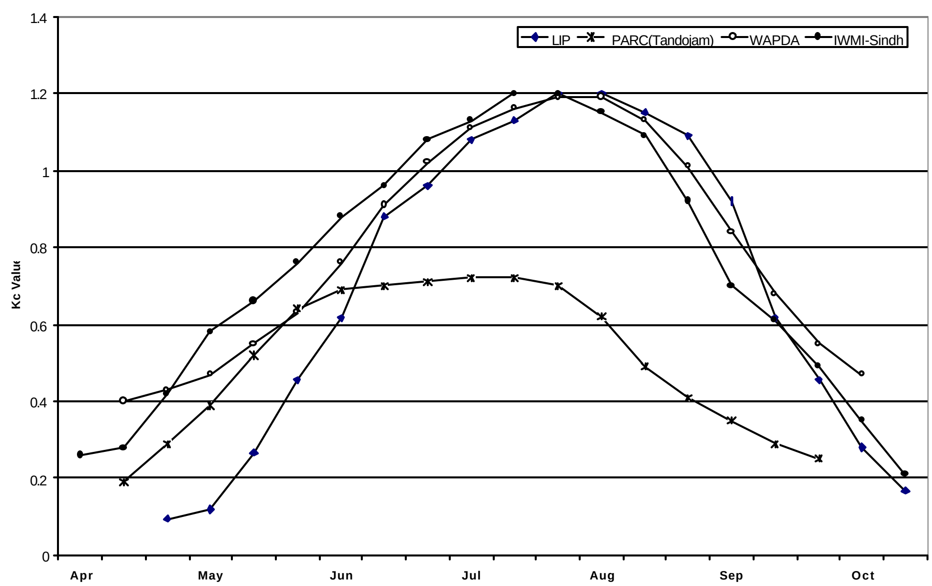


Figure 4.2b. K_c for Cotton in Sindh Assessed by Different Sources.



Sugarcane

In Indus basin the major sugarcane producing areas are in Sindh where the growing period is longer than other provinces (OFWM, 1998). By considering curves developed by Lower Indus Project, RAP study of WAPDA and PARC study, The K_c for sugarcane is developed. The sugarcane is planted in two periods:

Autumn Planting-September/October

Spring Planting- December to February

Mostly crop is planted in spring season so for computation purposes the whole area of Indus Basin is considered planted in this season and harvested during November to January. The crop period varies from 300 to 360 days. To accommodate the sowing and harvesting spread, whole year is considered as crop period for most of the group of canals as given in the Table C of Appendix III.

Maize

Maize growing areas are in Punjab and NWFP. It is grown mostly in Kharif (June-October) as rain fed or irrigated and on smaller scale in summer season (February-May). A uniform pattern is considered for all maize growing areas as given in the Table D of Appendix III. Crop duration varies from 90 to 120 days. The scattering effect of planting and harvesting is also considered in development of Kc curves. The crop co-efficient selected is most close to PARC (1980) study.

Sorghum and Millet

Both are grown almost all over Pakistan under varied soil and climatic condition. These are fodder and grain crops. There is wide diversity of plant types ranging from tall variety (2m) requiring 120 days to mature to varieties requiring only 90-100 days to mature. As a fodder crop both can be sown from beginning of March to the end of August. The optimal planting time is end of June to start of July and harvesting time is end of September to October. The difference in planting and harvesting dates in different zones is due to the variety and purpose of the crop and is accommodated in selection of Kc and is presented in Table E of Appendix III.

Rice

Rice in Pakistan is grown in wet conditions and is manually transplanted. The nursery-seeding schedule is very important. The nursery is planted during the period of May-June. Early sown nurseries are liable to insect attack. Late sown nurseries delay transplanting and eventually harvesting. The crop duration (transplanting to harvest) varies from 100 to 150 days. The IRRI Type rice has short crop duration than Basmati. A 1.5mm/day (LIP, 1966) depth of water was assumed as percolation loss after transplanting. The 10-daily values developed by IWMI as given in Table F of Appendix III are slightly lower than LIP and WAPDA. The nursery period is also considered by taking 2-6% total cropped area for selection of K_c by IWMI like LIP.

Oil-Seeds

Different types of oil-seeds grow all over Pakistan under varied soil and climatic conditions. The major oil-seed crop in Pakistan is Rape & Mustard, which are Rabi Crop. This type of oil-seed crop is planted in September-October and harvested in March-April. The crop duration varies from 150-180 days. The spread of sowing and harvesting dates are taken into account. LIP study for Sindh and CRBC study for Punjab are used as reference in developing crop coefficient values, which are presented in Table G of Appendix III.

Pulses

Different types of pulses are grown in Rabi. Lower Indus basin is a main producer of pulses where they are grown in “dubari” system (residual moisture after rice). The crop is planted in November and harvested in February. The crop duration varies from 100 to 110 days. Table H of Appendix III presents the selected Kc for pulses. The recommend values of LIP for pulses are taken into consideration.

Minor Crops

There are many crops other than these major crops in Rabi and Kharif. The development of Kc curves for minor crops is very cumbersome so these are grouped into Rabi and Kharif minor crops. Past work of different studies (LIP, 1966, PARC, 1980, RAP, 1979) was considered while selecting the Kc values for minor crops, which are given in the Table I, & J of Appendix III.

POTENTIAL EVAPOTRANSPIRATION FOR CANAL COMMANDS OF INDUS BASIN

Two agro-climatic factors contributing in the estimation of crop water demands, reference evapotranspiration and crop coefficient curves for different regions are discussed in the previous chapters. In addition, actual land use information, cropping pattern and intensities determine the volume of water required for agriculture in an area.

The collection of primary data for land use in each main canal command is difficult because of huge scale of the basin, small land-holdings and mixed cropping patterns. The information collected by routine procedures might be biased by multiple factors such as their specific purpose, data collection procedures and regional and political interests. In Indus basin, two set-ups exist for crop monitoring. The irrigation and revenue department collects irrigated area information for the hydraulic units of watercourse, secondary and main canals. The agriculture department assesses cropped area for the administrative units based on a sample survey. The information collected by provincial irrigation departments is well categorized and consistent in nature, still there is a likelihood of reporting problems, which may affect cropping intensities. For the calculation presented in this chapter irrigation department data are used. The cropping intensity issue is addressed by estimating potential evapotranspiration (PE) or the crop consumptive use for reported and fully cropped area.

The computations of crop water requirements is organized in the following sequence:

- *Potential evapotranspiration of major and the group of minor crops for different command areas.*
- *Potential water requirement of Indus basin canal commands for cropping patterns and intensities monitored by PID in 1993-94*
- *Potential evapotranspiration of fully cropped 1000 ha in each main canal CCA following the reported cropping patterns.*

Crop wise potential evapotranspiration for each canal command area

The water requirements of ten crops, six in Kharif and four in Rabi are computed by multiplying the average crop coefficient with average reference evapotranspiration for 10-daily period. The pre-planting irrigation needs for land preparation have been separately calculated for cotton and wheat and added to the crop water demand. Table 5.1 shows the average values for pre-planting in millimeters. The Potential water requirement of various crops in different zones is presented in Table 5.2.

The potential evapotranspiration of Rabi crops varies in a smaller range as compared to Kharif crops. The water demand for wheat, which is the major winter crop across the basin, varies from 271 to 515 mm at the canal command level, a variation of about 60%.

Table 5.1. Pre-Planting Irrigation for Wheat and Cotton

Name of Province	Wheat	Cotton
	mm	
Punjab	125	125
Sindh	75	200

The potential requirement of cotton varies from 627mm to 1161mm and sugarcane varies from 1278 mm to 1887 mm from the north to south of the basin that is eighty and seventy percent respectively.

Table 5.2. Potential Water Requirements in Millimeters for Different Crops in the Indus Basin.

Canal ID	Canal Name	Kharif Crops						Rabi Crops			
		S-cane	Rice	Cotton	Maize	Sorghum	Minor	Wheat	Oil-Seeds	Pulses	Minor
1	Upper Chenab	1375	630	673	310	399	724	336	268		372
2	Marala Ravi	1278	587	627	289	370	676	316	247		345
3	Central Bari Doab	1442	664	709	325	418	764	351	278		386
4	Upper Dipalpur	1518	696	746	341	439	803	369	293		407
5	Lower Dipalpur	1604	704	777	366	441	859	278	309		366
6	Gugera	1536	652	749	336	406	785	316	284		392
7	Jhang	1565	664	802	343	413	801	321	287		398
8	Upper Jehlum	1471	610	698	316	388	734	310	286		395
9	Lower Jehlum	1588	668	774	344	417	810	327	296		408
10	Thal Canal	1539	725	773	325	445	817	330	285		423
11	Lower Bari Doab	1604	710	777	366	441	859	278	309		366
12	Haveli Canal	1606	768	786	344	439	864	271	300		415
13	Mailsi Canal	1631	788	800	358	456	870	287	319		438
14	Pakpattan	1695	797	818	365	465	901	296	331		455
15	Fordwah	1694	841	881		531	931	392	323		458
16	Sadiqia	1714	850	889		537	940	400	332		468
17	Abbasia	1618	824	848		518	887	387	317		448
18	Bahawal	1616	826	850		521	888	379	313		441
19	Qiam	1693	799	819	367	467	900	299	335		459
20	Panjnad	1701	859	888		537	931	413	337		474
21	D. G. Khan	1707	798	850	358	490	898	383	331		487
22	Muzaffargarh	1632	773	820	347	475	864	357	307		455
23	Rangpur	1628	766	819	342	470	866	348	300		446
24	Path/Deseart	1880	1318	1157		390	1216	493	388	233	485
25	Begari	1887	1323	1161		391	1221	499	394	236	491
26	Ghotki	1690	1259	1038		396	1145	455	299	226	470
27	North West	1875	1317	1156		389	1219	493	394	236	490
28	Rice	1862	1303	1144		386	1210	495	397	238	493
29	Dadu	1841	1281	1127		382	1198	504	408	246	504
30	Khairpur West	1752	1303	1072		404	1187	476	314	238	491
31	Khairpur East	1738	1285	1059		403	1176	482	321	243	498
32	Rohri	1783	1225	1022		385	1139	514	362		517
33	Nara Canal	1741	1177	988		375	1111	515	362		518
34	Kalri	1648	1141				1138	467	357	248	527
35	Lined Channel	1618	1117				1114	466	355	247	526
36	Fuleli	1619	1118				1115	467	356	247	526
37	Pinyari	1630	1125				1126	467	357	248	527

The average potential water requirements of different crops for the upper and lower basin are shown in Figure 5.1. The Rabi requirement is less than half of the Kharif. The crop wise variation is twenty to thirty percent in Rabi (between wheat and vegetables) and fifty to hundred percent in Kharif (among cotton, rice and sugarcane).

