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WATER BALANCE, SUPPLY AND DEMAND AND IRRIGATION EFFICIENCY OF INDUS BASIN

IJAZ HUSSAIN, ZAKIR HUSSAIN, MAQBOOL H. SIAL
WAQAR AKRAM and M. F. FARHAN*

Abstract. The Indus Basin water is becoming scarce and its demand in rising over for various uses. The water resources statistics is often questionable and based on guesstimates. Keeping in view this assertion, the intent of this paper is to estimate the supply and demand coupled with projections for future in various sectors of economy. The study provides information on water balance and water use efficiency estimate in the competing sectors. The total water available is 274 BCM, of which 130 BCM is available for use, however 62 BCM is lost in the system besides out flow to the sea. The empirical results further revealed that gross water supply for agriculture was nearly 190 BCM while its demand was 210 BCM showing a shortfall of about 20 BCM.

The projected estimates showed that this gap would be further widened by 27 BCM in the year 2015.The crop consumptive use is only 68 BCM and the remaining water is lost in the system. The domestic and Industrial supply and demand showed a shortfall of 5 BCM and 0.15 BCM respectively in the corresponding year. The irrigation application efficiency is 35 percent which abysmally low. Therefore, sound water management strategies are required to increase water productivity, minimize water losses and build a consensus on water dams.

I. INTRODUCTION

There is an increasing demand for water among agricultural, industrial, Municipal, and environmental uses. The water in the Indus Basin was

*The authors are, respectively, Graduate Student of Economics at University of Sargodha (Pakistan); Vice-Chancellor, GC University, Faisalabad (Pakistan); Professor/Dean of Faculty of Management Sciences; Graduate Student of Economics at University of Sargodha (Pakistan); and Senior Marketing Specialist, Washington Mutual, San Francisco (USA).

becoming scarce; there was a need to use it efficiently. As there is a high interdependency among uses and users, considerable effort is being placed on improving for integrated management of water resources. As a large consumer of water in irrigation have profound impacts on basin-wide water use and availability. Higher demand from other sectors means reduced supply in irrigation. Irrigation agriculture needs to produce more with less water. Many basins worldwide are facing perceived water shortage due to increasing demands on water from all sectors (Mollinga *et al.*, 2006). It was imperative that basic knowledge about water use and availability was generated in a way that can be useful for policy makers. The water balance approach was useful to provide such information.

Conceptually, the water balance approach was straight forward. Often, though, many components were difficult to estimate and or were not available. For example, ground water inflows and out flows to and from an area of interest are difficult to measure (Mollinga *et al.*, 2006). The water balance was an accounting of the inputs and outputs of water. The water balance of a place, whether it is an agricultural field, watershed, or continent, can be determined by calculating the input, output, and storage changes of water at the Earth's surface. The major input of water is from precipitation and output is Evapotranspiration. The geographer C. W. Thornthwaite (1899-1963) pioneered the water balance approach to water resource analysis. The author and his team used the water-balance methodology to assess water needs for irrigation and other water-related issues (Ritter, 2006).

The definition of water use efficiency was often misconceived, *i.e.* if the efficiency was increased there will be a sustainable increase in down stream water use. In general, the major components of the numerator of the unit irrigation efficiency term (E_t and Leaching) remain relatively constant for a given series of crops in an area. Improvement in irrigation efficiency occurs mainly as a result of decreasing deliveries. However, much of the water delivered in excess of Evapotranspiration may return to the stream, such changes in efficiency do not result in proportional increases in available water for downstream users. Application of saved water to other lands due to an increase in irrigation efficiency may very well infringe upon a downstream water right. Gross return flow will be less than the losses. The net return flow generally will have higher salt contents (Jensen *et al.*, 1990).

Conceptually, the definition of global efficiency is correct but cannot be seen without the consideration of water quality concerns, which are rather acute in semi-arid and arid environments. The loss of water is not retrievable in the quality context, especially in areas having brackish groundwater. Thus, global definition of efficiency should be seen in the light of local environments (Ahmed, 2001).

Producing enough food and generating adequate income in the Indus Basin to better feed the poor and reduce the number of those suffering will be a great challenge. This challenge is likely to intensify, with a country's population that is projected to increase to 250 million in 2025, putting even greater pressure on national food security. Irrigated agriculture has been an important contributor to the expansion of national food supplies since the 1970s and is expected to play a major role in feeding the growing country's population. However, irrigation accounts for about 90 percent of Indus Basin water withdrawals; and water availability for irrigation may have to be reduced in many areas in favor of rapidly increasing non-agricultural water uses in industry and households, as well as for environmental purposes. With growing irrigation-water demand and increasing competition across water-using sectors, the nation now faces a challenge to produce more food with less water. This goal will be realistic only if appropriate strategies are found for water savings and for more efficient water uses in agriculture.

The Water Balance provides practitioners with a 'runoff-based tool' for source control evaluation and stream health assessment. The 'runoff-based approach' holds the key to assessing environmental impacts in watercourses and the effectiveness of mitigation techniques The increase in water demand and complications in managing competing and conflicting water uses require more systematic and comprehensive strategy for managing water resources within the context of localized concepts of efficiency. Thus, the global concepts of efficiency have to be adjusted for the local environments. The statistics of irrigation resources is at best estimates; there is no proper snow management and groundwater regulation. The surface water is not properly monitored; conveyance losses are tremendous and millions of cubic meter water goes to sea.

