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AN ANALYSIS OF LOSSES AND GAINS IN INDUS RIVER SYSTEM OF PAKISTAN

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SUMMARY - There are certain important issues relating to the management of surface water resources in the Indus Basin that still remains unresolved. To ascertain the phenomenon of losses and gains in the various reaches of rivers basin is the most important among those. The water losses in the system are the main threat to the surface water conservation and integrated water resources management. Thus there is an urgent need to analyze the phenomenon of losses and gains in the system so that better water management / regulation could be made at every level.
This paper reflects an overview of the water losses and gains pattern in the main rivers and their tributaries. The subject paper compiles losses and gains of the Indus Basin by considering historic data of almost last 63 years starting from the year 1940 to 2003. Also, the best effort has been made to highlight the critical reaches showing losses of the surface waters from the rivers. This preliminary attempt will obviously provide the basic guidelines for further research/study on such a crucial and demanding assignment and hence to resolve this ever pending issue.

Key words: losses and gains, Indus basin, water management, irrigation system.

INTRODUCTION

Pakistan is being served by the world's largest contiguous irrigation network. This system comprises of Kabul, Indus, Jehlum, Chenab, Ravi and Sutlej rivers and their tributaries i.e. Haro, Soan and Gomal rivers etc. The Indus River System (Fig. 1) is the largest of all the rivers and carries almost two-thirds of the annual river inflows.

God has gifted Pakistan with abundant water resources that currently irrigate over 36 millions hectares of land. Agriculture is the main stay of Pakistan and about 70% of its population depends on agriculture for its livelihood. On the other hand, availability of water, which is the main input for maximum yield, is diminishing rapidly due to sedimentation in the existing reservoirs. On an average, about 26.52 % of the total storage capacity has already lost. Although the construction of new reservoirs has a due importance and are of essential for the sustainable water resources management and definitely Government is taking necessary steps for its implementation but yet there are two major factors namely losses and gains cannot be over emphasized for the proper management and conservation of surface waters, even after having additional storages.

The losses are mainly of the following types:

(a) Evaporation losses from the free water surface,

(b) Losses to bank storage which appear as regeneration in subsequent periods,

(c) Losses in valley storage during rising flows which appear as gains during receding flows,

(d) Losses as deep percolation contributing to the ground water table, mostly pre- Monsoon period.

(e) Consumptive use of vegetation in the river valley.

Gains, on the other hand may be of the following types (RAP, 1979):

a) Gains from short term bank storage,

b) Gains from valley storage,

c) Gains from the unmeasured inflows of smaller streams, surface drains, escapes from canals in certain locations joining the reach, and from direct rainfall.

d) Gains from ground water seepage from the adjoining Doab (land area between two rivers).

The Indus Basin Irrigation System (IBIS), in its present state comprising of 19 Barrages and 45 main canals (Fig. 2) that divert almost 75% of the average annual river flow into the Basin. In addition to that there are 14 Link canals and many un-gauged canals in NWFP are also the part of the system.

The discussion on river gains and losses is as old as the IBIS itself dating back to the start of the 20th century. But the results of past studies, starting with the British Engineers (Indus Discharge Committee 1920).The research work of S. S. Kirmani (1958) on the subject, and the studies undertaken by WAPDA & some international foreign consultants (HARZA) in the 1960s, have largely remained inconclusive. Thus, based on the investigations of the past regarding this phenomenon, it is difficult to make accurate predictions with respect to future gains and losses in the different river reaches.

Furthermore, most of these studies were carried out in or prior to the sixties and their results (e.g., HARZA's loss coefficients for different reaches developed in 1963) are no longer valid, as the regimes of the rivers are changed. There are many issues, like that of breaches at river bends, the relationship between the area flooded and seepage, etc., that need to be investigated in order to assess the magnitude and patterns of such losses and gains. Besides there is also inconsistency in losses & gains within the same cropping season.

Fig. 1. The Indus River System, Pakistan

Each of the factors affecting the gain/loss phenomena in a river reach depends upon a number of other subsidiary factors (varying in time, space and magnitude). Some of these subsidiary factors vary with the changes in river flows while others are largely independent of such changes. Thus these factors may be categorized as: i) those dependent on the river flows and, ii) those independent of the river flows for example, type of vegetation, climate, soil type, shape and size of river valley etc. The latter may be varying from site to site and from season to season on account of other causes. Thus, it is not a simple task to determine the true gains or losses taking place within a river reach.