Figure 5.1. Average Potential Evapotranspiration of Different Crops for Punjab and Sindh Canal Commands by IWMI, 2000.

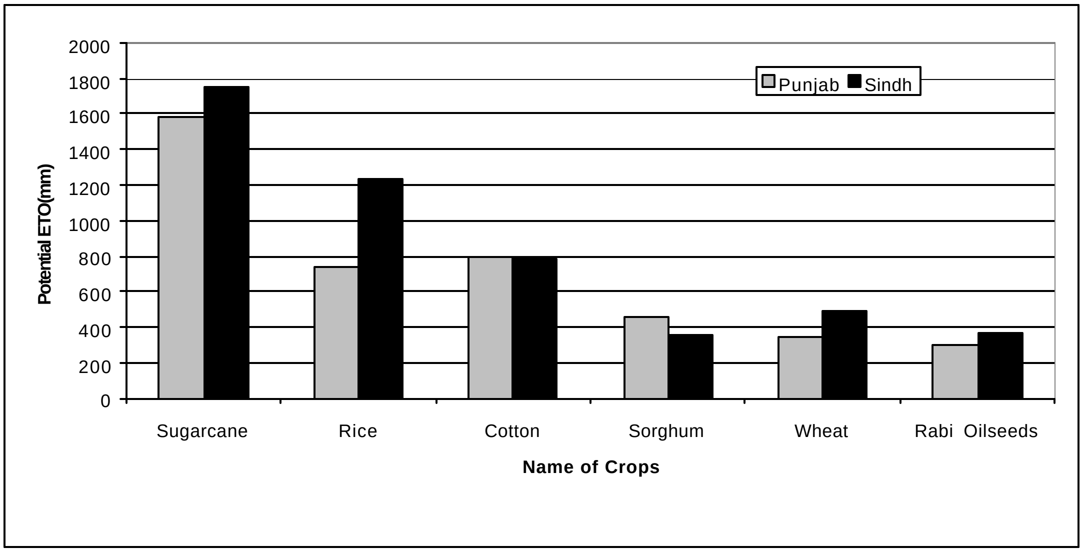
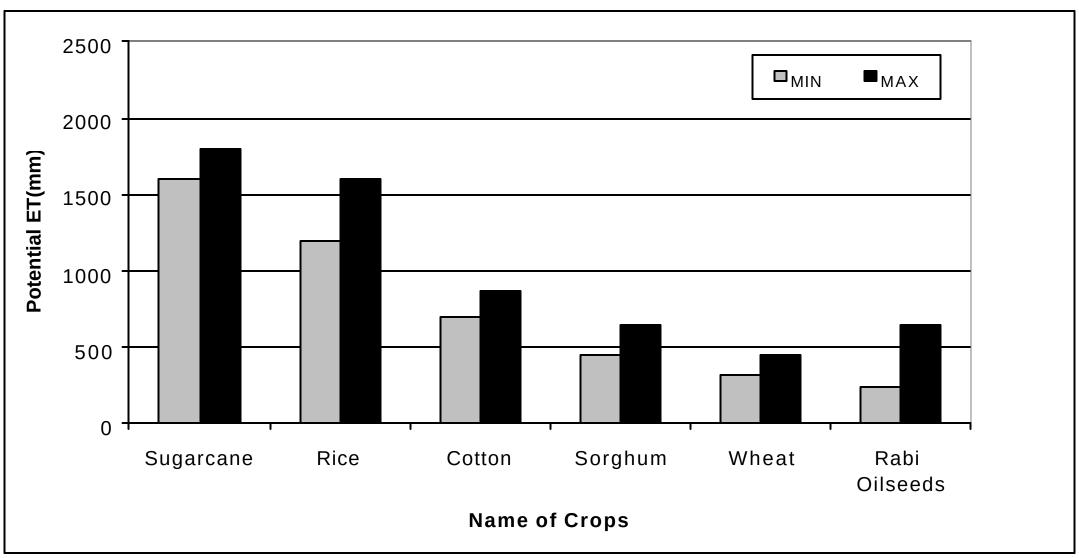


Figure 5.2. Range of Potential Evapotranspiration for Different Crops in Pakistan by OFWM, 97.



The estimations of average potential Evapotranspiration by IWMI for most of the crops are in the same range as recommended by On Farm Water Management, shown in Figure 5.2 (OFWM, 97). However, the maximum requirements computed by this study are comparatively higher for cotton and sugarcane.

Potential Crop Water Demand for Reported Cropped Area of 1993-94

The cropping patterns for various canal commands are different. These are presented in Table A of Appendix IV. The gross seasonal cropping patterns for Punjab and Sindh are shown in Figure 5.3 a-d.

Figure 5.3a. Average Cropping Pattern for Kharif 1993 of Punjab.

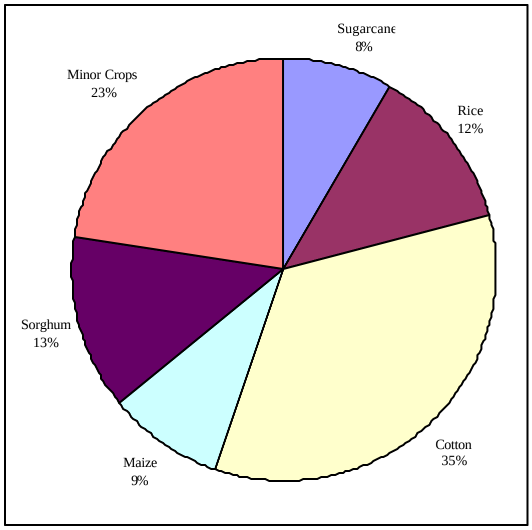
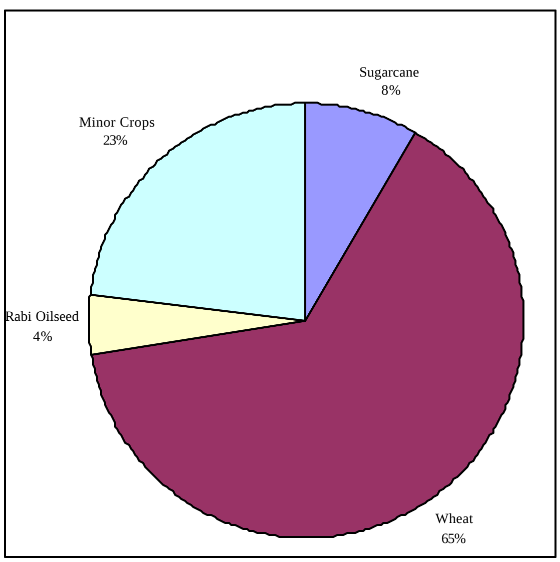


Figure 5.3b. Average Cropping Pattern for Rabi 1993-94 of Punjab.



In Punjab, wheat is grown on 64% of the cropped area in Rabi; rest of the area grows fodder, vegetable, pulses and oil-seeds. Punjab shows bigger crop diversification in Kharif. Cotton is grown on 35% of the area followed by rice, fodder and sugarcane covering 12 %, 10% and 8% respectively.

Figure 5.3c. Average Cropping Pattern for Kharif 1993 of Sindh.

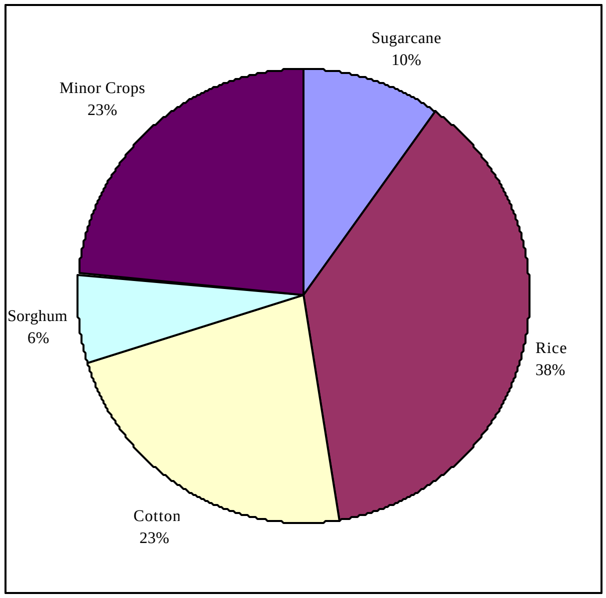
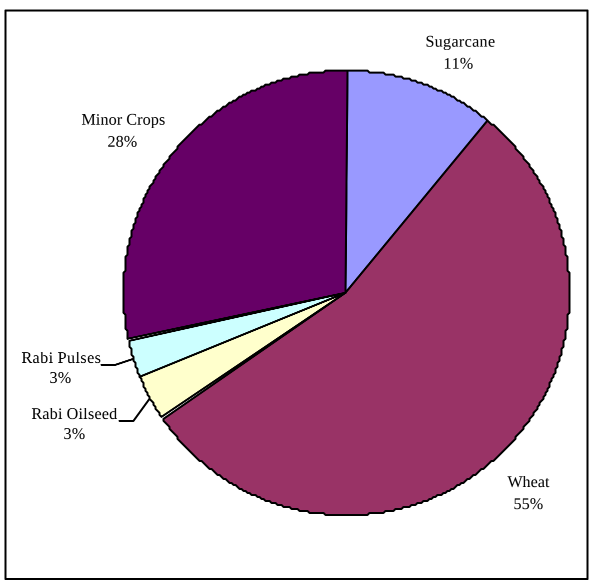


Figure 5.3d. Average Cropping Pattern for Rabi 1993-94 of Sindh.



In Sindh, during Rabi, wheat covers 55% of the average cropped area and minor crops cover about 34%. During Kharif rice is the major crop in Sindh as it cover 38% of the cropped area, cotton is the second big crop and covers 23% of the area, followed by sugarcane that covers 10% with minor crops covering 30%. The minor crops include orchards, maize, oil seeds and fodder.