The efficient use of water in agriculture is not adequately addressed in the country where the sustainability of the existing irrigation system is at stake. While surface irrigation is by far most widely used system in irrigation is practiced on nearly 80 percent of the irrigated area, the most water saving system through micro irrigation is seldomly practiced. Consequently, huge amounts of water diverted for irrigation in the region is wasted at the farm level. However, these losses often represent forgone opportunities for water because they delay the arrival of water at downstream diversion and almost poor quality water. Therefore, it is imperative to have reliable estimates for water resources, use, and efficiency for the Indus Basin. The intent of this paper is to provide water balance estimates, assess supply and demand situation and estimate water use efficiency.

II. DATA AND METHODOLOGY

The secondary data were taken from government sources such as the Agricultural Statistics of Pakistan, Water and Power Development Authority, Lahore, Pakistan Agricultural Research Council. There are different methods of estimation for water balance, supply and demand projections and water use efficiency.

Assuming the simple and highly restrictive system, which was completely impervious inclined plane surface, confined on all four sides with an outlet at one corner, the water balance equation was written as:

$$I - O = \frac{\Delta S}{\Delta t} \tag{1}$$

Where

I = inflow per unit time;

O = outflow per unit time; and

$\frac{\Delta S}{\Delta t}$ = the change in storage within the system per unit of time.

WATER BALANCE ABOVE THE SURFACE

Water balance above the surface of the basin was expressed as:

$$P + R_1 - R_2 + R_g - E_s - D_{di} + F_e - I = \Delta S_s \tag{2}$$

Water Balance below the surface

Water balance below the surface of the basin can be expressed as:

$$I + G_1 - G_2 - R_g - E_b - E_t = \Delta S_g \tag{3}$$

WATER BALANCE FOR THE INDUS BASIN

Water balance for the basin was expressed by combining the equations (2) and (3).

$$P - (R_2 - R_1) - (E_s + E_b) - (E_t) - (G_2 - G_1) - D_{di} + F_e = \Delta(S_s + S_g) \tag{4}$$

Where

P = Precipitation, M^3;

I = Infiltration, M^3;

R_g = Groundwater flow that was effluent to a surface stream, M^3;

R_1 = Runoff as an inflow to the basin, M^3;

R_2 = Runoff as an outflow from the basin, M^3;

G_1 = Groundwater flow entering the basin, M^3;

G_2 = Groundwater as an outflow from the basin, M^3;

E_s = Evaporation from the surface water bodies or other surface storage areas, M^3;

E_b = Evaporation from the bare soil surface, M^3;

E_t = Evapotranspiration from crops and native vegetation, M^3;

S_s = Surface storage, M^3;

S_g = Groundwater storage, M^3;

D_{di} = Water diverted for domestic and industrial uses, M^3; and

F_e = Flow of domestic and industrial effluents to the surface streams, M^3.

Therefore, the simplified water Balance for the basin was expressed by reducing the equation (4) to:

$$P - (R_2 - R_1) - (E_t) - D_{di} + F_e = \Delta(S) \tag{5}$$

Where

ΔS = change in storage.

SUPPLY AND DEMAND OF WATER FOR AGRICULTURE SECTOR

Water Supply

The gross water supply for the agriculture sector was estimated using the relationship:

$$WSA_{gross} = WSAG_{sw} + WSAG_{gw} \tag{6}$$

Where WSA_{gross}: gross water supply for the agriculture sector, billion M^3**;** $WSAG_{sw}$: gross surface water supply for the agriculture sector, billion M^3**;** and $WSAG_{gw}$: gross groundwater supply for the agriculture sector, billion M^3.

Water Demand

The net water demand for the agriculture sector was estimated using the following relationship:

$$WDA_{net} = 0.01 \times E_t \times A_c \tag{7}$$

Where WDA_{net}: net water demand for the agriculture sector, billion M^3**;** E_t: net crop water requirement, mm**;** A_c: basin's cropped area, million ha.

The gross water demand for the agriculture sector was estimated using the following relationship:

$$WDA_{gross} = \frac{WDA_{net}}{E_{is}} \tag{8}$$

Where WDA_{gross}: gross water demand for the agriculture sector, billion M^3; E_{is}: overall efficiency of the irrigation system, fraction.

SUPPLY AND DEMAND OF WATER FOR DOMESTIC SECTOR

Domestic Water Supply

The gross water supply for the domestic water sector was estimated using the relationship:

$$WSD_{gross} = WSDG_{sw} + WSDG_{gw} \tag{9}$$

Where WSD_{gross}: gross water supply for the domestic water sector, billion M^3**;** $WSDG_{sw}$: gross surface water supply for the domestic water sector, billion M^3**;** $WSDG_{gw}$: gross groundwater supply for the domestic water sector, billion M^3**.**

Domestic Water Demand

The net water demand for the domestic water sector was estimated using the following relationship:

$$WDD_{net} = 0.365 \times P_c \times WA_c \tag{10}$$

Where WDD_{net}: net water demand for the domestic water sector, billion gallons**;** P_c: country's population, million; and WA_c: water allowance, gallons per person per day.

The WDD_{net} was computed in billion gallons and for conversion to billion M^3, multiply WDD_{net} by 0.0045.

The gross water demand for the domestic water sector was estimated using the following relationship:

$$WDD_{gross} = \frac{WDD_{net}}{E_{pn}} \tag{11}$$

Where WDD_{gross}: gross water demand for the domestic water sector, billion M^3; E_{pn}: overall efficiency of the piped network, fraction.

SUPPLY AND DEMAND OF WATER FOR INDUSTRIAL SECTOR

Industrial Water Supply

The gross water supply for the industrial sector was estimated using the relationship:

$$WSI_{gross} = WSIG_{sw} + WSIG_{gw} \tag{12}$$

Where WSI_{gross}: gross water supply for the industrial sector, billion M^3**;** $WSIG_{sw}$: gross surface water supply for the industrial sector, billion M^3**;** $WSIG_{gw}$: gross groundwater supply for the industrial sector, billion M^3.

