Environmental Flows Indus River System in Pakistan

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Abstract

Water is becoming increasingly a scare commodity with competitive uses having there independent socio-economic consequences. The realization of this fact has initiated a policy debate on the most optimum utilization of this valuable resource. This diminution coupled by water resource base of Indus River Basin is leading to environmental hazards in Pakistan.

Selection of appropriate development and management strategies has become a principal planning concern. The objective of the paper is to assess minimum/environmental flow requirements of different environmental needs based on updated information.

The paper concludes that growing concerns of provinces about river life are genuine, while any realistic solution is going to be competitive for water available under different conditions, among the sectors and at the spatial scale. Developed and useable water resources are highly stressed to meet any drought conditions besides the planned future developments.

Actual environmental needs have a spatio-temporal character in demand. The paper concludes that provision of environmental flows especially in the winter season can only be assured through construction/establishment of an integrated water reservoir system and to properly present an integrated and holistic vision of the environmental issues, the paper presents estimations and scope of implementation in an action matrix format.

Introduction

Pakistan with a geographical area of 796,101 square kilometers possesses large river like Indus, which alongwith its tributaries namely Chenab, Jhelum, Ravi, Kabul and Sutlej, forms one of the mightiest river systems of the world. The River System comprises 3 super storages/reservoirs (Tarbela and Chashma on River Indus and Mangla on River Jhelum with present total live storage of about 14.56 BM^3 i.e. 11.818 MAF), 19 large river Headworks/Barrages, 45 independent irrigation canal commands measuring 63,000 kilometers, some 1.6 million kilometers of water courses and 144 large dams.

The total length of main canals alone is 58,500 km. Watercourses comprises another 1,621,000 kms. Diversion of river waters into off-taking canals is made through barrages, which are gated diversion weirs and a system of link canals (Figure -1). Water use pattern in Pakistan is 95% for agriculture sector, 3% for drinking & sanitation sectors besides 2% for the industry.

Water characteristics of Pakistan indicate large seasonal variations in water availability (80% in summer, 20% in winters) and sediment load in rivers ranges from 200 to 400 million tones causing depletion of storages @ 1% per year. Over the past decade or so, changes in climate and the accelerated pace of the earth's warming have moved the issue of climate change to the top of the global agenda.

On the above account water is becoming increasingly a scarce commodity with competitive uses having their independent socio-economic consequences. The realization of this fact has initiated a full scale policy debate on the most optimum utilization of this valuable resource.