For existing cropping pattern the potential water demand for 10-daily periods has been calculated by multiplying potential water demand of different crops in a canal command with their respective cropped area (Table A of Appendix IV). Pre planting irrigation for cotton and wheat as given in Table 5.1 are incorporated in the final calculations. Seasonal and annual potential water demand of canal commands is summarized in Table 5.3. The crop consumptive use in canal commands varies from 0.18 bcm in Marala Ravi Link to 7.36 bcm in Rohri canal. This difference of potential water demand (consumptive use) among the canal commands is mainly due to difference of CCA. In Punjab, annual potential evapotranspiration/cropped area varies from 945mm for Marala Ravi Link canal to 1487mm for Punjnad Canal. This difference is due to variation in potential evapotranspiration and cropping pattern. Similar effect of potential evapotranspiration and cropping pattern was also found in Sindh where annual potential evapotranspiration/cropped area varies from 1582mm for Kalri canal and 1883mm for Pat Feeder canal.

It is indicative from the above discussion that the type of crops grown, cropping intensity and physical location of the area, influences the spatial variation in potential evapotranspiration, at the canal command scale. The temporal variation is contributed by climatic difference of summer and winter, which is quite wide across the Indus plains, and low consumptive use of winter crops. Approximately two third of annual potential water demand is for the Kharif crops. The computed annual consumptive requirements of 97 bcm for the Indus canals in 1993-94 carry the bias of reported data, but can easily be adjusted for a change in crop area. It must be considered that these calculations at the crop requirement level do not include any application and conveyance losses and hence are not equivalent to the actual water demand of canal commands. However, these calculations provide base-line information for the planning or assessment of the net requirements based on project or manager's assumption for conveyance factors.

Table 5.3. Potential Crop Water Demands for Reported Crop Area of 1993-94.

Canal ID	Canal Name	CCA (ha)	Total Potential ET 93-94 (bcm)			Potential ET/Crop Area (mm)			Potential ET/Culturable Command Area (mm)		
			Kharif	Rabi	Annual	Kharif	Rabi	Annual	Kharif	Rabi	Annual
1	Upper Chenab	580147	1.45	0.99	2.44	605	384	989	250	171	420
2	Marala Ravi	63615	0.12	0.06	0.18	585	360	945	187	97	285
3	Central Bari Doab	265700	0.85	0.71	1.56	623	398	1020	320	266	586
4	Upper Dipalpur	141711	0.39	0.16	0.55	737	465	1202	273	112	385
5	Lower Dipalpur	247718	1.19	0.37	1.56	765	547	1313	481	150	632
7	LCC East (Gugera)	647502	3.13	2.00	5.13	718	399	1117	484	308	792
8	LCC West (Jhang)	588614	2.59	1.82	4.40	693	405	1098	439	309	748
9	Upper Jehlum	220094	0.89	0.70	1.59	604	432	1036	402	319	721
10	Lower Jehlum	614488	2.58	1.82	4.40	740	412	1152	420	297	717
11	Thal	773843	2.93	1.60	4.53	778	389	1167	379	207	586
13	Lower Bari Doab	675667	3.95	2.30	6.25	735	444	1180	585	341	926
14	Haveli	411711	2.65	1.32	3.97	814	437	1251	643	321	964
15	Mailsi	277956	2.19	0.96	3.15	918	492	1409	788	345	1132
16	Pakpattan	516233	3.74	1.95	5.69	838	491	1329	725	377	1102
17	Fordwah	173111	1.03	0.46	1.49	902	468	1371	596	267	863
18	Sadiqia	424850	2.54	1.24	3.79	954	465	1419	599	292	891
19	Abbasia	96139	0.45	0.21	0.66	946	449	1394	469	220	689
20	Bahawal	299776	2.14	0.99	3.13	935	461	1396	713	330	1043
21	Qaim	17121	0.14	0.06	0.20	912	501	1413	809	349	1158
22	Panjnad	551926	4.16	1.86	6.02	993	494	1487	754	338	1092
23	Dera Ghazi Khan	368546	1.65	0.83	2.48	854	472	1327	448	226	673
24	Muzaffergarh	331764	1.50	0.77	2.27	843	434	1278	452	232	683
25	Rangpur	139769	0.72	0.37	1.08	809	435	1245	512	263	776
29	Pat/Desert	157786	1.06	0.62	1.67	1356	526	1883	670	391	1061
31	Begari	340641	2.30	0.65	2.96	1330	474	1804	676	192	868
32	Ghotki	368335	2.29	0.50	2.79	1132	574	1706	621	137	758
33	North West	309093	1.17	0.34	1.50	1317	492	1809	377	109	486
34	Rice	209695	1.37	0.39	1.76	1307	488	1795	653	186	839
35	Dadu	236605	0.72	0.41	1.13	1278	519	1797	305	174	479
36	Khairpur West	130299	0.59	0.40	0.99	1126	590	1716	451	308	759
37	Khairpur East	182528	0.90	0.50	1.40	998	584	1582	495	272	766
38	Rohri	1045145	4.66	2.71	7.36	1065	581	1646	446	259	704
39	Nara	882491	3.04	1.71	4.75	1085	612	1697	344	194	538
40	Kalri	258592	0.52	0.23	0.75	1030	553	1582	201	88	289
41	Lined Channel	220137	0.84	0.26	1.10	1116	491	1607	382	117	499
42	Fuleli	360604	1.36	0.33	1.69	1059	651	1710	378	90	468
43	Pinyari	322112	0.49	0.22	0.72	1114	473	1587	153	69	223

Potential Evapotranspiration for 1000 Fully Cultivated Hectares in Each Canal Command (PE_{1000})

The proposed annual cropping intensities for the main canal commands of Indus vary grossly between 70% to 100% while for the non-perennial areas (entitled to river supply for summer season only) a minimum level of 30% can be expected in Kharif season. The reported annual cropping intensities during 1993-94 vary between 30% and 150%, indicating substantial increase in cropped areas and land use practices in some of the canal commands and quite stagnant situation in some other canals. Also, actual cropping patterns have been shifted from the planned patterns and a further drift could be expected. The potential water requirements of major crops presented in a previous section would help in land use planning. The consumptive requirements of the maximum cultivated command area, based on existing patterns, are presented in this section. This information would help in a quick estimation of potential water needs for different levels of planned cropping intensities.

Fully cultivated means area cropped once in a season or having an annual crop. Hence, theoretically, PE_{1000} water is required to irrigate 100% of CCA in each season or 200% per annum. Multiplying PE_{1000} with total CCA and cropping intensities could estimate the total potential crop water requirement of an area. The factor of PE_{1000} can readily be used to incorporate any change in cropping intensities.

Table 5.4. 10-daily Potential Evapotranspiration for 1000 ha Cropped Area (cropping pattern 1993-94).

Month	No. of 10-Daily	Punjab	Sindh	Month	No. of 10-Daily	Punjab	Sindh
		Mm^3				Mm^3	
JAN	1	0.15	0.28	JUL	1	0.52	0.82
	2	0.16	0.29		2	0.56	0.83
	3	0.17	0.29		3	0.58	0.84
FEB	1	0.25	0.36	AUG	1	0.56	0.73
	2	0.25	0.33		2	0.56	0.71
	3	0.24	0.31		3	0.54	0.65
MAR	1	0.34	0.40	SEP	1	0.45	0.53
	2	0.30	0.37		2	0.43	0.49
	3	0.25	0.47		3	0.40	0.43
APR	1	0.33	0.63	OCT	1	0.29	0.41
	2	0.28	0.39		2	0.25	0.41
	3	0.25	0.26		3	0.31	0.44
MAY	1	0.31	0.42	NOV	1	0.33	0.20
	2	0.48	0.47		2	0.35	0.21
	3	0.35	0.60		3	0.33	0.23
JUN	1	0.38	0.77	DEC	1	0.20	0.18
	2	0.47	0.91		2	0.11	0.20
	3	0.56	0.97		3	0.11	0.23

The PE_{1000} is estimated by using land use data of 1993-94 for each canal command, accumulated and standardized for Punjab and Sindh. The 10-daily average crop consumptive use from 1000 cropped hectares in both provinces is given in Table 5.4. For the cultivation of same area, annual potential water demand in Sindh is about 55% higher, difference is more in summer due to higher level of aridity. The peak demand in Punjab is relatively more distributed over three months. Computations for Sindh show peak demand in June due to the adopted crop coefficients for cotton, rice, sugarcane and minor crops. In reality, July might be sharing a part of it.

Comparison With Previous Studies

In the past, two studies have computed crop water demand for the main canals of Indus basin. This information has never been used for planning or water management, though referred in debates about regional water requirements for agriculture. Two components of agriculture demand, conveyance losses and field efficiency are beyond the scope of present analysis. Only, the estimation of potential evapotranspiration is compared in this section to see how this core factor is assessed over time.

The Lower Indus Project (LIP) in 1965 conducted big field exercise in the selected areas of Sindh province to estimate the crop water requirements. Water and Power Development Authority conducted another big study called "Revised Action Plan for Irrigated Agriculture" during 1977-79. The crop water requirements were estimated using lake evapotranspiration and average crop coefficient curves adopted from USBR.

Table 5.5. Comparison of Potential Water Demand (Mm^3) Estimated by LIP, WAPDA and IWMI for 1000 Cultivated ha at Farm Level.