Industrial Water Demand

The net water demand for the industrial sector was estimated using the following relationship:

$$WDI_{net} = 0.365 \times WDI_{daily} \tag{13}$$

Where WDI_{net}: net water demand for the industrial sector, billion gallons**;** WDI_{daily}: daily water demand of the industrial sector, million gallons per day.

The WDI_{net} was computed in billion gallons and for conversion to billion M^3, multiply WDI_{net} by 0.0045.

The gross water demand for the industrial sector was estimated using the following relationship:

$$WDI_{gross} = \frac{WDI_{net}}{E_{pn}} \tag{14}$$

Where WDI_{gross} gross water demand for the industrial sector, billion M^3; E_{pn}: overall efficiency of the piped network, fraction.

III. RESULTS AND DISCUSSION

WATER BALANCE ESTIMATES FOR THE INDUS BASIN

The estimation of Water Balance and change in storage was obtained using the data given as under:

Indus Basin Data

Basin Area	=	16.8 million ha
Inflow to the basin (R_1)	=	175 billion M^3
Outflow from the Basin (R_2)	=	35 billion M^3
Precipitation in the Basin (P)	=	250 mm
Crop Evapotranspiration (E_t)	=	625 mm
Surface Water Storage Capacity (S)	=	15 billion M^3
Amount of water used by domestic and industrial sectors (D_{di})	=	10.25 billion M^3
Flow of domestic and industrial effluents to surface streams (F_e)	=	8.25 billion M^3

Water Balance

Basin Area	=	16.8 million ha
	=	16.8 × 10000 million M^2
	=	168 billion M^2
E_t	=	625 mm
	=	0.625 m
	=	168 billion M^2 × 0.625 m
	=	104.16 billion M^3
P	=	250 mm
	=	0.25 m

The change in storage both in surface and groundwater was estimated using the following expression:

$$\Delta S = P - (R_2 - R_1) - E_t - D_{di} + F_e \tag{15}$$

$$\Delta S = 42 - (35 - 175) - 104 - 10.25 + 8.25$$

$$\Delta S = 42 - 35 + 175 - 104 - 10.25 + 8.25$$

$$\Delta S = 76 \text{ billion } M^3$$

If the surface water storage in the basin was around 15 billion M^3, then the groundwater storage was computed as:

$$\Delta S_g = \Delta S - \Delta S_s$$

$$\Delta S_g = 76 - 15$$

$$\Delta \mathrm{S_g} = 61 \text{ billion } \mathrm{M}^3$$

There was a net recharge to groundwater of the Indus Basin to the order of 61 billion M^3, which was available for consumptive and non-consumptive uses.

WATER BUDGET

The data were obtained from the Agricultural Statistics, Government of Pakistan (2006). The crop E_t was taken from Pakistan Agricultural Research Council, 2002 and recorded at Mona Reclamation Project. The analysis of the daily and monthly flows also indicated variation. This variability in river flows affected the diversion of water to the canal system (WCD, 2000). In the event of high variability in river flows and canal diversions, water balance was estimated taking the mean values of flows and canal diversions.

Due to the stochastic nature of river flows, the concept of probability of river flows and canal diversions at 50 percent level should be used in formulating the water budget. The 50 percent probability means that at this probability, there is 50 percent chance of having flows of less than the predicted value (WCD, 2000).