The known historic data of gains and losses for different river reaches in the Indus Basin actually provides the cumulative net effect of all the variables affecting the phenomena. At the present circumstances, the question is not that the task is of difficult or simple nature but we have to accept the challenge and deal with such precious subject. The present effort is basically an initiative to invite the attention of the water resource planners, managers and the water management organizations responsible to cope with such issues.

LOSSES AND GAINS IN THE WHOLE SYSTEM

During the major part of the Kharif season when the river stage starts rising, heavy losses are incurred in conveying the river water from the Rim Stations (Indus Tarbela, Kabul Nowshera, Jehlum Mangla and Chenab Marala) to various points of canal diversions. Some gains start taking place towards late September from river/channel bank storage, as the river starts receding. On average, there is a net loss during the Kharif season and gain in the Rabi season in the system.

Seasonal historic data of gains and losses for the period of 1961~62 to 2002~03 for the whole network has been taken for the analysis. However, by considering the data from 1961-62 to 2002~03, a comparison regarding trend of system inflow and losses/gains has been made (Fig. 3) which reveals that the system losses are increasing with the time particularly during post-Tarbela period. Maximum losses of 40.78 MAF were observed during the year 1989~1990. This is because of neither the issue of losses has properly been addressed/ nor practical steps have been taken to manage such losses. During this 42 years period, there are minor gains in early nineties that contributed the system. Although the post-Tarbela flow data represents a wet sequence but the annual inflow of system is declining which may be due to long term cyclic and stochastic hydrologic variations.

The entire Indus River System largely shows net annual losses of 10.16 MAF on average. During the pre-Tarbela the average annual loss of surface water observed was10.16 MAF which increased to 18.90 MAF in post-Tarbela period as shown in *Table 1*. On the whole, during Kharif there are enormous losses before and after Tarbela period (average) where as the same period shows little gains during Rabi season. These entire system losses are due to the huge losses in the various Indus River reaches as well as due to the unmeasured tributary inflows downstream of certain reaches of the rivers like Jehlum. Some of the factors for these Kharif losses are scanty rainfall, considerable meander width of the river and an abundance of vegetation in the riverain area (RAP, 1979).

Table 1. System Losses & Gains in Pre-Tarbela and Post-Tarbela Periods

Period	**System losses/gains** (MAF)*		
	Kharif	**Rabi**	**Annual**
Pre-Tarbela	-13.79	+3.63	-10.16
Post-Tarbela	-17.49	-1.14	-18.90