Canals	IWMI 2000		WAPDA 1979		LIP 1965		
	Kharif	Rabi	Kharif	Rabi	Kharif-Fresh	Kharif-Saline	Rabi
Upper Chenab	5.97	3.43	7.82	3.67	-	-	-
Lower Dipalpur	7.29	3.88	7.28	4.64	-	-	-
LCC East (Gogera)	7.05	3.82	7.26	4.47	-	-	-
Thal	7.67	3.30	6.44	3.74	-	-	-
Fordwah	8.67	3.84	7.39	5.04	-	-	-
Sadiquia	8.87	4.10	7.37	4.76	-	-	-
Panjnad	9.17	4.17	7.55	5.55	-	-	-
Dera Ghazi Khan	7.93	3.65	8.15	4.83	-	-	-
Ghotki Canal	10.39	4.86	8.26	4.76	7.88	12.38	4.83
Begari Canal	13.38	4.47	11.72	4.58	7.15	11.82	4.58
North West Canal	13.27	4.50	11.85	5.23	7.25	-	4.33
Rice Canal	13.17	4.57	12.51	4.58	-	11.69	-
Dadu Canal	12.49	5.00	11.85	4.96	7.44	-	4.96
Khairpur West Canal	10.93	6.05	11.45	6.89	8.11	-	6.89
Khairpur East Canal	9.15	5.54	8.59	5.71	8.68	-	5.71
Nara Canal	10.11	6.08	9.37	6.10	9.76	-	6.10
Lined Channel	11.27	6.83	11.31	6.46	-	10.88	6.46
Kalri	10.31	5.47	7.54	5.47	-	-	5.47

The estimation of potential evapotranspiration for a few Punjab and Sindh canals is given in Table 5.5. The estimation by LIP is low, especially for summer in sweet groundwater zone. WAPDA estimations are same as LIP for Rabi. As WAPDA did not conduct field studies, the LIP report estimations are used. IWMI's computations are towards higher side, with a maximum difference of about 25%. The difference with WAPDA is mainly due to short crop maturing period (chapter 4) and higher percentage of low delta crops considered by WAPDA in 1979. The lower Indus study has adopted longer crop-periods with almost same accumulated K_c as WAPDA. The difference between LIP and IWMI mainly comes from cropping patterns. Both previous studies used lesser percentage of high delta crops, sugarcane, vegetables and gardens. The comparison shows an important role of cropping patterns in the net requirement of water for agriculture.

SUMMARY AND CONCLUSIONS

Summary

The different components of potential crop water requirement at the canal-command level are computed using updated information, including field experiments and data of maximum years. The water needs of major crops, fully irrigated standard units and the actual irrigated areas of each canal command are estimated to make output of this report readily useable for further research or planning.

The Behavior of Climatic Variables

Seasonal difference in climatic variables is substantial. The climate varies from north to south of the Indus Plains. To delineate the spatial distribution of climatic variables over canal command area of Indus Plain, monthly climatic data (maximum temperature, minimum temperature, humidity, wind speed, sunshine) from seventeen stations has been used. The behavior of climatic variables in Indus basin is concluded as:

- *Peshawar has minimum mean annual temperature and Hyderabad has maximum mean annual temperature. The mean annual temperature increases from north to south and ultimately effects the crop water requirement.*
- *The mean monthly temperature gradually increases from January to June and then sharply decreases in July due to monsoon effect. It remains more or less constant and then declines for the rest of the year. While the mean minimum temperature increases from January to June and then decreases.*
- *The highest humidity occurs during monsoon, which extends from early July to around mid-September. The average humidity in North is higher in winter, which is reversed in South.*
- *The wind speed is the maximum in the month of June in the entire Indus Basin due to the development of low-pressure area by the heating up of land during that month (Khan, 1991).*
- *The maximum sunshine hours are in the month of May and minimum in the month of December and January for Northern part and July-August for southern part of the Indus Basin.*
- *The mean annual precipitation ranges from less than 100 mm in parts of Lower Indus Plain to over 750 mm in the Upper Indus Plain near the foothills.*

Grouping of Canals

Based on variation in climate and major crops, Indus basin has been divided into different agro climatic and ecological zones. The Pakistan Agricultural Research Council in 1980 divided Pakistan in 10 Agro-Ecological zones, based on a survey carried out by FAO and review of the available literature on physiography, climate, soils, land use and other factors affecting agriculture production. In 1979 WAPDA conducted a study for agricultural planning. In this study the irrigated areas of Indus basin were grouped into seven agro-climatic zones. Areas in some of these zones have different crop calendars, reference evapotranspiration and different cropping patterns. Therefore, crop coefficients within some of the zones vary substantially. The current analysis divides 44 main canal commands into eleven groups based on crop calendar and average crop coefficients. A uniform water management policy can be adopted for each group.

The Computation and Variation of ET_o

The Penman Monteith equation is selected for the computation of ET_o. The computation of TAM consultants for CRBC and IWMI using Penman are quite close though different climatic data sets are used for the calculations. A bigger difference is shown by Penman Monteith (IWMI, 2000) with Delta II model (SPMP, 1988) and Priestley method (Bastiaanssen, 98), 10% higher and 20% lower respectively.

The ET_o computed by Hargreaves and Penman Monteith (FAO, 1998) for two stations with extreme climatic conditions indicates that Hargreaves computes 20% higher ET_o for Jaccobabad than Sialkot while Penman 75% higher. In the calculation of individual stations, Hargreaves is 10% lower for Jacobabad and 32% higher for Sialkot.

The upper and northeastern parts of the basin have reference evapotranspiration in the range of 1200-1300 mm because of mild climate. Whereas, the Southern Punjab and Sindh have ET_o in the range of 1700-2100 mm. During Kharif, Guddu and Sukkur barrage Right Bank canals (near to desert) have maximum ET_o value while in Rabi lower Sindh canals (near to sea) have maximum ET_o. The monthly evapotranspiration is highest in June except Kotri Barrage canals (Indus delta) where the maximum occurs in May due to sea effect. The monthly reference evapotranspiration in canal commands varies from 180 to 310 mm in June and from 30 to 90mm in December.

Selection of K_c

The variation of reference evapotranspiration along with different land forms results in diversified agriculture with respect to crop calendar and period. The crop coefficient curves of major crops are developed for each zone. Some of the crops have big difference in their duration for example rice and sorghum. While two main crops, wheat and cotton have a spatial shift in their sowing periods. Sugarcane is an annual crop, and has two crop calendars. The planting and harvesting dates vary from region to region due to climate and cropping patterns and within canal commands due to irrigation practices, crop variety and availability of water.

The periods of planting and harvesting, crop duration and crop growth stages are determined on the basis of primary and secondary information about cropping practices across the basin. For the major crops, planting and harvesting period extends for two to four weeks.

Average potential water requirements of different Rabi crops are in the same range of 240 mm to 462 mm. whereas; Kharif crops have quite variable requirements, 341 mm to 1004 mm. The average potential water requirements are higher towards south while the crop periods are shorter. The variation in the total potential water demand of different crops is from 14 to 50 percent in the basin.

The 10-daily potential water requirements of fully cultivated 1000 ha with existing cropping patterns show that water demand of Sindh is higher than Punjab. The demand pattern of Punjab is relatively flat due to a shift in sowing periods of different zones. Despite a scatter in peak demand, the months of higher and lower water demand are almost the same in both provinces.

Conclusions

- The agricultural practices differ substantially in the Indus Basin due to climate, soils, cropping patterns and availability of water. During last fifty years, potential water demand for irrigation has increased because of high delta crops and enhanced cultivation intensities. For the assessment of potential water demand for agriculture at the regional scale, grouping of canal commands based on potential crop water demand variables, i.e. reference evapotranspiration and crop coefficients is imperative. It adds to cropping patterns based agro-climatic division of Indus basin carried out in seventies.

- The estimation of reference evapotranspiration has a big impact on the assessment of crop water requirements, the computation and comparison with previous studies indicates:

  1. The time scale of climate data collected for 17 stations in Indus basin is adequate for the calculations of reference evapotranspiration. The ET_o calculated by Penman method with thirteen years gap (1987 and 2000) shows a difference of 5% only, indicating consistency of data collection procedures.
  2. A substantial difference in ET_o is introduced by the method of calculation due to empirical coefficients. Various methods used in Indus Basin estimate in different ranges. Hargreaves and Delta estimates 10% higher while Priestley Taylor computes 20% less than the Penman Monteith.
  3. The variation of annual reference evapotranspiration from North to South ranges from 1200mm to 2100 mm using Penman. The energy balance gives a range for actual evapotranspiration demand between 400mm to 1400mm.

- The average coefficients of crops grown in the basin have 15% variation over the season and 20% among the seasonal crops. The peak values of these coefficients are attenuated due to a scatter in growing periods, which dilates the coefficient curves. A two to four weeks shift in crop seasons and peak demand in different region is an important flexibility for water regulation during high stress periods.

- The spatial variation of potential water requirement among canal command areas is more than two folds for existing cropping patterns and same cropping intensities. Seasonal variation is about three folds. The demand hydrograph of each group of canals would help in operational planning of water resources.

- Cropping patterns and intensities are two important factors influencing potential crop water requirement in a CCA. The reported intensities vary from 30% to 150% for CCAs, introducing a factor of five in the variation of current potential water requirements. It indicates that some of the areas have more chances of increased water needs in future as compared to others.

- The importance of reliable data about cropping patterns and cultivated area is paramount in assessing the potential water demands for agriculture and the level of expected water stress.

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APPENDICES

Appendix I

Table A. Characteristics of Agro-Ecological Region.

Sr. No	Region	Temperature	Rain	Soil	Crops	Special
I	Indus Delta	34-40 19-20	125-250	Clayey Soil Silty Soil	Rice, Sugarcane, Pulses, Berseem, Wheat	Salinity of Soil, Poor Drainage
II	Southern irrigated plain	38-45 8-12	125-250	Silt Loam, Sandy Loam, Silty Clay	Rice, Wheat, Cotton, Sorghum, Mustered Sugarcane, Gram	20% Salt Affected Area
III(a)	Sandy Desert	39-41 7	125-250	Sandy Soils, Moving Sand Dunes, Clayey Soils	Guar, Millets, Wheat	Dust Storm are Common
III(b)	Sandy Desert	40 5.5	150-350	Stable Sand Ridges (sand and loamy fine sand soils)	Gram, Wheat, Cotton, Sugarcane	Internal Drainage
IV(a)	Northern Irrigated Plain	39.5-42 6-6.2	200-500	Sandy Loam, Clayey Loam	Rice, Wheat, Cotton, Sugarcane, Maize, Oilseeds, Melons	Canal Irrigated Cropping
IV(b)	Northern Irrigated Plain	38 5	500	Clayey	Sugarcane, Maize, Tobacco, Wheat, Berseem	Intensively Cultivated Area
V	Barani Land	38-38.5 3-7	200-1000	Silty Loam, Silty Clayey loam, Clay Loam	Wheat, Millets, Rice, Maize, Oilseeds, Pulses, Fodder	Shallow Soils Unsuitable for Root Growth
VI	Wet mountain	35 0-4	>1000	Silt Loams, Silty Clays	Maize, Wheat, Rice, Deciduous Fruit	Steep Mountain Slopes
VII	Northern Dry Mountains	Undifferentiated	300-1000	Deep and Clayey formed of Colluvial material and alluvial deposits	Maize, Wheat, Fodders, Fruit, Apricot	Glaciers and Snow fields
VIII	Western Dry Mountain	30-39 -3-7.7	125-500	Strongly Calcareous Soils, Gravelly Soils	Fruit, Wheat, Vegetables, fodder, Maize	Numerous Hill Torrents
IX	Dry Western Plateau	33-40.5 3-15	50-200	Strongly Calcareous Silt Loams Soils, Gravelly Soils	Tropical Fruits, Wheat, Summer Cereals	Sailaba Agriculture System
X	Sulaiman Piedmont	40-43.6 5.8-7.6	125-250	Loamy, Clayey	Wheat, Gram, Lentils, Oilseeds, Millet, Sorghum	Sailaba Agriculture System

Box 2.1. Agro-climatic regions of Indus Basin.