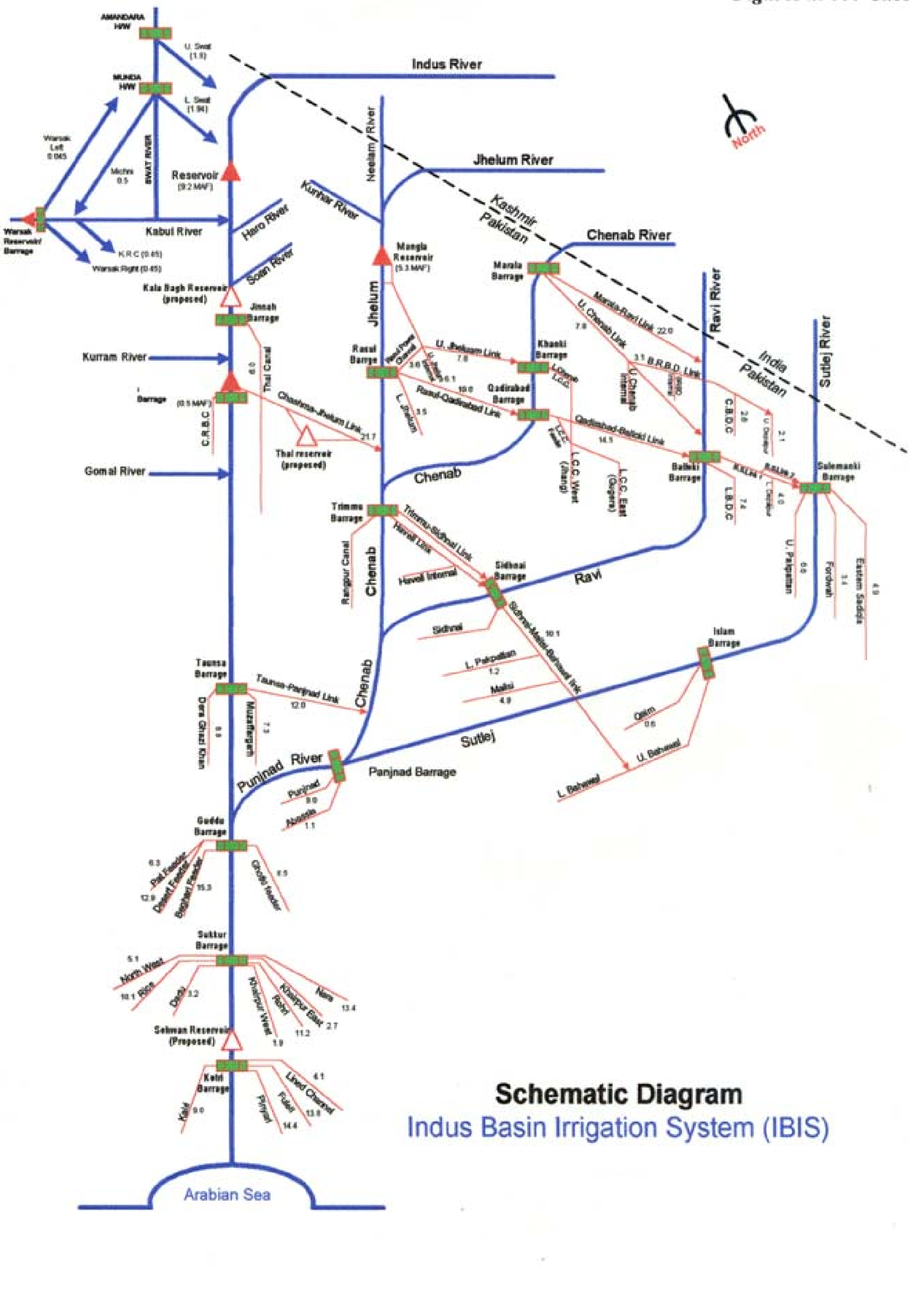
The above diminution coupled by degradation of water resource base of the Indus Basin is leading to environmental hazards in all the four provinces (Punjab, Sindh, NWFP & Balochistan). The selection of appropriate development and management strategies has become a principal planning concern. Therefore, to assess the minimum/environmental flow requirements, within Indus River System, of different environmental needs, an attempt is made through this paper.

Water and Environment Issues

Of the 145 MAF of water that enters the Indus Basin annually 104 MAF is diverted for irrigation at the canal heads. It is estimated that about 35% of the water is lost in transit from canals to fields and 25% because of inefficient irrigation techniques. With the continuing increase in population at the current rate of 2.7 %, there is a need to optimize the water resources management: irrigation efficiencies, optimization of consumptive uses, amending cropping patterns compatible with agro-ecological zones, harnessing of hill torrents and harvesting rain-fed areas. This is also essential to stop the per capita availability of water from falling below the minimum required threshold of 1000 cubic meter capita per annum which will lead to Pakistan falling into the category of water scarce countries. Hence availability of surface water is also an issue that poses a considerable threat to the resource base-the environment. The continued abstraction of groundwater particularly through over-pumping has led to the depletion of the water table in many areas. This problem has become more acute in recent years due to the continued and extended drought cycle being suffered by Pakistan.

The Indus Basin Irrigation System

Figures in 000 Cusecs



Schematic Diagram
Indus Basin Irrigation System (IBIS)

Surface and ground water quality is also deteriorating day by day. The indiscriminate discharge of industrial and domestic wastewater into open water bodies and groundwater is the most serious threat to the Indus Basin water resources. The conditions further aggravate during low flows or in the dry reaches of the rivers. The root causes of the problem are the competitive demands on the water resources as well as the inadequate enforcement of water related regulatory measures and standards. The water bodies such as lakes, rivers reaches, streams etc. are being increasingly contaminated by pollution from industrial, agricultural and municipal wastes.