Source: WAPDA**/IRSA***

*MAF = Mega Acre foot

**WAPA = Water and Power development authority.

***IRSA = Indus river system authority.

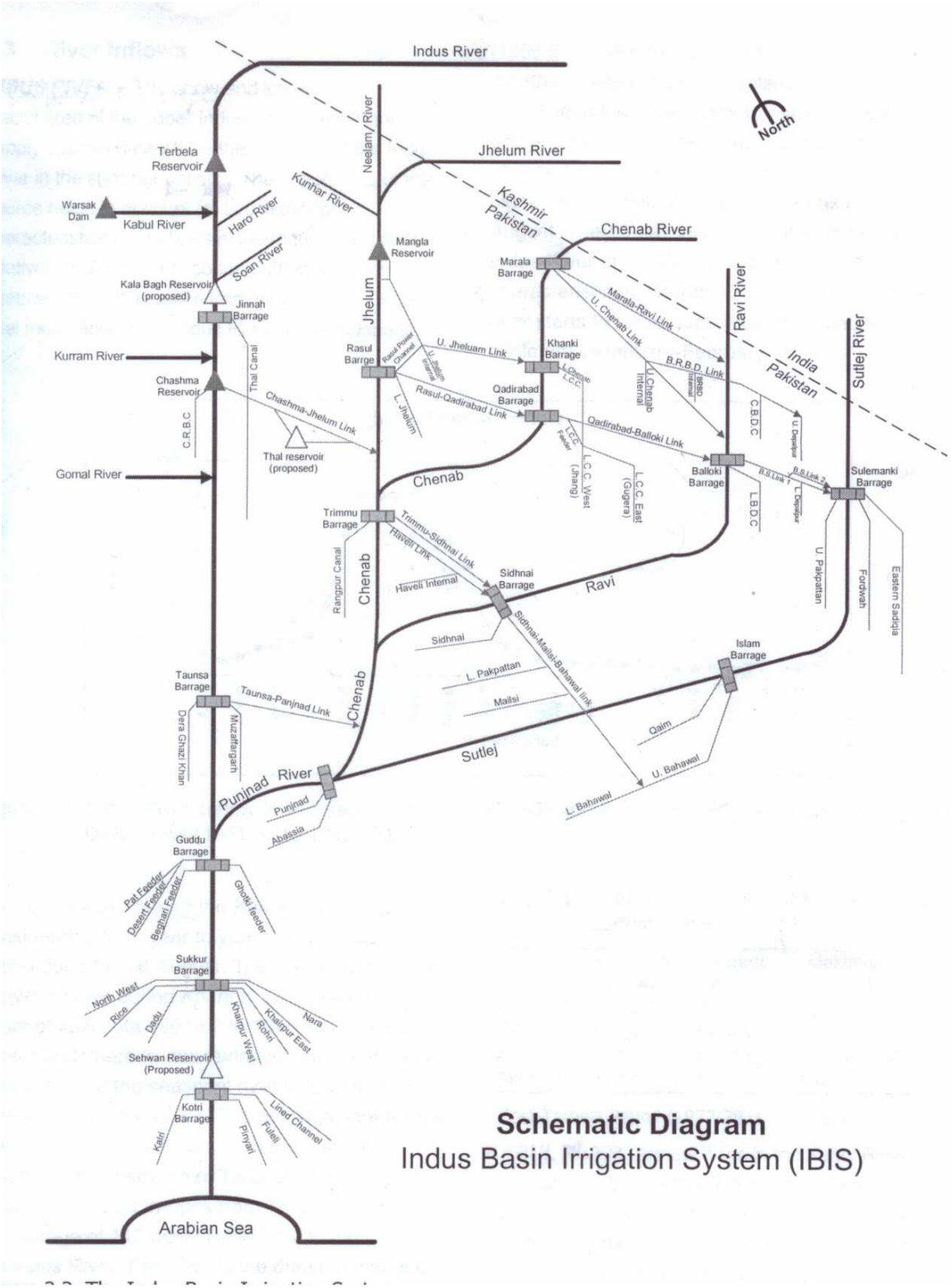

Fig. 2. Indus Basin Irrigation System

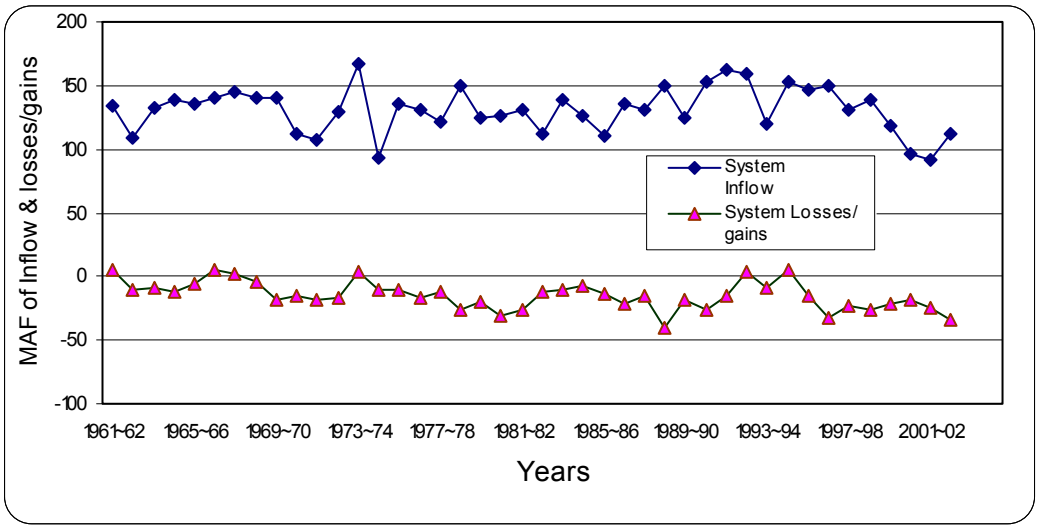

Fig. 3. System Inflow and Losses/Gains

ZONING OF THE SYSTEM

The IBIS has been divided into two key zones namely Indus Zone and Jehlum-Chenab Zone (J-C Zone).