Northwest Frontier Mixed Cropping (NFMC)

Kabul River and its tributaries, the swat and kalapandi, drain the half saucer-shaped alluvial valley of Peshawar. It has semi-arid sub-tropical continental type of climate, with meager rain both in winter and summer. Salinity and sodicity is a very minor problem, occurring in the central part in small patches. This region is one of the most intensively cultivated areas of the country. Due to canal irrigation main crops are sugarcane, maize, tobacco, wheat and Berseem. In addition, considerable proportion of the area is under fruit orchard of pears and plums.

Punjab Mixed Cropping (PMC)

This zone contains nearly two million acres canal command area, mostly on the left bank of the Indus below the Jinnah barrage. The Paharpur and Chashma Right Bank canal command areas in the NWFP Province also included in this zone. The low cropping intensities and yields are due to rough topography, sandy soils and high seepage. The presence of fresh groundwater and localized waterlogging in most of the area favors the potential for tubewell development.

Punjab Rice Wheat (PRW)

This zone comprises of about 2.8 million acres, virtually all of it is underlain by fresh groundwater. This area has intensive development of tubewells. The abundance availability of water results in highest cropping intensities. The Basmati rice is the dominant cash crop. The rapid mechanization was observed due to relatively high returns to farming combined with a shortage of labour.

Punjab Sugarcane Wheat (PSW)

This area lies between PMW and PRW, and covers about 4.4 million acres. The major crops are wheat and sugarcane. About one third of the zone is saline, but the groundwater is extensively used in the rest of area. Water shortages do exist and are largely attributed to low watercourse efficiencies.

Punjab Cotton Wheat (PCW)

This is the largest agro-climatic zone in the Indus Basin Irrigation System, covering over 11 million acres on left bank of the Indus among Sindh Province, India, and the other Punjab zones. Cotton and wheat are dominant crops with some of the highest yields in Pakistan. Groundwater is extensively used regardless of that approximately one fourth of total area is severely saline and waterlogged.

Sindh Cotton Wheat (SCW)

It covers about 6 million acres. Nearly half of the north and most of the south is saline or waterlogged. Yields of the cultivated area are favourable. Groundwater potential through tubewell development is minimal due to saline/brackish water. Surface water supplies are hampered by high losses, particularly at watercourse level.

Sindh Rice Wheat (SRW)

About two-thirds of 4.4 million acres in the north is saline and the entire south is similarly classified. Rice is most favourable crop for that type of soil. Because of high water table cropping intensities and yields for other crops are lower, particularly in the south of the basin.

Table B. Average Monthly Maximum Temperature (^oC)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVG
Saidu Sharif	14	15	19	26	32	36	34	33	32	28	22	16	26
Peshawar	18	19	24	30	36	40	38	36	35	31	26	20	29
D. I. Khan	20	22	27	33	39	41	38	37	37	33	28	22	31
Jhelum	20	22	27	33	38	41	36	34	35	33	28	21	31
Sialkot	18	21	25	32	38	40	34	33	33	31	26	20	29
Mianwali	20	22	27	33	39	43	39	38	37	34	28	22	32
Sargodha	20	23	28	34	39	42	38	36	36	34	28	22	32
Lahore	20	22	27	34	39	40	36	35	35	33	27	22	31
Faisalabad	19	22	28	33	38	41	37	36	36	33	28	22	31
Jhang	20	23	27	34	40	42	38	37	36	34	28	22	32
Multan	21	23	29	35	40	42	39	38	37	35	28	23	33
Bhawalnagar	20	23	28	35	41	42	38	37	36	34	29	23	32
Bahawalpur	22	24	30	36	41	42	40	38	37	35	29	24	33
Khanpur	22	25	30	37	41	43	40	38	37	35	29	23	33
Jacobabad	22	25	31	38	43	44	41	38	37	35	30	24	34
Larkana	23	26	32	38	43	44	41	38	37	36	30	25	34
Nawab Shah	24	27	33	39	43	43	40	39	38	37	31	26	35
Hyderabad	25	28	34	39	42	40	38	36	37	37	32	26	34

Table C. Average Monthly Minimum Temperature (^oC).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVG
Saidu Sharif	4	4	8	14	18	22	21	20	19	15	10	6	14
Peshawar	4	6	11	17	21	26	27	26	22	16	10	5	16
D. I. Khan	4	7	13	14	18	27	27	26	24	17	10	5	16
Jhelum	5	8	12	18	22	26	26	25	23	17	10	6	16
Sialkot	5	7	12	17	22	25	25	25	22	16	10	6	16
Mianwali	4	6	12	18	23	27	28	27	24	16	9	5	16
Sargodha	3	7	12	18	22	26	27	26	24	17	10	5	16
Lahore	6	9	14	20	24	27	27	26	24	18	12	7	18
Faisalabad	4	7	12	18	22	25	27	27	24	17	10	5	16
Jhang	5	8	13	19	24	28	28	27	24	18	11	6	18
Multan	4	8	13	19	24	29	29	28	25	18	11	5	18
Bhawalnagar	6	9	14	20	25	28	28	27	25	19	13	8	18
Bahawalpur	5	8	14	20	24	28	29	28	25	18	11	6	18
Khanpur	4	7	13	19	24	27	27	26	23	16	10	5	17
Jacobabad	8	11	16	22	27	29	29	28	26	20	14	9	20
Larkana	8	10	16	20	25	28	28	27	25	20	15	10	19
Nawab Shah	6	9	14	20	24	28	28	26	24	18	12	7	18
Hyderabad	11	14	19	23	26	28	28	27	25	22	17	12	21

Table D. Average Monthly Relative Humidity.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVG
Saidu Sharif	65	66	63	57	47	39	63	70	60	57	60	67	60
Peshawar	59	58	60	55	42	39	58	67	60	56	60	64	57
D. I. Khan	60	57	57	51	43	47	64	69	62	57	61	63	57
Jhelum	67	61	58	49	40	44	66	75	68	62	67	70	61
Sialkot	75	68	64	51	41	46	73	79	74	68	74	78	66
Mianwali	67	63	63	54	43	43	60	65	61	59	65	69	59
Sargodha	67	61	58	50	41	45	63	71	64	61	67	71	60
Lahore	66	59	56	45	38	45	68	73	65	60	66	69	59
Faisalabad	67	62	59	51	42	43	65	69	64	58	65	68	59
Jhang	64	59	58	46	36	41	60	65	62	56	61	66	56
Multan	62	57	53	44	37	42	58	61	58	55	64	67	55
Bhawalnagar	65	60	57	44	37	41	62	65	62	56	61	67	56
Bahawalpur	63	60	57	46	39	45	58	63	61	60	63	66	57
Khanpur	59	54	50	42	37	44	55	60	60	56	60	62	53
Jacobabad	51	48	44	32	32	42	57	64	61	51	50	54	49
Larkana	67	61	55	46	44	51	64	71	73	66	65	68	61
Nawab Shah	59	56	53	48	46	55	64	68	65	58	61	63	58
Hyderabad	48	46	44	46	52	60	66	68	64	51	48	50	53

Table E. Average Monthly Wind Speed (Km/day).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AVG
Peshawar	64	74	89	93	112	111	113	103	79	55	54	52	83
D. I. Khan	76	88	101	111	126	127	139	123	94	67	53	56	96
Jhelum	57	73	88	98	107	105	90	72	59	51	41	49	74
Sialkot	41	57	76	75	76	84	76	57	47	36	25	31	60
Mianwali	50	56	68	77	92	93	97	79	60	45	35	39	70
Sargodha	89	112	138	150	159	170	179	151	121	98	83	86	129
Lahore	47	72	91	98	97	104	103	82	61	48	34	36	73
Faisalabad	49	68	81	85	94	103	107	93	76	57	44	43	74
Jhang	64	87	112	132	153	177	181	147	118	82	58	51	113
Multan	46	74	102	102	105	158	139	131	113	61	38	39	92
Bhawalnagar	114	145	172	184	215	252	242	211	180	130	107	98	178
Bahawalpur	73	103	107	106	123	167	167	146	125	85	67	61	111
Khanpur	82	114	133	128	140	186	190	157	122	90	70	74	124
Jacobabad	104	141	190	206	231	273	288	249	183	123	91	83	196
Larkana	111	140	175	197	225	287	288	248	185	123	96	96	194
Nawab Shah	123	136	146	179	214	314	289	245	188	124	106	121	188
Hyderabad	100	102	124	171	248	321	314	282	221	110	89	103	180

Table F. Average Daily Sunshine Hours.

Month	Hyd-abd	Nwbshah	Rohri	Multan	Faslabd	B-nagar
Oct-93	9.85	9.73	9.48	7.99	9.22	9.16
Nov-93	8.25	8.48	9.45	7.53	7.70	8.18
Dec-93	8.20	8.20	9.05	6.76	7.35	5.53
Jan-94	8.39		7.81	5.82	4.58	4.73
Feb-94	9.28	8.96	7.59	7.38	6.43	7.26
Mar-94	9.09	8.60	9.35	9.35	8.30	8.49
Apr-94	9.28	8.00	8.99	8.14	8.43	8.99
May-94	10.20		10.18	9.17	10.25	9.51
Jun-94	7.18	9.72	11.24	8.89	9.10	9.09
Jul-94	3.45	6.26	7.49	7.61	6.99	6.16
Aug-94	3.66	6.06	8.55	8.20	7.16	8.08
Sep-94	8.23	8.96	9.36	8.51	9.45	8.61

Appendix II

Table A. Reference Evapotranspiration of Canals of Indus Basin Irrigation System.