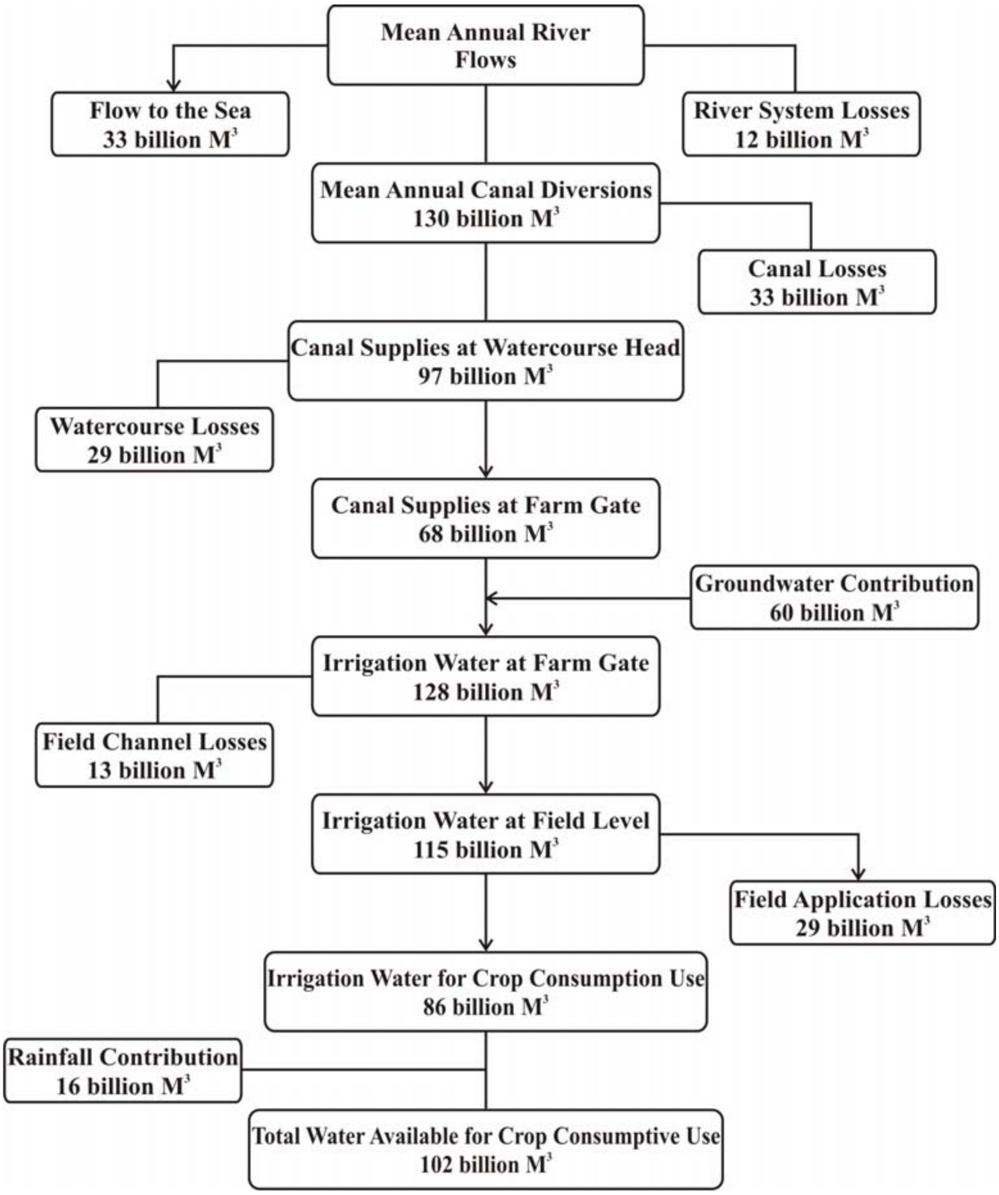
Mean annual river flows to the Indus Basin are nearly 175 billion M^3. The river system losses were about 12 billion M^3 in an average year. Nearly 130 billion M^3 was diverted to canals per annum in an average year. This leaves 33 billion M^3, which flowed to the Sea in an average year (PARC, 2001).

The canal conveyance losses were around 25 percent and therefore, 33 billion M^3 was lost in the canal system. Thus, only 97 billion M^3 was available at the watercourse head. The average watercourse losses were assumed to be around 30 percent (29 billion M^3) leaving only 68 billion M^3 available at the farm gate. This means that out of the canal diversions of 130 billion M^3, meanly 62 billion M^3 was lost in the conveyance of canal water. The loss of 62 billion M^3 of water, was not available for crops, however, it helped to recharge the groundwater (Ahmed, 2001).

Groundwater in the Indus Basin was now extensively used through over 900,000 private tube wells and pumping around 60 billion M^3 (GOP, 2006). This made 128 billion M^3 available at the farm gate. Conveyance losses in farmer’s field channels were assumed to be about 10 percent primarily due to shorter channel lengths (Ahmed, 2001). Therefore, nearly 13 billion M^3 was lost in the field channels. Thus, 115 billion M^3 was available for meeting field gross irrigation requirement.

FIGURE 1

Water Budget of the Indus Basin Irrigation System Based on
Mean Annual River Flows and Mean Annual Canal Diversions



Surface irrigation was primarily practiced in the Indus Basin. The fields were not often leveled and irrigation was not scheduled based on the management allowed deficit. Thus, the field application losses were nearly 25 percent (29 billion M^3) (GOP, 2006). This left only 86 billion M^3 available at field level for crop consumptive requirement. Thus, it was considered as net irrigation water available for crops consumptive needs.

The contribution of effective rainfall in the Indus Basin was estimated as 16 billion M^3. Therefore, total water available for crop consumptive requirement was 102 billion M^3, which fulfilled the water requirement of 16.8 million hectares (mha) in the Indus Basin.

ALTERNATE WATER BUDGET ESTIMATION

The estimation of the water budget was based on Pakistan Water Resource Strategy (PNWRS), Ministry of Water and Power, Government of Pakistan, 2003. The estimation was obtained in Table 1 through Table 4. The total water flowed from the river Indus and its tributaries was 172 billion M^3 annually (GOP, 2003). The total consumptive use was 57 billion M^3 (consumptive use: 38 billion M^3, municipal use 6 billion M^3 and outflow to sea water intrusion12.5 billion M^3) and the losses were 115 billion M^3. The losses through the surface supplies were huge. Water losses were of two types, conveyance losses (84 billion M^3) and loss to the sea 31 billion M^3 after accounting for seawater intrusion. The conveyance losses included canal to watercourse head (32 billion M^3) losses for watercourse head to outlet (43 billion M^3) and application losses (15 billion M^3).

TABLE 1

Water Balance for Indus Basin (2003-04) Water Inflows

S. No.	Water Inflows	BCM	% Share
1.	Rim Station Inflows	172.00	93.10
2.	East River's Contribution	2.46	1.34
3.	Tributary Inflows	10.20	5.56
4.	Storage Changes (±)	0.00	0.00
Total Water Inflows		184.00	100.00

The loss to the sea was colossal but mostly out flow was during the monsoon. Pakistan was becoming a water poor country. Drought was already at the doorstep due to global warning. Parts of Sindh and Balochistan were already experiencing worst drought of the past 30 years. Therefore, it seemed imperative to conserve water at all cost. There were 18 feasible dam sites for water reservoirs. Government should make efforts to develop political consensus and resolve the issue of dam sites. There was a need for strong political will to resolve this vital issue and save the country from pauperism.