River Jehlum and Chenab normally feed the area under *J-C Zone*: however, Chashma Jehlum (C-J) link canal having capacity of 21,700 cusecs gets water from Indus particularly during floods and draws it to Jehlum River to meet the demands of J-C Zone. There are three other link canals namely R-Q link, Q-B link and B-S link canal have a big contribution in supplying the waters to J-C Zone by inter-linking Chenab, Ravi and Satluj rivers. The RQBS system of link canals usually gets waters from Mangla Reservoir. To calculate the river losses/gains usually 5-reaches are considered historically.

Indus Zone: as the name itself indicates, this zone is totally irrigated with the flows of Indus River. The area on both sides of Indus i.e. left and right banks ranges from Tarbela to Kotri Barrage. However from Tarbela to Panjnad Barrage zone is purely Indus Zone. In this zone although heavy losses are experienced historically but some smaller tributaries of the main Indus River, the Haro, Soan, and Gomal Rivers, collectively contribute the average seasonal flows of about 2.19 MAF (*Table 2)* towards the total annual system inflows. Of these rivers, the Haro and Soan join the main Indus River upstream of the Kalabagh on the left bank, while the Gomal joins on the right bank approximately midway between the Chashma and Taunsa Barrages. The contributions from these tributaries and numerous other hill torrents falling into the main Indus, Jehlum and Chenab Rivers downstream of their respective rim stations are automatically taken care of while considering the phenomena of Gains and Losses in different river reaches. Particularly during late Kharif period Jinnah, Chashma, Taunsa, mainly as well as Panjnad feed the Indus Zone.

Table 2. 20-Years Average Seasonal Flows of smaller Distributaries (1966-67 to 1986-87)

	Kharif (MAF)	**Rabi** (MAF)	**Annual** (MAF)
Haro	0.44	0.21	0.65
Soan	0.87	0.23	1.10
Gomal	0.32	0.12	0.44
		Source:	WAPDA/IRSA

MAIN RIVER REACHES AND ZONE-WISE LOSSES & GAINS

Normally one reach is considered between the two controlling structures/gauging points on the main river and there are the following 12 main rivers reaches in the system:

1) Mangla-Rasul
2) Trimmu-Panjnad
3) Khanki-Trimmu
10) Taunsa-Guddu
2) Rasul-Trimmu
4) Marala-Khanki
6) Balloki-Sidhnai
11) Guddu-Sukkur
7) Attock-Kalabagh
8) Kalabagh-Chashma
9) Chashma-Taunsa
12) Sukkur-Kotri

Losses and Gains in Indus Zone

The Indus Zone comprises of six reaches in which the longest reach is Sukkur-Kotri (450 km) with maximum time lag of 5 days in the months of November to April 4 days in May & June and 3 days from July to August. Based on analysis of seasonal historical data, the Indus Zone as a whole shows the net annual loss of 29.08 MAF. If we analyze the losses and gains phenomena in the Indus Zone for pre-Tarbela and post-Tarbela periods separately (*Table 3)*, it is clear that maximum losses occurred during Kharif in pre-Tarbela as well as in post-Tarbela with increasing trend of 19 %. However, during Rabi, the pre-Tarbela period is gaining period with the average gains of 2.51 MAF but after Tarbela the gains changed into losses of 2.34 MAF.

Table 3. Losses & Gains in Indus Zone

Period	**Indus Zone** (MAF)		
	Kharif	**Rabi**	**Annual**
Pre-Tarbela (1940~77)	-13.37	+2.51	-10.86
Post-Tarbela (1977~2003)	-15.88	-2.34	-18.22

Source: WAPDA/IRSA

When the reach-wise records of Indus Zone are examined (*Table 4)*, then the three river reaches namely Kalabagh-Chashma, Chashma-Taunsa and Taunsa-Guddu, show net annual gains. Kalabagh-Chashma reach indicate the gains due to the contribution of two main tributaries namely Haro and Soan entering at upstream of Kalabagh Barrage on Indus. Taunsa-Guddu is a gaining reach because of the Gomal River (smaller tributary) joins the main Indus River midway between Chashma and Guddu Barrages. Another motive of gains is that the water from Panjnad River (Jehlum, Chenab and Sutlej) falls into Indus at Mithan Kot upstream of Guddu Barrage. As discharge past the Panjnad is significant only in the Kharif season, the reach shows gain during Kharif, even during post-Tarbela period. The reach exhibits minor losses averaging 0.69 MAF in the post-Tarbela period during the Rabi season.