There are 9 major ecological zones and 21 out of the 22 recognized Asian Wetland types are found in Pakistan. About 6000 plant species have been identified, of which around 5000 are indigenous- and 370 species are considered to be endemic. At present the blind Indus Dolphin (*Platanista gangetica minor*) inhabits in the Indus River, in five fragmented sub-populations separated by diversion barrages. The dolphin now occupies only one-fifth of its original range. The Indus Blind Dolphin was listed as “endangered species” in the IUCN’s Red Data Book of 2000. However, conservation measures revived the dolphin population despite the reduction of water flows and the fragmentation of the habitat. In Punjab, between Taunsa and Guddu Barrages (Figure-1), the population increased from 70 in 1985 to 345 in 2001. Same is the case in Sindh, where its population between Guddu and Sukkur Barrages (Figure-1) increased from 150 in 1974 to 620 in 2001. The construction of barrages, reservoirs and spurs for the utilization of the Indus water created many artificial wetlands. Two out of three Ramsar sites in Punjab are Chashma and Taunsa barrages, which are attracting birds, particularly migratory waterfowls in winter, the population of waterfowl has increased from 22,576 in 1986 to 190,092 in 2001 on Chashma Barrage.

The development of Indus Basin irrigation systems resulted in a reduction in inundation in the riverine area, thus having a negative impact on the riverine forest ecosystem. However, introduction of tubewell irrigation, replaced the flood recession agriculture in most of the riverine belts. This led to a change in agro-ecology with improved cropping patterns and regular water supply brought change in the socio-economic conditions and provided better opportunities of livelihoods for the local populations in most of the cases. In dry reaches where quality of tubewell water deteriorated or lowered toward uneconomic preposition, the communities had to migrate. In fact, people adopted their own way and were driven by their own preferences and priorities. However, they are also strongly influenced by climatic events such as droughts, the status of natural resources and seasonal unpredictability.

Measures to Reverse Negative Trends

Environmental Flow Concept: River and ground water systems need water to maintain themselves and their functions, uses and benefits to people. The amount of water needed for this purpose is known as environmental flow. This concept illustrates a reality and is of increasing concern. The consequences of neglecting the need to maintain environmental flows are becoming increasingly evident and costly.

Water sources and water availability in the Indus Basin

The Indus Basin covers 71% of Pakistan's geographical area, comprising of full territories of Punjab, Sindh and NWFP provinces and eastern part of the Balochistan province. The total drainage area of the Indus River is 106 Mha, about 56% in Pakistan and rest in China, Afghanistan and India. The Indus River originates from the western Himalayan ranges. The snow melt is the major source of water (about 80%) supported by the rains, notably during summer months of June to September. About 35% of Balochistan is supported by two small basins. The Kharan basin covers 16% of Balochistan, having Mashkel and Marjen the main sources of water, while the Makran Coastal covers 17% of the Balochistan and hosts flashy rivers Hub, Porali, Hingol and Dasht as the principal sources of water.

The surface water resources of the Indus Basin comprised of 145 MAF. Below the RIM station of Indus, a major western tributary Kabul and four eastern tributaries, Jhelum, Chenab, Ravi and Sutlej, join Indus River after they traverse major part of the Punjab. After the Indus Waters Treaty with India in 1960, the average Eastern inflow (estimated value of 29 MAF - Treaty documents) has gradually decreased to an average value of 8 MAF (from 1978 to 2004). The actual current contribution consists of only flood surplus and no flows in dry years. It is estimated that approximately 80% of Indus River's inflow occurs during *Kharif* season (Monsoon period between June-September).

The Indus Basin has a high spatio-temporal variability of rainfall from the North to South and from a dry to a wet year. During the last ten years these variations can be seen from 553 mm average rainfall in 1994-95 to 150 mm in 2001, with corresponding quantitative value of 120 and 30 MAF respectively. The spatial variation of the rainfall is more drastic, normally the basin is divided into five precipitation zones with annual rainfall of more than 1000 mm to 150 mm. The development of groundwater exploitation has followed a fast pace during the last twenty years in the rural as well as in the urban areas. Practically, it has become a major complementary water resource in agriculture, and the only source of water in the well irrigated areas. Major domestic and industrial water supply comes from the pumpage in the private and public sector.