TABLE 2

Water Balance for Indus Basin (2003-04) Water Uses (–)

S. No.	Water Inflows	BCM	% Share
1.	Canal withdrawals		
1.1	Head of Water Course (1.2 + 1.5)	96	
1.2	Field outlets (1.3 + 1.6)	53	
1.3	Consumptive Use	38	29.81
1.4	Conveyance Losses (Canal)	32	25.00
1.5	Conveyance Loses Head to Naka	43	33.65
1.6	Field Application Losses	15	11.54
Total Canal Withdrawal Consumptive Use + Losses)		128	100
2.	Industrial and Municipal Uses	6.15	3.5% of A-1
3.	Required See Outflow to Check Sea Intrusion	12.3	
Total Use of Water (1.3 + 2 + 3)		57	
C	Water Losses		
1.	Conveyance, Evaporation and other losses	84	
2.	Excess Outflow towards Sea	31	
	Total Water Losses	115	

Surface Water Balance (BCM)

Inflows = Uses + Losses

$A = B + C$

172 = 57 + 115

Besides surface water, the country was endowed with ground water resources. The ground water was pumped through scarp tubewells (11 billion M^3) and private tubewells (54 billion M^3). Of the total ground water (65 billion M^3), 36 billion M^3 was consumptively used for crops and the rest were losses. The public tubewells were installed in late 50s and early 60s to control water logging and salinity. The design capacity of these public tubewells was 4-6 cusecs and they were installed in the periphery of canals and through these tubewells effluent water was pumped and discharged in the canals. The scarp tubewells outlived their utility and were phased out. Since the capacity of these tubewells was large, farmers were unable to purchase and maintain at this capacity.

Ground and Rain Water Sources

TABLE 3

Ground Water Balance in the Indus Basin

Ground Water Balance	BCM	Percent
SCARP	11.07	17
Private	54.12	83
Total	65.19	100
At field Outlets	50.43	
Crop Consumptive Uses	35.67	
Field Application Losses	29.52	

Ground Water Balance (BCM*)*

Total Extraction = Consumptive Use + Losses

Total Extraction = 35.67 + 29.52

In addition to above two sources of water, rainwater especially in monsoon was available. Annually about 37 billion M^3 of water was received. Of which 11 billion M^3 was consumptively used and rest were losses through seepage, run-off and outflow to sea. The rainfall was a natural gift and the country has to manage and conserve rainfall water especially in Rodkohi areas where large tracks of land can be brought under cultivation by proper diversion.

Overall water available was 274 billion M^3 (surface flows; 172 billion M^3 + tubewells, 65 billion M^3 + rains; 37 billion M^3). Out of this total water availability 104 billion M^3 was consumptively used, 139 billion M^3 were losses and 31 billion M^3 outflows to the sea. This showed overall water balance of the Indus Basin.

TABLE 4

Rain Water Balance in the Indus Basin

Rain Water Balance	BCM
Consumptive Use	11
Field Application Losses	5
Rain	37
Run Off	21

Total Rainfall = Cons. Uses + Losses

37 = 11 + 26 BCM

Overall Water Balance

Surface Flows + Ground Water + Rainfall = 172 + 65 + 37; D = 274 BCM

Consumptive Use + Losses + Outflow = 104 + 139 + 31; E = 274 BCM

Both estimates showed that nearly 102-104 BCM of water was available from all three sources and were consistent with PNWRS (2003) and FAO (1999). The estimates of Water Balance were, slightly at variance with Zhu (2006), however, it was close to the estimates in agriculture use. Zhu *et al.* (1994) also used similar method to estimate water balance in the Nile Basin. The crop E_t was very close to estimates of the present study. A tentative implication from this study was that 274 BCM represented of an estimate of how much water was at least needed to sustain the current Indus Basin economic development under condition of adequate water management. The calculated 38 BCM of crop consumptive use was reasonable lower bound of the amount of water beneficially contributed to the nation's crop production. However, system losses were colossal and Government should take measures to minimize these losses. The recent initiative of government of water course improvement was step in the right direction.

ESTIMATION OF SUPPLY AND DEMAND

For the Indus Basin, estimates of net and gross water supply and demand of water for agriculture were as under:

Indus Basin Data

Basin Area	=	16.8 million ha
Gross surface water supply agriculture sector ($WSAG_{sw}$)	=	130 billion m^3
Gross groundwater supply ($WSAG_{gw}$)	=	60 billion m^3
Net Evapotranspiration	=	625 mm
Overall irrigation efficiency	=	50 percent

Supply and Demand Agriculture Sector

The gross water supply for the agriculture sector (WSA_{gross}) was estimated as under:

$$WSA_{gross} = WSAG_{sw} + WSAG_{gw} \tag{16}$$

$$= 130 + 60 = 190 \text{ billion m}^3$$

The gross water supply for the agriculture sector was nearly 190 billion m^3 from both surface and groundwater resources.

The net water demand for the agriculture sector (WDA_{net}) was estimated using the following relationship:

$$WDA_{net} = 0.01 \times E_t \times A_c \tag{17}$$

$$= 0.01 \times 625 \times 16.8$$

$$= 105 \text{ billion m}^3$$

The gross water demand for the agriculture sector (WDA_{gross}) was computed using the following relationship:

$$WDA_{gross} = \frac{WDA_{net}}{E_{is}} \tag{18}$$

$$= \frac{105}{0.50} = 210 \text{ billion m}^3$$

The gross water demand for the agriculture sector was about 210 billion M^3. Thus, there was a shortfall of around 20 billion M^3 for the sector.