Name of Canal	ET_o in mm												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Upper Chenab	41	59	106	142	185	187	155	144	130	96	54	38	1337
Marala Ravi	39	58	104	141	182	184	149	140	125	92	51	36	1303
Upper Dipalpur	43	62	112	151	195	195	162	146	136	100	55	40	1396
Lower Dipalpur	45	66	119	154	197	211	177	164	145	103	57	43	1481
BRBD-INT	41	59	107	145	186	188	153	142	129	95	53	37	1334
Gugera	43	62	111	147	193	195	165	150	138	101	56	41	1401
Jhang	44	63	113	150	199	203	172	156	141	103	58	42	1445
Upper Jehlum	48	65	114	155	204	207	168	144	144	121	78	53	1501
Lower Jehlum	48	67	117	158	211	216	179	156	147	118	74	51	1542
Thal	48	67	120	157	207	222	190	173	150	108	61	46	1549
Lower Bari Doab	45	66	120	154	197	214	181	168	147	104	58	43	1497
Haveli	49	69	124	161	211	231	197	181	153	109	62	47	1593
Mailsi	47	69	126	157	198	227	193	182	155	107	59	46	1565
Pakpattan	47	69	126	157	198	227	193	182	155	107	59	46	1565
Fordwah	62	83	139	194	258	269	205	195	170	136	84	58	1853
Sadiqia	59	81	132	180	235	250	199	190	164	129	79	55	1752
Abbasia	58	82	133	172	217	235	199	188	158	123	75	55	1695
Bahwal	56	78	126	165	211	230	193	185	159	122	74	52	1652
Qaim	58	81	120	178	232	246	198	188	158	127	75	54	1715
Panjnad	58	82	133	172	217	235	199	188	158	123	75	55	1695
D.G.Khan	47	69	126	157	198	227	193	182	155	107	59	46	1565
Muzaffergarh	47	69	126	157	198	227	193	182	155	107	59	46	1565
Rangpur	49	69	124	161	211	231	197	181	153	109	62	47	1593
Pat Feeder	80	98	172	226	287	305	246	214	181	144	91	68	2112
Desert	80	98	172	226	287	305	246	214	181	144	91	68	2112
Begari	77	96	167	218	282	300	238	207	182	140	92	69	2069
Ghotki	72	92	159	205	262	280	227	202	174	135	87	65	1959
North-West	77	96	167	218	282	300	238	207	182	140	92	69	2069
Rice	74	94	163	210	278	295	230	200	182	137	93	70	2026
Dadu	80	99	160	206	273	289	227	195	183	144	96	77	2031
Khairpur West	74	94	163	210	278	295	230	200	182	137	93	70	2026
Khairpur East	80	99	164	213	278	294	233	202	182	144	95	74	2058
Rohri	83	100	160	207	271	272	215	188	183	147	97	80	2003
Nara	87	104	158	205	268	261	208	182	183	153	100	85	1991
Kalri	88	103	159	208	267	238	191	172	182	153	99	86	1946
Lined-Channel	88	103	159	208	267	238	191	172	182	153	99	86	1946
Pinyari	88	103	159	208	267	238	191	172	182	153	99	86	1946
CRBC	50	68	118	149	198	206	186	171	143	103	60	46	1497
NWFP Canals	42	55	96	131	178	188	161	152	125	87	52	37	1303

Appendix III

Table A. Kc values of Wheat for Different Groups of Canals.

Month	10-daily	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9	G-10	G-11
Oct	1											
	2									0.23	0.23	0.23
	3									0.37	0.37	0.37
Nov	1	0.30					0.28	0.28	0.37	0.45	0.45	0.45
	2	0.37	0.28	0.28	0.28	0.28	0.28	0.28	0.37	0.61	0.45	0.45
	3	0.37	0.28	0.38	0.38	0.38	0.38	0.38	0.45	0.77	0.61	0.61
Dec	1	0.44	0.37	0.45	0.45	0.45	0.42	0.42	0.61	0.83	0.77	0.71
	2	0.52	0.49	0.54	0.54	0.54	0.56	0.56	0.77	0.92	0.92	0.92
	3	0.61	0.62	0.71	0.71	0.71	0.82	0.82	0.92	1.16	1.16	1.16
Jan	1	0.73	0.74	0.91	0.91	0.91	0.91	0.91	1.16	1.23	1.25	1.32
	2	0.89	0.87	1.00	1.00	1.00	1.00	1.00	1.25	1.32	1.32	1.33
	3	0.93	0.99	1.10	1.15	1.15	1.10	1.10	1.32	1.33	1.33	1.23
Feb	1	1.05	1.05	1.10	1.15	1.15	1.15	1.15	1.33	1.23	1.23	1.16
	2	1.10	1.10	1.10	1.15	1.15	1.15	1.15	1.23	1.16	1.16	1.08
	3	1.19	1.10	1.10	1.15	1.15	1.00	1.00	1.16	1.08	1.08	0.86
Mar	1	1.19	1.10	1.00	1.05	1.05	0.88	0.88	1.08	0.96	0.96	0.66
	2	1.10	0.95	0.88	0.88	0.88	0.71	0.71	0.96	0.81	0.81	0.63
	3	0.93	0.86	0.71	0.71	0.71	0.56	0.56	0.81	0.66	0.66	0.60
Apr	1	0.76	0.67	0.56	0.56	0.56	0.43	0.43	0.65			
	2	0.56	0.62	0.43	0.43	0.43	0.30	0.35				
	3	0.23	0.40	0.23	0.30	0.30						
May	1		0.20									
	2											
	3											

Table B. Kc values of Cotton for Different Groups of Canals.

Month	10-daily	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9	G-10	G-11
Apr	1								0.26	0.26	0.26	
	2								0.28	0.30	0.30	
	3	0.28							0.42	0.38	0.36	
May	1	0.32	0.28	0.32			0.32	0.32	0.58	0.49	0.44	
	2	0.39	0.32	0.39	0.32	0.32	0.39	0.39	0.66	0.55	0.50	
	3	0.52	0.39	0.52	0.39	0.39	0.52	0.52	0.76	0.66	0.60	
Jun	1	0.72	0.52	0.72	0.52	0.52	0.72	0.72	0.88	0.76	0.76	
	2	0.93	0.72	0.93	0.72	0.72	0.93	0.93	0.96	0.88	0.88	
	3	1.09	0.93	1.09	0.93	0.93	1.09	1.09	1.08	0.96	0.96	
Jul	1	1.12	1.09	1.12	1.09	1.09	1.12	1.12	1.13	1.08	1.08	
	2	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.15	1.13	1.13	
	3	1.09	1.12	1.09	1.12	1.12	1.09	1.09	1.15	1.15	1.15	
Aug	1	1.00	1.09	1.00	1.09	1.09	1.00	1.00	1.15	1.15	1.15	
	2	0.85	1.00	0.85	1.00	1.00	0.85	0.85	1.09	1.15	1.15	
	3	0.74	0.85	0.74	0.85	0.85	0.74	0.74	0.92	1.00	1.00	
Sep	1	0.67	0.74	0.67	0.74	0.74	0.67	0.67	0.70	0.86	0.86	
	2	0.63	0.67	0.63	0.67	0.67	0.63	0.63	0.61	0.62	0.62	
	3	0.51	0.63	0.51	0.56	0.56	0.51	0.51	0.49	0.46	0.46	
Oct	1	0.47	0.51	0.47	0.51	0.51	0.47	0.47	0.35	0.27	0.27	
	2	0.42	0.47	0.42	0.47	0.47	0.42	0.42	0.21	0.15	0.15	
	3	0.37	0.42	0.36	0.42	0.42	0.40	0.40				
Nov	1	0.26	0.40	0.30	0.40	0.40	0.37	0.37				
	2		0.37	0.26	0.37	0.37		0.34				
	3											

Table C. Kc values of Sugarcane for Different Groups of Canals.

Month	10-daily	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9	G-10	G-11
Jan	1		0.77				0.40	0.77	0.51	0.51		
	2		0.68				0.40	0.68	0.51	0.51		
	3		0.59				0.40	0.59	0.51	0.51		
Feb	1	0.28	0.40	0.28	0.28	0.28	0.40	0.45	0.53	0.53	0.51	0.51
	2	0.37	0.40	0.37	0.37	0.37	0.45	0.45	0.53	0.53	0.51	0.51
	3	0.45	0.40	0.45	0.45	0.45	0.54	0.45	0.53	0.53	0.51	0.51
Mar	1	0.53	0.40	0.53	0.53	0.53	0.62	0.45	0.91	0.91	0.51	0.51
	2	0.60	0.45	0.60	0.60	0.60	0.71	0.49	0.96	0.96	0.51	0.51
	3	0.70	0.54	0.70	0.70	0.70	0.80	0.58	1.07	1.07	0.51	0.51
Apr	1	0.91	0.62	0.91	0.91	0.91	0.89	0.66	1.11	1.11	0.53	0.53
	2	0.99	0.71	0.99	0.99	0.99	0.97	0.74	1.11	1.11	0.53	0.53
	3	1.12	0.80	1.12	1.12	1.12	1.06	0.82	1.11	1.11	0.53	0.53
May	1	1.13	0.89	1.13	1.13	1.13	1.10	0.90	1.16	1.16	0.91	0.91
	2	1.14	0.97	1.14	1.14	1.14	1.15	0.98	1.16	1.16	0.96	0.96
	3	1.15	1.06	1.15	1.15	1.15	1.15	1.06	1.16	1.16	1.07	1.07
Jun	1	1.19	1.19	1.20	1.16	1.16	1.15	1.15	1.19	1.19	1.11	1.11
	2	1.19	1.19	1.20	1.18	1.18	1.15	1.15	1.19	1.19	1.11	1.11
	3	1.19	1.19	1.20	1.21	1.21	1.15	1.15	1.21	1.21	1.11	1.11
July	1	1.19	1.19	1.20	1.24	1.24	1.15	1.15	1.21	1.21	1.16	1.16
	2	1.19	1.19	1.20	1.25	1.25	1.15	1.15	1.17	1.17	1.16	1.16
	3	1.19	1.19	1.20	1.25	1.25	1.15	1.15	1.17	1.17	1.16	1.16
Aug	1	1.19	1.19	1.20	1.23	1.23	1.15	1.15	1.01	1.01	1.19	1.19
	2	1.19	1.19	1.20	1.17	1.17	1.15	1.15	1.01	1.01	1.19	1.19
	3	1.19	1.19	1.20	1.12	1.12	1.15	1.15	1.01	1.01	1.21	1.21
Sep	1	1.19	1.19	1.20	1.11	1.11	1.15	1.15	0.85	0.85	1.21	1.21
	2	1.19	1.19	1.20	1.06	1.06	1.15	1.15	0.85	0.85	1.17	1.17
	3	1.19	1.19	1.20	1.05	1.05	1.15	1.15	0.85	0.85	1.17	1.17
Oct	1	0.95	1.19	1.20	1.05	1.05	1.15	1.15	0.69	0.69	1.01	1.01
	2	0.89	1.19	1.20	1.02	1.02	1.15	1.15	0.69	0.69	1.01	1.01
	3	0.70	1.19	1.20	1.00	1.00	1.10	1.15	0.69	0.69	1.01	1.01
Nov	1	0.52	1.19	1.20	0.95	0.95	1.05	1.05			0.68	0.68
	2	0.46	1.19	1.13	0.89	0.89	0.96	0.96			0.66	0.66
	3	0.42	1.19	1.01	0.70	0.70	0.87	0.87			0.63	0.63
Dec	1		1.05	0.89	0.52	0.52	0.77	0.77				
	2		0.96	0.77	0.46	0.46	0.68	0.68				
	3		0.87	0.65	0.42	0.42	0.59	0.59				

Table D: Kc values of Maize for Different Groups of Canals.