Except the above three reaches, the remaining three reaches of Indus Zone reaches i.e. Attock-Kalabagh, Guddu-Sukkur and Sukkur-Kotri reveal the substantial losses in the Kharif season. Though it is necessary to analyze all these reaches showing net annual losses in Kharif as well as in Rabi season. However, the net annual loss of 6.29 MAF (Pre-Tarbela) and 22.89 MAF (post-Tarbela) on average only in these three reaches, stresses the need to concentrate on this enormous phenomenon in greater depth. Depending upon the historical data, it is therefore declared that these two reaches are the critical reaches as showing extensive losses and the pattern of water losses in these particular reaches should be comprehensively explored.

In the light of the forgoing facts and figures although the phenomena of river gains and losses in the Indus Zone, could only be fully investigated thorough an independent and detailed study, however a very brief discussion has been made to determine the rational behind the excessive reach losses (only Attock-Kalabagh & Sukkur-Kotri being critical reaches) on the Indus River.

Table 4. Reach-wise Losses/Gains in Indus Zone *(MAF)*

River Reaches	Pre-Tarbela			Post-Tarbela		
	Kharif	**Rabi**	**Annual**	**Kharif**	**Rabi**	**Annual**
Attock-Kalabagh	-0.95	-0.04	-0.99	-8.67	-3.30	-11.97
Kalabagh-Chashma	-1.27	0.53	-0.74	3.11	2.09	5.20
Chashma-Taunsa	2.09	0.65	2.74	5.20	-1.03	4.16
Taunsa-Guddu	2.64	0.25	2.89	1.80	-0.69	1.11
Guddu-Sukkur	-0.14	0.12	-0.03	-0.16	-0.15	-0.31
Sukkur-Kotri	-6.26	0.99	-5.27	-10.83	0.21	-10.62

Source: WAPDA/IRSA

The Attock-Kalabagh Reach

This 150 km reach lies between Attock, the confluence of the Indus River 20 km downstream of Tarbela Dam and the Kabul River, and the Jinnah (or Kalabagh) Barrage. The Indus River follows through a narrow path from Attock to Kalabagh. It flows into a narrow gorge 305 meters wise and 8 km long downstream of Attock. In the pre-Tarbela period (i.e. before 1976-77), the losses in Kharif averaged 0.95 MAF and a mere 0.04 MAF in the Rabi season. Thus it is a 'losing' reach having net annual losses of about 12.96 MAF. In the post-Tarbela period, the losses during Kharif and Rabi have increased a great deal (*Table 4*).

Thus in the Indus Zone, Attock-Kalabagh reach indicates huge losses in Kharif and relatively minute losses in Rabi season (Fig. 4) with net annual loss of 12.96 MAF. The data show a drastic increase in the net annual losses from 0.99 MAF in pre-Tarbela to 12.96 MAF in post-Tarbela period. This enormous increase in the post-Tarbela period is not justified and the historic gains and losses computed in respect of the Attock-Kalabagh Reach by WAPDA need further examination.

The Sukkur-Kotri Reach

Approximately 450 Km long reach is the last reach on Indus River before it falls into the Arabian Sea, is a "losing" reach with net annual losses that increased from 5.27 MAF in pre-Tarbela period to 10.62 MAF (more than double) in post –Tarbela period. In 1986-87 the reach losses in Kharif season (average) amounted to 29.38 MAF.

The average Kharif losses in this reach in Pre-Kotri period (1955-56) were only 2.39 MAF, which rose to 7.27 MAF in the post-Kotri period and further increased to 10.83 MAF in post-Tarbela period. On the other hand, the gains reduced consecutively from 0.99 MAF in pre-Tarbela to 0.21 MAF in post-Tarbela period. So, there were jumps in losses (with the increasing trend) of the subject reach.

If the available data is further analyzed, then water lost in this reach contributes the water table with a very little magnitude. Another reason of such a huge loss may be due to very low recharge to the river during Rabi. The average losses/gains in the different time periods (Fig. 5). The rising trend of water losses in different periods showed that water losses have swelled alarmingly and this massive rise in water losses in Sukkur-Kotri reach is a matter of great concern. Therefore necessary steps are needed to avoid such quantitative losses.