Projections of Supply and Demand for Year 2015

The estimation of gross projected demand and supply of water for the agriculture sector for the next decade and half using the given data listed was as under:

Indus Basin Data

Demand of water for the current year (*$WDAC_{gross}$*)	=	210 billion M^3
Supply of water for the current year (*$WSAC_{gross}$*)	=	190 billion M^3
Supply of surface water for the current year	=	130 billion M^3
Supply of groundwater for the current year	=	60 billion M^3
Growth rate of Irrigation demand (*ID_{gr}*)	=	2 percent per annum
Growth rate of Irrigation supply (*IS_{gr}*)	=	2 percent per annum
Additional storage available during 2005-2006	=	15 billion M^3
Additional storage available during 2009-2010	=	10 billion M^3

Supply and Demand Projections of Agriculture

Projections of water demand ($WDAP_{gross}$) and supply for the agriculture sector ($WSAP_{gross}$) was computed using the following relationship:

$$WDAP_{gross} = WDAC_{gross} \times \left(1 + \frac{ID_{gr}}{100}\right)^{Nyear} \tag{19}$$

$$WSAP_{gross} = WSAC_{gross} \times \left(1 + \frac{IS_{gr}}{100}\right)^{Nyear} \tag{20}$$

The total projected supply during the period 2014-2015 was 256 billion M^3; whereas the projected demand for the same period 283 billion M^3. Thus, there was shortfall of about 27 billion M^3 (10 percent) per annum. Therefore, either targeted increase in irrigation facility of 2 percent was to be reduced accordingly, or the additional resources have to be provided by saving of existing losses in the conveyance system. Kahlown *et al.* (2003) estimated that there was shortfall and 49 BCM and projected the shortfall of water as 110 BCM by the year 2010. The PNWRS (2003) predicted 34 BCM short falls in agriculture at the farm gate in the years 2025. Thus, projections of Kahlown *et al.* (2003) were overly pessimistic but the projections of the present study were consistent with PNWR (2003).

SUPPLY AND DEMAND FOR THE DOMESTIC USE

For the Indus basin, computation of net and gross water supply and demand of water for the domestic sector using the given data listed was as under:

Indus Basin Data

Gross domestic water supply from surface water ($WSDG_{sw}$)	=	7.5 billion m^3
Gross domestic water supply from groundwater ($WSDG_{gw}$)	=	2.5 billion m^3
Country's Population (P_c)	=	160 million
Net water allowance (WA_c)	=	50 gallons per capita per day
Efficiency of the piped network (E_{pn})	=	75 percent

Supply and Demand Domestic Use

The gross water supply (WSD_{gross}) for the domestic water sector was estimated as under:

$$\begin{aligned} WSD_{gross} &= WSDG_{sw} + WSDG_{gw} \\ &= 7.5 + 2.5 = 10 \text{ billion } m^3 \end{aligned} \tag{21}$$

The gross water supply for the domestic water sector was estimated as 10 billion M^3 from both surface and groundwater resources.

The net water demand for the domestic water sector (WDD_{net}) was estimated using the following relationship:

$$\begin{aligned} WDD_{net} &= 0.365 \times P_c \times WA_c \\ &= 0.365 \times 160 \times 50 \\ &= 2920 \text{ billion gallons} \\ &= 2920 \times 0.0045 \\ WDD_{net} &= 13.14 \text{ billion } M^3 \end{aligned} \tag{22}$$

The gross water demand for the domestic water sector was computed using the relationship:

$$\begin{aligned} WDD_{gross} &= \frac{WDD_{net}}{E_{pn}} \\ &= \frac{13.14}{0.75} = 17.52 \text{ billion } M^3 \end{aligned} \tag{23}$$

The gross water demand for the domestic water sector was estimated as 17.52 billion M^3. Thus, there was a shortfall of nearly 7.52 billion M^3 for the sector.

Projection of Supply and Demand for Domestic Use 2015

The computation of gross projected water demand and supply for the domestic water sector for the next decade and half using the given data was listed as under:

Indus Basin Data

Gross demand of water for the current year ($WDDC_{gross}$)	=	14.2 billion m^3
Supply of water for the current year ($WSDC_{gross}$)	=	10 billion m^3
Supply of surface water for the current year	=	7.5 billion m^3
Supply of groundwater for the current year	=	2.5 billion m^3
Domestic water supply growth rate (PWD_{gr})	=	2 percent per annum
Domestic water demand growth rate (PWS_{gr})	=	2 percent per annum

Supplies of surface water were fixed and thus increase in water supply expected solely from the groundwater.

Supply and Demand

Projections for demand ($WDDP_{gross}$) and supply of water ($WSDP_{gross}$) for the domestic water sector were computed using the following relationship:

$$WDDP_{gross} = WDDC_{gross} \times \left(1 + \frac{PWD_{gr}}{100}\right)^{Nyear} \tag{24}$$

$$WSDP_{gross} = WSDC_{gross} \times \left(1 + \frac{PWS_{gr}}{100}\right)^{Nyear} \tag{25}$$

The total projected supply during the period 2014-2015 was 13.5 billion M^3; whereas the projected demand for the same period was19.1 billion M^3. Thus, there was a shortfall of nearly 5.5 billion M^3 (29 percent) per annum. Therefore, either targeted increase in provision of piped water facility of 2 percent has to be reduced accordingly, or the additional resources have to be provided by saving of existing losses in the piped network system. The PNWRS (2003) study estimated a shortfall of 8 BCM in the year 2025. The estimates of the present study were consistent with PNWRS (2003).