Month	10-daily	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9	G-10	G-11
Jun	1											
	2	0.09										
	3	0.12	0.09	0.09	0.09							
July	1	0.35	0.12	0.12	0.12	0.09	0.09					
	2	0.63	0.23	0.23	0.23	0.12	0.12					
	3	0.77	0.32	0.32	0.32	0.23	0.23					
Aug	1	0.79	0.63	0.63	0.63	0.32	0.32					
	2	0.82	0.77	0.77	0.77	0.63	0.63					
	3	0.83	0.79	0.79	0.79	0.77	0.77					
Sept	1	0.82	0.82	0.82	0.82	0.79	0.79					
	2	0.72	0.83	0.83	0.83	0.82	0.82					
	3	0.56	0.82	0.82	0.82	0.83	0.83					
Oct	1	0.41	0.72	0.72	0.72	0.82	0.82					
	2	0.18	0.56	0.56	0.56	0.72	0.72					
	3		0.33	0.33	0.33	0.56	0.56					
Nov	1					0.33	0.33					
	2					0.18	0.18					
	3											

Table E. Kc values of Sorghum for Different Groups of Canals.

Month	10-daily	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9	G-10
Jun	1							0.18	0.20		
	2		0.18				0.18	0.23	0.23	0.20	0.20
	3		0.23	0.18	0.18	0.18	0.23	0.30	0.26	0.23	0.23
July	1		0.30	0.23	0.23	0.23	0.30	0.38	0.32	0.26	0.26
	2		0.38	0.30	0.30	0.30	0.38	0.49	0.42	0.32	0.32
	3		0.49	0.38	0.38	0.38	0.49	0.66	0.59	0.40	0.40
Aug	1		0.66	0.49	0.49	0.49	0.66	0.80	0.79	0.56	0.56
	2		0.80	0.66	0.66	0.66	0.80	0.92	0.85	0.79	0.79
	3		0.92	0.80	0.80	0.80	0.92	0.98	0.86	0.90	0.90
Sep	1		0.98	0.92	0.92	0.92	0.98	0.97	0.85	0.90	0.90
	2		0.97	0.98	0.98	0.98	0.97	0.93	0.79	0.90	0.90
	3		0.93	0.97	0.97	0.97	0.93	0.83	0.65	0.82	0.82
Oct	1		0.83	0.93	0.93	0.93	0.83	0.68	0.52	0.67	0.67
	2		0.68	0.83	0.83	0.83	0.68	0.38	0.37	0.52	0.52
	3		0.38	0.68	0.68	0.68	0.38	0.23		0.37	0.37
Nov	1		0.23	0.38	0.38	0.38	0.23				
	2			0.23	0.23	0.23					
	3										

Table F. Kc values of Rice for Different Groups of Canals.

Month	10-daily	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9	G-10	G-11
Apr	1											
	2								0.06	0.06	0.06	
	3								0.12	0.12	0.12	
May	1							0.04	0.24	0.24	0.24	0.12
	2		0.03			0.04	0.04	0.10	0.48	0.48	0.48	0.24
	3		0.05	0.03	0.03	0.10	0.10	0.17	0.75	0.75	0.75	0.48
Jun	1		0.10	0.05	0.05	0.17	0.17	0.33	1.13	1.13	1.13	0.75
	2		0.21	0.10	0.10	0.33	0.33	0.67	1.35	1.35	1.35	1.23
	3		0.35	0.21	0.21	0.67	0.67	0.90	1.45	1.45	1.45	1.45
Jul	1		0.82	0.45	0.45	0.90	0.90	1.20	1.55	1.55	1.55	1.45
	2		1.03	0.72	0.72	1.20	1.20	1.35	1.55	1.55	1.55	1.55
	3		1.30	1.03	1.03	1.35	1.35	1.35	1.55	1.55	1.55	1.55
Aug	1		1.35	1.30	1.30	1.35	1.35	1.45	1.45	1.45	1.45	1.55
	2		1.40	1.35	1.35	1.45	1.45	1.35	1.34	1.40	1.34	1.45
	3		1.40	1.40	1.40	1.35	1.35	1.13	1.17	1.26	1.17	1.34
Sep	1		1.35	1.40	1.40	1.13	1.13	0.96	0.87	0.87	0.87	1.17
	2		1.13	1.35	1.35	0.96	0.96	0.69	0.73	0.73	0.73	0.87
	3		0.96	1.13	1.13	0.69	0.69	0.55	0.58	0.58	0.58	0.73
Oct	1		0.69	0.96	0.96	0.55	0.55	0.42	0.29	0.29	0.29	0.58
	2		0.55	0.69	0.69	0.42	0.42	0.30	0.14	0.14	0.14	0.29
	3		0.42	0.55	0.55	0.30	0.30	0.19				0.29
Nov	1		0.30	0.42	0.42	0.19	0.19					0.14
	2		0.18	0.30	0.30							
	3			0.18	0.18							

Table G. Kc values of Oilseeds for Different Groups of Canals.

Month	10-daily	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9	G-10	G-11
Sep	1										0.068	0.12
	2							0.12	0.024	0.068	0.24	0.24
	3		0.12	0.12	0.12	0.12	0.12	0.19	0.124	0.16	0.332	0.32
Oct	1		0.19	0.19	0.19	0.19	0.19	0.28	0.224	0.2	0.42	0.42
	2		0.28	0.28	0.28	0.28	0.28	0.35	0.324	0.272	0.486	0.486
	3		0.35	0.35	0.35	0.35	0.35	0.4	0.42	0.4	0.651	0.651
Nov	1		0.4	0.4	0.4	0.4	0.4	0.49	0.486	0.44	0.73	0.73
	2		0.49	0.49	0.49	0.49	0.49	0.59	0.651	0.558	0.88	0.88
	3		0.59	0.59	0.59	0.59	0.59	0.7	0.7	0.7	0.94	0.94
Dec	1		0.7	0.7	0.7	0.7	0.7	0.81	0.88	0.88	1	1
	2		0.81	0.81	0.81	0.81	0.81	0.9	0.94	0.94	1	1
	3		0.9	0.9	0.9	0.9	0.9	1	1	0.94	0.94	0.94
Jan	1		1	1	1	1	1	1	1	0.95	0.67	0.665
	2		1	1	1	1	1	0.97	1	0.95	0.57	0.57
	3		0.97	0.97	0.97	0.97	0.97	0.91	0.9	0.95	0.31	0.38
Feb	1		0.91	0.91	0.91	0.91	0.91	0.88	0.8	0.8	0.23	0.38
	2		0.88	0.88	0.88	0.88	0.88	0.66	0.7	0.646	0.171	0.285
	3		0.66	0.66	0.66	0.66	0.66	0.56	0.6	0.475		
Mar	1		0.56	0.56	0.56	0.56	0.56	0.43	0.5	0.2375		
	2		0.43	0.43	0.43	0.43	0.43	0.32	0.43	0.19		
	3		0.32	0.32	0.32	0.32	0.32	0.23	0.217	0.12		
Apr	1		0.28	0.28	0.28	0.28	0.28	0.12	0.18			
	2		0.23	0.23	0.23	0.23	0.23	0.06	0.06			
	3		0.12	0.12	0.12	0.12	0.12					

Table H. Kc values of Pulses for Different Groups of Canals.

Month	10-daily	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9	G-10	G-11
Nov	1											0.34
	2								0.34		0.34	0.4
	3								0.4		0.4	0.44
Dec	1								0.44		0.44	0.51
	2								0.51		0.51	0.61
	3								0.61		0.61	0.74
Jan	1								0.75		0.75	0.94
	2								0.94		0.94	1
	3								1		1	1.15
Feb	1								1.15		1.15	0.92
	2								0.92		0.92	0.47
	3								0.47		0.47	0.29
Mar	1								0.29		0.29	0.19
	2								0.19		0.19	
	3											

Table I. Kc values of Rabi Minor Crops for Different Groups of Canals.