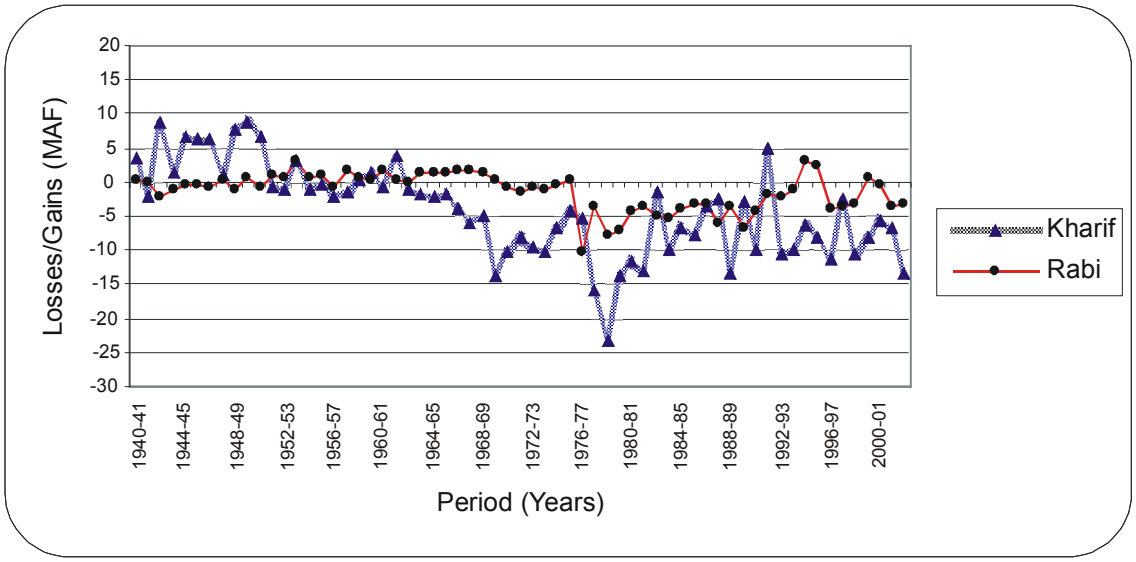

Fig. 4. Losses/Gains in Attock-Kalabagh reach (1940-41 to 2002-03)

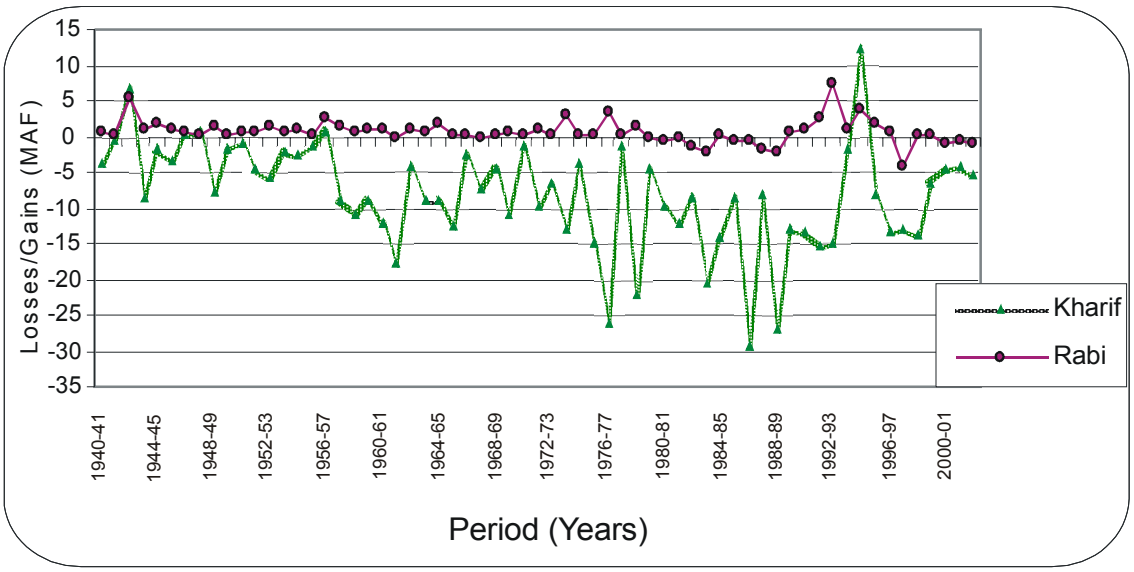

Fig. 5. Losses/Gains in Attock-Kalabagh reach (1940-41 to 2002-03)