The reported tube wells in 2005 are more than 600 thousands compared with less than 10 thousands in 1960 (Economic Survey 2005, Water Sector Investment Planning Study 1990). The discharge or pumpage potential of this infrastructure is quite high, while, a recent value for the "useable groundwater potential" is 55 MAF for the whole country (excluding the saline zone). The natural aquifer potential is not well estimated but is considered extended as the whole Indus plains have many meters deep thick alluvial complex. About 30% comprised of fine grained deposits of low permeability, while remaining 65 to 75 % is highly transmissive with a high recharge potential. The wide-spread network of surface channels and tube wells can support an active discharge-recharge process.

During the recent drought years, groundwater levels have shown depletion in sweet water areas of all provinces. Smaller areas close to rivers and link canals can reverse a water level trend over a short span, while the areas having well-dependent high cropping intensities will have increasing demand and groundwater extraction. While, the saline areas have local variations of water levels, decrease in levels during a dry year quickly compensated, because of ineffective drainage and low usability of the groundwater. The key outputs of water balance analysis are summarized below:

- The contribution of rainfall is important for the groundwater recharge and winter agriculture. The years with high rainfall have sizeable influence on the cultivation of grains, especially wheat. The high rainfall areas have higher well density. However, because of high variability, the annual effective rainfall in the Basin may vary from about 30 MAF in a dry year (2001) to 120 MAF in a wet year (1995);
- The agricultural demand is an important factor. It is satisfied not only by the canal and well irrigation, the root zone utilization of soil moisture is substantial in the rain-fed and high water table areas. . For 2000-01, estimated crop water requirements of the canal irrigated, well irrigated and rain-fed *(Barani)* areas were 79.5, 13.7 and 17.2 MAF respectively;
- The existing gross annual recharge and discharge vary almost in the same range, 40 to 60 MAF, in response of wet or dry conditions. However, high recharge occurs in a year when the abstraction tends to be the minimum, and the vise versa; and
- The groundwater balance of the Rabi season (October-March) is consistently negative, while the gross balance may vary from a few MAF positive in a wet year to about 15 MAF negative in a dry year.

While analyzing the water balance, spatial boundaries and groundwater recharge-discharge relations are important to suggest meaningful technical and management measures. Three factors are important to understand the water scarcity scenario of Pakistan. These are:

- The gross available water has decreased at the source after 1960 while the population has increased from 41 million to 160 million. It imparts a big decline in per capita availability changing from 5000 cubic meters per capita in 1960 to about 1300 in 2001;
- The useable water resources are decreasing with still a decrease in the Eastern flows and a gradual loss of groundwater aquifer; and
- The demand-supply gap is increasing in the agriculture as wells as in the sectors declared to have high priority by the Government. The environment is another emerging sector, which requires not only estimation of water demand, but, also water allocations and mechanism to implement environmental demands.

Mathematical models for the estimation of Environmental Flows

The basin level integrated analysis up-scales the detail of local investigations of the spatial components (reaches, rivers, provinces) and interrelates physical as well as regulatory processes along a time line of 50 years. In some cases, output at a higher level is down-scaled and split to answer the questions raised at a particular level. The collection and organization of the databases and information was the first step, followed by a comprehensive statistical and accumulative analysis of the water and ecological resources. The environmental needs were grossly estimated as demand for the key river-based water use systems. Based on preliminary analysis, a dynamic water balance model and a basin level water resources planning model are defined and applied.