Month	10-daily	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9	G-10	G-11
Sep	1											
	2	0.18					0.18	0.18	0.18	0.18	0.18	
	3	0.24	0.18	0.18	0.18	0.18	0.24	0.24	0.24	0.24	0.24	0.18
Oct	1	0.38	0.24	0.24	0.24	0.24	0.38	0.38	0.38	0.38	0.38	0.43
	2	0.45	0.38	0.38	0.38	0.38	0.45	0.45	0.45	0.45	0.45	0.7
	3	0.56	0.45	0.45	0.45	0.45	0.56	0.56	0.56	0.56	0.56	0.82
Nov	1	0.72	0.56	0.56	0.56	0.56	0.72	0.72	0.72	0.72	0.72	0.88
	2	0.8	0.72	0.72	0.72	0.72	0.8	0.8	0.8	0.8	0.8	0.84
	3	0.84	0.8	0.8	0.8	0.8	0.84	0.84	0.84	0.84	0.84	0.8
Dec	1	0.88	0.84	0.84	0.84	0.84	0.88	0.88	0.88	0.88	0.88	0.76
	2	0.93	0.88	0.88	0.88	0.88	0.93	0.93	0.93	0.93	0.93	0.74
	3	0.96	0.93	0.93	0.93	0.93	0.97	0.97	0.97	0.97	0.97	0.72
Jan	1	0.96	1	1	0.95	1	1	0.98	0.96	0.96	0.96	0.96
	2	0.98	0.98	0.98	0.95	0.98	0.98	0.96	0.93	0.93	0.93	0.93
	3	0.96	0.96	0.96	0.95	0.96	0.96	0.93	0.88	0.88	0.88	0.88
Feb	1	0.93	0.93	0.93	0.9	0.93	0.93	0.88	0.85	0.85	0.85	0.85
	2	0.88	0.88	0.88	0.88	0.88	0.88	0.85	0.81	0.81	0.81	0.81
	3	0.85	0.85	0.85	0.81	0.85	0.85	0.81	0.76	0.76	0.76	0.76
Mar	1	0.81	0.81	0.81	0.78	0.81	0.81	0.76	0.67	0.67	0.67	0.67
	2	0.76	0.76	0.76	0.67	0.76	0.76	0.67	0.63	0.63	0.63	0.63
	3	0.67	0.67	0.67	0.52	0.67	0.67	0.63	0.52	0.52	0.52	0.52
Apr	1	0.56	0.63	0.63	0.31	0.63	0.63	0.52	0.31	0.31	0.31	0.31
	2	0.42	0.52	0.52	0.18	0.52	0.52	0.31				
	3	0.21	0.31	0.31	0.12	0.31	0.31					

Table J. Kc values of Kharif Minor Crops for Different Groups of Canals.

Month	10-daily	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9	G-10	G-11
Feb	1											0.08
	2											0.10
	3											0.15
Mar	1									0.10	0.10	0.20
	2									0.20	0.20	0.30
	3									0.37	0.37	0.37
Apr	1	0.37				0.37	0.37	0.37	0.70	0.76	0.76	0.76
	2	0.49				0.49	0.49	0.49	0.76	0.76	0.76	0.76
	3	0.56	0.37	0.37	0.37	0.56	0.56	0.56	0.80	0.76	0.76	0.76
May	1	0.61	0.49	0.49	0.49	0.61	0.61	0.61	0.80	0.76	0.76	0.76
	2	0.68	0.56	0.56	0.56	0.68	0.68	0.68	0.60	0.57	0.57	0.57
	3	0.74	0.61	0.61	0.61	0.74	0.74	0.74	0.70	0.67	0.67	0.67
Jun	1	0.80	0.68	0.68	0.68	0.80	0.80	0.80	0.76	0.72	0.72	0.72
	2	0.84	0.74	0.74	0.74	0.84	0.84	0.84	0.80	0.76	0.76	0.76
	3	0.84	0.80	0.80	0.80	0.84	0.84	0.84	0.80	0.76	0.76	0.76
Jul	1	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.80	0.76	0.76	0.76
	2	0.84	0.95	0.95	0.95	0.84	0.84	0.84	0.80	0.76	0.76	0.76
	3	0.84	0.95	0.95	0.95	0.84	0.84	0.84	0.80	0.76	0.76	0.76
Aug	1	0.84	0.95	0.95	0.95	0.84	0.84	0.84	0.80	0.76	0.76	0.76
	2	0.84	0.95	0.95	0.95	0.84	0.84	0.84	0.80	0.76	0.76	0.76
	3	0.84	0.95	0.95	0.95	0.84	0.84	0.84	0.80	0.76	0.76	0.76
Sep	1	0.79	0.95	0.95	0.95	0.79	0.79	0.79	0.85	0.81	0.81	0.81
	2	0.73	0.84	0.84	0.84	0.73	0.73	0.73	0.90	0.86	0.86	0.86
	3	0.63	0.79	0.79	0.79	0.63	0.63	0.63	0.80	0.76	0.76	0.76
Oct	1	0.54	0.73	0.73	0.73	0.42	0.54	0.54	0.76	0.72	0.72	0.72
	2	0.42	0.63	0.63	0.63		0.23	0.23	0.70	0.67	0.67	0.67
	3		0.46	0.46	0.46				0.63	0.60	0.60	0.60
Nov	1								0.47	0.43	0.43	0.43
	2								0.32	0.29	0.29	0.29
	3								0.23	0.19	0.19	0.19

Appendix IV

Table A. Area Under Different Crops in Canal Commands of IBIS.

Canal ID	CANALS	CCA	Kharif Crop Area	Rabi Crop Area	Total	Scane	Rice	Cotton	Maize	Sorghum	Kharif Minor	Kharif Rauni	Wheat	Rabi Oilseed	Rabi Pulses	Rabi minor	Rabi Ruani	Cropping Intensity (%)		
																		Kharif	Rabi	Annual
1	Upper.Chenab.	580147	239467	257818	437955	6687	140163	704	16257	54003	21653	2375	107697	4337	0	139098	3148	41	44	86
2	Marala Ravi Link	63616	20385	17188	37573	321	18373	5	67	1451	168	85	4192	34	0	12641	6	32	27	59
3	Central Bari Doab.	265700	136581	177902	314484	14821	22766	9771	26998	52694	9531	0	118628	6047	0	35057	0	51	67	118
4	Depalpur upper	141711	52550	33985	86535	6118	13946	6175	0	11301	15010	64	21089	562	0	38407	102	37	24	61
5	Depalpur lower	247718	155736	68099	223835	5165	24292	58120	18602	5066	44492	11888	37236	1457	0	6216	1606	63	27	90
6	LCC East (Gugera)	647502	436324	500701	937025	77949	52410	51602	103298	41945	109120	108	290575	28306	0	103870	441	67	77	145
7	LCC West (Jhang)	588614	373504	448640	822144	74063	55245	29435	82389	84736	47636	2498	260921	24393	0	89263	180	63	76	140
8	Upper Jehlum Canal	220094	146618	162419	309037	21529	53254	3136	4210	47392	17098	579	95431	1723	0	43737	4137	67	68	135
9	Lower Jehlum Canal	614488	348487	442860	791347	53399	33830	16110	43435	77055	124658	6051	232446	3888	0	153126	3625	57	72	129
10	THAL	773843	376698	411484	788182	30278	16394	28552	2906	81682	216885	302	277142	27597	0	76467	166	49	53	102
11	Lower Bari Doab	675667	537278	518208	1055486	38834	43414	191003	114809	50037	99180	68	328055	43932	0	107387	131	80	77	156
12	Haveli	411711	325555	302544	628098	8031	21149	159030	21206	41102	75036	339	194909	6928	0	92675	399	79	73	153
13	Mailsi	277956	243221	198729	441950	3017	4090	200102	2812	3686	29514	79	157866	9668	0	28179	305	86	70	156
14	Pakpattan	516233	446754	396330	843084	18815	32023	280495	34294	52688	28439	524	305991	20119	0	51404	513	87	77	163
15	Fordwah	173111	114336	98544	212880	6101	30607	41052	0	12389	24187	262	72251	3141	0	17051	712	66	57	123
16	Eastern Sadiqia	424850	266660	267072	533732	25229	15749	150144	0	29170	46368	350	180655	33159	0	28028	325	63	63	126
17	Abbasia	96139	47631	47205	94837	5653	1465	24626	0	2427	13461	25	27147	2932	0	11473	0	50	49	99
18	Bahawal	299776	228731	214711	443442	13387	10834	143328	0	7505	53677	758	163091	8740	0	29493	369	76	72	148
19	Qaim	17121	15173	11939	27112	235	2113	10507	0	208	2111	1	9812	123	0	1770	0	89	70	158
20	Panjnad	551926	418782	377465	796247	26666	19166	260517	0	4106	108327	8846	263731	8024	0	79043	13139	76	68	144
21	D.G.Khan	368546	193049	176148	369197	3833	37072	101855	3439	24045	22805	222	149839	5041	0	17434	1803	52	48	100
22	Muzzafargarh	331764	177700	176975	354675	10239	16785	74880	5066	26584	44146	726	123824	294	0	42618	1234	54	53	107
23	Rangpur	139769	88443	84552	172995	1885	9345	39610	2052	18318	17233	343	55464	1391	0	27413	919	63	60	124
24	PAT & Desert	157786	77977	117198	195175	8	76902	0	0	1055	12	0	106807	2444	0	7947	0	50	74	124
25	Begari	340641	173093	137994	311087	75	169324	250	0	555	2889	0	41324	3499	13657	79439	0	50	41	91
26	Ghotkl	368335	202268	87896	290163	6743	16381	107775	0	8494	62875	0	31527	1996	7714	39916	0	55	24	79
27	North West	309093	88524	68583	157107	533	84384	0	0	706	2900	0	35102	4389	5247	23312	0	29	22	51
28	Rice	209695	104778	80074	184852	9	102061	0	0	688	2020	0	25740	12917	0	41408	0	50	38	88
29	Dadu	236605	56556	79264	135821	2816	40195	3867	0	2081	7597	0	53580	1621	3664	17584	0	24	33	57
30	Khairpur West	130299	52204	68077	120281	3974	2066	7675	0	0	38489	0	41285	637	0	22181	0	40	52	92
31	Kharipur east	182528	90481	84826	175307	5533	3879	37835	0	23492	19742	0	63785	2468	150	12890	0	50	46	96
32	Rohri	1045145	437236	465992	903227	65277	26125	161203	0	67843	116788	0	285416	15710	0	99589	0	42	44	86
33	Nara	882491	280108	279275	559382	24154	21081	104994	0	6391	123488	0	171979	9489	0	73653	0	31	32	63
34	Kalri	258592	50359	41410	91769	3141	36000	930	0	1824	8464	0	10381	0	5899	21989	0	19	16	35
35	Lined Channel	220137	75439	52367	127806	32644	28705	0	0	1089	13000	0	10653	0	90	8980	0	34	24	58
36	Fuleli	360604	128752	50004	178756	18071	82544	7	0	351	27779	0	16903	0	2479	12551	0	36	14	50
37	Pinyari	322112	44280	47269	91548	15733	18026	0	0	207	10314	0	13860	0	9527	8149	0	13.5	14.5	28

* All values are in Hectare.