Losses and Gains in Jehlum-Chenab Zone

Although there are 11 reaches in the Jehlum-Chenab Zone, however as far as losses/gains are concerned, Mangla-Rasul, Rasul-Trimmu, Trimmu-Panjnad, Panjnad-Khanki usually considered for the analysis. From the summary of losses/gains (historical data) in the J-C Zone, it is very clear that there are net annual loss of 0.44 MAF *(Table 5)*. This zone shows total loss of 2.56 MAF in Kharif period where as the total gains of 2.12 MAF in Rabi. Therefore the losses and gains in the said zone are almost equalized. The reason may be that the unrecorded flows from hill torrents joining the various rivers reaches.

One thing is to be noted that the pre-Tarbela period indicates net annual gains where as in the Post-Tarbela (particularly in post-IRSA period) losses are experienced (even more than two times of the gains).

This is because of serious affect of dry hydrological cycle started from later nineties till the year 2003. If the phenomenon of losses/gains in the different river reaches are taken under deliberation, the most critical reach is Trimmu-Panjnad with net annual loss of 5.18 MAF. The second water losing reach which needs to be analyzed thoroughly is Rasul-Trimmu on Jehlum River showing net annual loss of 3.96 MAF.

The maximum loss in both these reaches occurred during Post-Tarbela period. However, Balloki-Sidhnai reach on the river Ravi, which is the smallest of all the major tributaries of the Indus River, also shows net loss but the other three reaches namely Mangla-Rasul, Marala-Khanki and Khanki-Trimmu are totally gaining reaches with net annual gains of 4.07, 1.48 and 2.98 MAF respectively.

The Mangla-Rasul and the Marala-Khanki reaches of the Jehlum and Chenab Rivers, respectively, show gains in the Kharif season also averaging 1.5 bcm. This is because of contributions from the hill torrents joining the main river in between these reaches. These hill torrents are affected by the Monsoon rains and are, therefore, very 'flashy' in nature. Both these reaches are short reaches, each having a length of approximately 40 km. Rasul-Trimmu and Trimmu-Panjnad reaches are 'losing' reaches, having net annual loss of about 3.6 bcm.

Table 5. Losses & Gains in Jehlum Chenab Zone

Period	**J-C Zone** (MAF)		
	Kharif	**Rabi**	**Annual**
Pre-Tarbela (1940~77)	-0.85	+1.18	0.32
Post-Tarbela (1977~2003)	-1.70	+0.94	-0.76

DISCUSSIONS

From the forgoing analysis of the losses and gains in various river reaches, it can be well elaborated that the enormous increase in losses particularly in the post-Tarbela period is not justified and hence need further investigation.

It is therefore affirmed that the method of discharge measurement should be as accurate as possible for the truthful assessment of these valuable losses. For this, stage-discharge curves and empirical formulae being used at different Barrages/Off-taking canals should be verified and revised (if need) by an independent agency because the losses/gains can be estimated to some degree of accuracy only if the discharge measurement at Barrages/Canal heads are reliable. The data should be observed on hourly basis, not only during the flood season but round the year. Secondly, the latest techniques for the determination of actual discharge should be given top priority. Telemetry System is one of the latest available tool which can explore the actual discharge and hence actual losses and gains between different river reaches. Although, telemetry system has already been installed at various controlling points of the rivers but its correct operationalization should be assured. Once the telemetry system will give factual water position in different reaches, then its implementation should be in the whole IBIS.

To understand and account for the unpredictable losses and gains, an extensive study and investigation is needed to find the actual losses, may be due to seepage, evaporation and/or water theft, which currently is of vital importance to avoid the water shortages. The recommended study needs to develop a computer model for accurate assessment of the system losses. In the whole river system, the critical reaches regarding the losses are Attock-Kalabagh and Sukkur-Kotri which should be prioritized while investigating the phenomenon. The accounting of the surface water resources would be momentous only if a credible explanation is available for anomalies in case of the above mentioned two critical reaches. To control the seepage as well as evaporation losses, the remedy may be to channelize the river flows.

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