Estimating quantitative requirements for different rivers and spatial units at the basin scale covers the broad range of environmental needs. The estimated needs of three main ecological concerns; sustainability of lakes and wetland, river based aquatic life and riverine area vegetation are based on the secondary data, case studies etc. These estimations can be briefly summarized as:

i. The estimated summer replenishment of the wetlands is 1.83, 1.53 and 0.2 MAF respectively for Punjab, Sindh and NWFP provinces. These bodies replenish from the summer raised flow levels (bank-full) and slowly deplete in winter because of local uses and evaporation. The summer storage and soils moisture left on the inundated land is used mostly for agriculture. No mechanism exists to protect this healthy, regenerative and a seasonal water transfer cycle;
ii. Based on the primary remote sensing data of year 2000 and the latest available secondary data (2001 & 2004) river reach wise estimation of riverine areas and their land use patterns were calculated and summed up as 1.05 Mha in Punjab and 0.404 Mha in Sindh province. The crop's evapo-transpiration from these areas was estimated for 100% annual (with diff. seasonal percentage). The gross values were estimated as 6.83 MAF for Punjab and 3.23 MAF for Sindh province.
iii. A minimum water depth of half to one meter is suggested in all rivers for the winter cross-sections. The corresponding cross sections can be termed as "effective aquatic cross-section" of the rivers. Based on the monitoring of the River Survey Division, about 5% of the full cross-section is taken as the effective cross-section for all rivers. The estimated minimum flows for the whole length of Indus, Jhelum, Chenab, Ravi and Sutlej rivers are 6,179; 2,648, 3,531; 1715 and 2,648 cusecs, respectively. The reach wise division of these flows vary approximately between 500 to 1200 cusecs.

Estimation of the Environmental Flows

First, daily data of the two years were used for the estimation of dryness of the river reaches. During a very dry year, storage releases in winter were highly regulated. The year 2002 had nine (9) river reaches released with no water for more than 150 days to almost full year. The year 2003 had five (5) reaches with no flows for 100 days. A combined impact of reduced flows and irrigation priorities is pronounced on the tail reaches of all rivers.

The ecological water requirements and the river reaches "drying phenomenon" were addressed by selecting different minimum flow options for all river reaches and were analyzed by using a basin level hydraulic model against the availability of water, quantitative competition with river diversions and the resultant water reaching at Kotri Barrage (the last structure on River Indus before Arabian Sea).

Two methods for the environmental flow implementation were evaluated for all river reaches; a) constant monthly minimum flow, and, b) variable monthly inflow percentage. Both of these methods are internationally applied to address the aquatic and terrestrial ecosystems. Starting from the uniform base scenarios, quantities were evolved on the basis of ecological demand, length of the reach and extent of dryness.

The base minimum flow of 1000 cusecs for a river reach is close to the average reach flows required to satisfy aquatic winter cross sections. It is two to three times higher than the riverine crop requirements at the root zone (crop Et) for different reaches. The value is in the range of 10% of Rabi inflows in all rivers except the Indus River reaches (those having much higher flows). The "10% of the river inflow" approach follows the natural hydrograph allowing environmental flows vary in a twelve-fold range from the month of low to the month of high flows. In practical terms, this water is used for replenishment of wetlands and recharge of groundwater in summer. Monthly volumes computed for each river reach on the basis of these flow rates. For all computations, the "minimum flow" is inclusive in the actual flows, *i.e.* if the actual flow is higher no minimum flow is required. For both approaches, base scenario is elaborated by defining sub-scenarios to investigate:

- Quantitative reach wise monthly shortage with reference to the historical flows
- from 1978 to 2004;
- After utilizing existing systems' potential, the impact on existing agricultural
- requirements; and
- Refinements of the base scenarios.

Three sets of the minimum flow scenarios are discussed. The 1st group represents the actual situation with reference to 1960, the 2nd group consists of below Kotri Barrage options, while the 3rd group represent the minimum flow options evaluated by the paper, upstream of Kotri Barrage. The computation of these scenarios was suggested by the International Panel of Experts who had been engaged for their views on paper outcome. The key results of these scenarios can be summarized as:

1. From the pre-1960 to the post-Tarbela dam (1974) period, average irrigation diversions increased by 30 MAF, while outflow at Kotri Barrage has decreased by about 50 MAF. This sizable reduction is contributed by the increased irrigation diversions, especially from the Indus river, reduced Eastern rivers inflows, increased network losses and developments upstream of the RIM stations (projects on the Swat and Kabul river systems in NWFP province). Downstream Kotri Barrage, agreed canal allocations are about 108.46 MAF. The capacity and operational constraints of the system make only 103 MAF diversions on the average possible from 1978-2004.
2. The base flow scenario of 1000 cusecs minimum could not be achieved by 2 MAF, most of it occurs in Rabi, while the shortage is shared equally with irrigation. This shortage is concentrated in the dry reaches and partly it is due to capacity constraint. The volumetric average shortage with respect to 10% of the inflow is 2.8 MAF, which is more evenly distributed over the months as compared to the constant flow scenario. The percentage base scenario under the existing capacities and operations (not fully achieved) is close to the current actual conditions and can be considered representing current environmental uses.
3. The Scenario I is improved by increasing minimum flow to 3000 cusecs in four reaches having longer dry spans, and utilizing 30% of this water within the reaches. It is confirmed with the irrigation department that 3000 cusecs discharge can build a flow channel in the winter river section. The impact on the existing irrigation diversion will be about 2 MAF, while outflow at Kotri barrage decreases from 33.9 to 26.28 MAF. In the context of environmental demand, this scenario provides a realistic level of compromise for the Rabi season (Low Flow period during the year).
4. The Scenario II-2 improves variable flow base scenario by considering 30% uses from the minimum flows inclusive of losses considered in the base scenario. The capacity constraint is addressed with an increased capacity of the link canals while the existing storage level is kept. The major impact is on the *Kharif* diversions, which are reduced by 4 MAF as compared to the base case. The current trend of increase in river losses suggests that this type of situation can be expected in future. To satisfy wetlands water demand and to create a recharge friendly situation, it is appropriate to take 10% of the inflow as the minimum flow in *Kharif*. The net uses are in the range of the constant; however, their variation from across the rivers and reaches is a function of river regime at the monthly scale.

Flow Balances at Kotri Barrage – all values are in MAF						
Indus downstream of Kotri Barrage						Irrigation diversions below RIM stations
Kharif *	*Rabi*	Annual	*Kharif*	*Rabi* **		Annual
Simulated diversions for Water Apportionment Accord Allocations	30.6	3.3	33.9	69.8	33.1	102.9
Scenario I-1 (base case)	29.18	3.47	32.7	69.5	32.5	101.8
Scenario I-2 (proposed for Rabi)	24.51	1.77	26.28	69.53	32.35	101.88
Scenario II-1 (base case)	29.8	3.4	33.2	68.9	33.6	102.5
Scenario II-2(proposed for Kharif)	25.91	2.88	28.79	68.58	33.67	102.25

* April-September, ** October- May

Based on the above, a combination of scenarios I-2 and II-2 is recommended for provision of minimum flow security in Rabi and better support to the eco-systems in *Kharif*. Also in *Kharif*, minimum flow will correspondingly decrease in a dry year and increase in a wet year. However, it is also emphasized that the selection and implementation of the minimum flows against accepted ecological demands involve decisions at the policy, strategy and management levels. The actual selection will also be based on the agreed future development option. A recommended procedure at this stage could be to move towards the field experience now.

Conclusions and Recommendations

The following are the general conclusions

- i The paper has demonstrated a need for considering environmental flow and integrated basin level approach as essential components of Integrated Water Resources Management;
- ii The environmental flow should be partly generated from water savings rather than any reduction in the irrigators' entitlement. The savings can be created through reducing irrigation losses, wastages, seepage and general inefficiency;
- iii An additional source of environmental flows could be from the water recovered from treatment of saline effluent and sewage water;
- iv The environmental/minimum flow is not a well known concept. However, reasons to protect all water sources and their ecosystems are urgent and eminent. The river-based ecosystems and watercourses of abandoned river reaches are facing negative impacts;
- v The environmental flows can improve annual cycle of groundwater balance in the riverine areas. Hence, comprehensive management plans should be developed while considering all alternatives like agro-forestry, recharge basins and other low water use options;

vi The environmental flows partly provide future security for the human access to water, and can help to protect a future devastation not foreseen in the areas of depleting water resources. In a highly exploited basin like Indus, this is the time to carefully allocate water, giving a due consideration and priority to the self-sustained natural regenerative processes;