INDUSTRIAL SUPPLY AND DEMAND

For the Indus Basin, the estimation of net and gross water supply and demand of water for the industrial sector using the given data listed was as under:

Indus Basin Data

Current groundwater use for industrial sector ($WSIG_{gw}$)	=	0.25 billion M^3/annum
Current surface water use for industrial sector ($WSIG_{sw}$)	=	0.00
Current demand (WDI_{daily})	=	182.6 million gallons per day
Efficiency of the piped network (E_{pn})	=	75 percent

Supply and Demand

The gross water supply for the industrial sector was estimated as under:

$$\begin{aligned} WSI_{gross} &= WSIG_{sw} + WSIG_{gw} \\ &= 0.0 + 0.25 \\ &= 0.25 \text{ billion m}^3 \end{aligned} \tag{26}$$

The gross water supply for the industrial sector was 0.25 billion M^3 from groundwater resources.

The net water demand (WDA_{net}) for the industrial sector was estimated using the following relationship:

$$\begin{aligned} WDA_{net} &= 0.365 \times WDI_{daily} \\ &= 0.365 \times 182.6 \\ &= 66.65 \text{ million gallons} \\ &= 66.65 \times 0.0045 \\ WDI_{net} &= 0.30 \text{ billion M}^3 \end{aligned} \tag{27}$$

The gross water demand for the industrial sector was computed using the relationship:

$$WDI_{gross} = \frac{WDI_{net}}{E_{pn}} \tag{28}$$

$$= \frac{0.30}{0.75} \;=\; 0.40 \text{ billion } M^3$$

The gross water demand for the industrial sector was 0.40 billion M^3. Thus there was a shortfall of around 0.15 billion M^3 for the sector.

Projection of Supply and Demand for the Industrial Use 2015

The projected gross water demand and supply for the industrial water sector for the next decade and half using the given data were as under:

Indus Basin Data

Gross demand of water for the current year	=	0.30 billion M^3
Supply of water for the current year	=	0.25 billion M^3
Industrial water supply growth rate	=	2 percent per annum
Industrial water demand growth rate	=	2 percent per annum

Supply and Demand

Projections for water demand ($WDIP_{gross}$) and supply for the industrial sector ($WSIP_{gross}$) were computed using the following relationship:

$$WDIP_{gross} = WDIC_{gross} \times \left(1 + \frac{PWD_{gr}}{100}\right)^{Nyear} \tag{29}$$

$$WSIP_{gross} = WSIC_{gross} \times \left(1 + \frac{PWS_{gr}}{100}\right)^{Nyear} \tag{30}$$

The total projected industrial water supply during the period 2014-2015 was 0.34 billion M^3; whereas the projected industrial water demand for the same period was 0.40 billion M^3. Thus there was shortfall of about 0.060 billion M^3 (17 percent) per annum. Therefore, either targeted increase in provision of piped water facility of 2 percent has to be reduced accordingly, or the additional resources have to be provided by saving of existing losses in the pipeline network system.

WATER USE EFFICIENCY

The water use efficiency for open the basin was presented in this study. The purpose was to describe variations in efficiency as affected by types of basins and context of local/global definitions.

Open Basin

Open Basin was described where there was outflow from the basin, which was not available for use within the current context of water management. In case of the Indus basin, there was an outflow from the basin, as river outflow was common during the Monsoon of excess water, where various users' in the country did not require water and storage was limited for carry-over of excess water. Thus, the result was the outflow to the sea.

Water Use efficiency

The computation of water use efficiency both local and global efficiencies for the Indus Basin using the given data listed were given as under:

Indus Basin Data

River inflow	=	175 billion M^3
Outflow to sea	=	33 billion M^3
Existing Storage	=	10 billion M^3
Water for domestic/industrial use	=	10.25 billion M^3
Water for the ecosystem	=	1.5 billion M^3
Average annual Precipitation	=	250 mm
Basin area	=	16.8 mha
Evapotranspiration	=	625 mm

Estimation

Consumptive use for agriculture	=	168 billion $M^2 \times 0.625$ m
	=	105 billion M^3
Consumptive use for domestic/ industrial sector	=	10.25 billion M^3
Total Consumptive Use	=	105 + 10.25
	=	115.25 billion M^3
Available storage in the basin	=	10 billion M^3
Water needed for the ecosystem	=	1.5 billion M^3
Total Non-consumptive use	=	10 + 1.5
	=	11.5 billion M^3

Total Water Use	=	115.25 + 11.5
	=	126.75 billion M^3
Precipitation	=	168 × 0.25
	=	42 billion M^3
Total Available Water (surface and groundwater)	=	175 + 42 = 217 billion M^3
Water Use Efficiency /Local		
Water Use/Available Water	=	$\frac{126.75}{217} \times 100$
	=	58.4 percent
Water Use Efficiency (global)	=	$\frac{\text{Global Water Use}}{\text{Available Water}}$
	=	$\frac{217 - 33}{217} \times 100$
	=	85 percent

In fact, only 33 billion M^3 was the outflow from the basin and the rest of the inflow and precipitation was used in the basin. Any loss in water use was recoverable either from groundwater or from storages. The global water use efficiency was 85 percent. The actual amount of water used for agriculture, domestic, industrial and eco-systems came to 126.75 billion M^3 and thus the local water use efficiency was 58.4 percent, which was less than the global water use efficiency. The local water use efficiency concept was more practical for the Indus Basin considering the problems associated with poor quality groundwater and shortage of surface water. Thus, abstraction of fresh groundwater was restricted in the basin because losses of fresh surface water are not retrievable in terms of quality. The system efficiency was always less than 100 percent. Thus in real terms, there was shortfall in net water availability for various users'. Therefore, the local water use efficiency was less than 100 percent and was a function of system efficiency.