vii The management and regulation of environmental flows especially in the winter season, will also need sufficient water storages: reservoirs, series of dams, barrages and hydraulic infrastructure. There should be no room for distrust in water demanded, supplied and utilized for environmental flows;

viii In Pakistan's context, from the water resources perspective, management transfer is understood as a contraction of government responsibilities upstream and the Government to manage only the main system from diversion to the distributary's head. Private sector entities or farmers group can take over the management functions of the distributaries and the sub-systems;

ix The enforcement of environmental regulations on industry to control disposal of hazardous effluents in surface and underground water bodies is very weak. This has resulted deterioration of their quality. The quality of water bodies is also deteriorating in urban areas as well, mainly due to disposal of sewage wastewater directly or indirectly;

x Dumping of untreated municipal discharge into rivers and lakes has caused contamination of water bodies including underground aquifers;

xi There is a need to strengthen /establish a comprehensive public policy framework to incorporate environmental concerns in water sector development;

xii An integrated, efficient and comprehensive MIS as decision support system based on RS/GIS is an imperative, not yet available.

The following are the main recommendations made by the author:

i The implementation of the environmental flows is a policy issue. An integrated planning framework is the next step to move into actions from the policy arena. The demands of non-traditional uses like environmental flows and groundwater conservation efforts should be key targets of this framework;

ii The paper has proposed minimum flows for all the river reaches upstream of Kotri Barrage on seasonal basis. Due to high water stress in Rabi season (Low flow period), a minimum flow of 1000 cusecs is recommended for all except for four dry and long river reaches. For those dry reaches 3000 cusecs discharge is suggested assuming that about 30% of this flow will be used within the reach. In *Kharif* season (monsoon period), because of high water demand (of wetlands, recharge etc,) and higher availability of water, 10% of the natural inflow is considered as minimum flow in each river, about one third of which is expected to be utilized at this stage;

iii The environmental flows need to be gradually introduced on a pilot basis; Pakistan may set its own standards for minimum flows given its stage of development and multiple competing demands;

iv The implementation of the environmental flows will need higher network flexibility and increased surface storage during flood months. Development of series of reservoirs would be essential for establishment and regulation of environmental flows;

v Highest priority must be accorded to groundwater conservation and its replenishments by recharge;

vi Environmental Data Base Management System, inclusive of GIS/RS applications, should be adopted as a component of Basin Level Decision Support Systems;

vii A nationwide campaign to enhance public awareness about river's health and its impacts on society and economy should be launched and the environmental flow concepts should be incorporated in the higher education curricula of engineering and environment disciplines.

Provision of environmental flows, especially in the winter season, can only be assured through construction/establishment of an integrated water reservoir system consisting of dams, lakes, barrages etc. To properly present an integrated and holistic vision of the environmental issues, recommendations and estimations of environmental flows are presented in a matrix form as below.

S. No.	Recommendations	MAF of Water
*1.	Recommended Environmental Flows allocation for the Indus River, Chenab, Ravi, Sutlej, Jhelum	*Rabi: 2.25* *Kharif*: 6.0
*2.	Recommended Environmental Flows allocation for Punjab (Lakes, Water bodies, Riverine Areas etc.,)	*Rabi: 1.82* *Kharif*: 4.4
*3.	Recommended Environmental Flows allocation for Sindh (Lakes, water bodies, riverine areas etc.,)	*Rabi:* 0.43 *Kharif:* 2.1
4.	Construction of Integrated series of water reservoirs (dams, lakes, aquifer replenishment, barrages etc)	-
5.	Indus Basin Environmental Flow Management System (IBEFMS) consisting of Data bases, GIS/RS,	-
6.	Integrated Water Resource Management System for optimal management of the surface, ground and rain waters	-
7.	Feasibility of treatment of saline water being pumped out of Punjab and its sale to large urban areas	6
8.	Feasibility of treating the urban/industrial sewage from all the large and medium size centres	≈ 1
9.	Remodeling of the Irrigation Systems for carrying the environmental flows as well as to cut down wastages.	-

* The recommended allocation for environmental flows are based on the minimum flow scenarios.

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