Irrigation Efficiency

Irrigation efficiency of the Indus Basin irrigated agriculture was described in segments covering canals, watercourses, field channels and field application sub-systems. The research studies conducted in the country in the last three decades measured basin-wide efficiencies for various sub-systems. The local efficiencies of various sub-systems at basin-wide level were described as under:

Indus River and its tributaries flow through alluvial plains and thus the phenomenon of losses and gains assumes significant importance. In the Indus River system, losses generally occur in the rising stage during the period from April to July. During the falling flows, covering the periods from end of July to September and from October to March, the rivers usually gain water from base-flow. The net river losses were nearly 7.14 percent of the annual flows (Ahmed 2001). Basin-wide canal conveyance efficiency was nearly 75 percent covering main canals, branch canals, distributaries and minor canals watercourse conveyance efficiency was around 70 percent. The watercourse represents the tertiary system of the Indus basin.(Ahmed,2001).

Field channel conveyance efficiency was around 90 percent (Ahmed, 2001) for farm level channels used for both canal and tubewells supplies. Length of farm channels is a function of farm size and normally small compared to watercourses. Thus, higher efficiency was assumed for the basin. However, for larger farms, this efficiency was relatively lower. Field application efficiency was around 75 percent covering application and uniformity losses within the field (Ahmed, 2001). For estimation of overall irrigation efficiency of the Indus basin, efficiencies of the four sub-systems were multiplied using the following relationship:

$$E_I = E_C \times E_{WC} \times E_{FC} \times E_A \tag{31}$$

Where E_I: Irrigation Efficiency at the Basin level; E_C: Canal Conveyance Efficiency at the basin level; E_{WC}: Watercourse Conveyance Efficiency at the basin level; E_{FC}: Field Channel Efficiency at the basin level; and E_A: Field Application Efficiency at the basin level. Using the above relationship, the basin-wide overall irrigation efficiency was:

$$E_I = 0.75 \times 0.70 \times 0.90 \times 0.75$$

or $$E_I = 35.4 \text{ say } 35 \text{ percent}$$

Overall irrigation efficiency at the basin level was nearly 35 percent, which was low as 65 percent water was lost before it was consumptively used by crops. The estimates were consistent with Kahlown *et al.* (2003). The author's estimates were in the range of 35 to 40 percent.

In summary the estimation of water balance showed that water losses were enormous and the availability of water from all the sources was not enough to meet the consumptive needs of various crops. The analysis showed water was scarce rather than excess. The future projection showed that every year there was a short fall of 18 to 20 BCM. Similarly, there was shortfall of 5.5 BCM in municipal and industrial use. In all the study showed that nearly 27 BCM of water was short. Water Resource Strategy, 2003 showed the short fall of 45 BCM. In the situation, even after building additional storage to store excess water, concerted efforts were needed to conserve water and follow productivity enhancement strategies Thus, the analysis revealed that water scarcity was looming large in the Indus basin. This supports the hypothesis that water scarcity in the Indus basin. It seemed imperative that government should develop political consensus on water reservoirs.

IV. CONCLUSIONS AND RECOMMENDATIONS

The water resources of Indus basin are becoming scarce. Indus and its tributaries coupled with groundwater and rain is the main source of water. The efficient irrigation in the Indus basin has vital role to play is sustainable food production and agricultural development in the future. One of the major concerns is the generally poor efficiency with which water resources have been used fro irrigation. The future emphasis must be directed towards increasing the efficiency of water use and increasing water productivity as well as moving seriously towards tapping non-conventional water resources to increase agricultural productivity.

The water statistics in Pakistan is vital for distribution of water across provinces and its efficient use. There are several agencies which claim as custodian of water statistics but number never add up, provincial governments have their own estimates, Water and Power Development Authority and the Ministry of Water and Power have their own statistics. Thus, River Indus Authority is often at odd with provincial estimates while distributing irrigation among the provinces. It is therefore, imperative to maintain water resource statistics at federal level. The intent of this to provide water balance estimates and assess supply and demand and estimate the water use efficiency.

The analysis revealed that nearly 274 BCM water is available from all source, of which 130 BCM is available for use; nearly 68 BCM is consumptively used for crops, and 62 BCM are losses. The supply and demand in agriculture a short fall of 20 BCM which was protected be 27 BCM by the year 2015 The crop consumptive use is the lower bound. Some of lost water can be captured by pumping but only sweet zones. There was a shortfall 27 BCM annually. The local irrigation efficiency was 54 percent and global efficiency was 85 percent but application irrigation efficiency was only 35 percent.

The analysis led us to believe that water is becoming increasingly scarce; therefore, government should develop water management strategies. The emphasis should also be given to increase crop per drop by using high irrigation efficiency methods, (drip and sprinkle irrigation) especially high value crops (orchard and vegetables). The strategies must include but not limited to:

1. Increase water productivity by bringing high value crops in the cropping system.
2. Water statistics must be made more reliable and transparent, Ministry of water and Power must issue the final figures for water resources after consulting with WAPDA, Provincial irrigation departments, IRSA and Water Resource Council. The government should make arrangements for snow management and sustainability of catchment's areas
3. The groundwater must be regulated to stall over exhaustion of the aquifer. The government should establish Groundwater Research Institute to handle issues confronting the aquifer.
4. The rain water run off must be stored and conserved through developing appropriate water structure, check dams.
5. The telemetry system must be made functional and remove the defects in the present installed system.
6. The political consensus on construction of dams and water reservoirs must be developed now than later in order to address looming water scarcity.

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