A NEW APPROACH TO OVERCOME THE WATERLOGGING AND SALINITY PROBLEMS IN THE ARAL SEA BASIN[1]

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ABSTRACT
The annual irrigated area from the water of the rivers Amu Darya and Syr Darya in the Aral Sea Basin has increased from 2.5 million hectares (1900) to 8.0 m ha (2000). The estimated average available annual water resource is about 120 billion cubic metres (bcm). The volume or return water is about 30 bcm, a major part of which is disposed off into the rivers.

The water logging and salinity conditions have caused decline in agriculture produce. It is estimated that out of an irrigated area of 8 m.ha, 5.7 m.ha area needs drainage. The drainage measures have so far been carried out over a total area of about 4.5 m ha, an area of 1.0 m.ha is provided with sub surface horizontal drainage, 0.8 m.ha with vertical drainage and rest with open drains. The results of the practised drainage measures are far from satisfactory on account of many reasons.

The reported levels of salinity in the drainage return waters for the period 1990-97 are as follows:

		Salinity in mg/l
Upper reaches	:	1500-3000
Middle reaches	:	3500-6000
Lower reaches	:	5000-7000

The salinity of the natural water of the rivers, in the beginning of the century used to be about 250 mg/l in the upper water shed and 1000 mg/l in the low lands. It has been progressively increasing everywhere. The major cause of this increase is the discharge of saline drainage water from irrigated lands into the rivers.

The scenario of discharge of drainage water into the river thereby increasing river water salinity, then using greater volumes of saline river water for irrigation and again discharging back salts into the river results in a vicious cycle in which the demand for irrigation water keeps on growing and the salinity of river water keeps on increasing. The Aral Sea Basin, unfortunately, is caught in this vicious cycle.

The discharge of saline drainage water from irrigated lands into the rivers is the major cause of the problem. The drainage measures such as the horizontal sub-surface or open drains that are contributing to the problem can be a part of the solution, only if the drainage water can be conveyed to the sea through out fall drains without ever getting into the rivers and/or disposed off in evaporation tanks with safe disposal of accumulated salts. Another way could be to demineralise drainage water before it is discharged into the rivers. None of these seems to be feasible.

The right approach, therefore, would be to reduce and ultimately stop altogether the discharge of drainage water into the rivers. Biodrainage in which excess groundwater is removed from the soils by tree plantations by transpiration can be a feasible option. This can prevent the flow of saline drainage water into the river thereby helping to restore the salinity levels in the river water, to the original natural levels of less than 250 mg/l.

Water logging/salinity problem in irrigated lands in the Aral Basin cannot be overcome by traditional drainage measures. There is a threat of its getting worse and worse with passage of time. Biodrainage, by itself or in combination with other drainage measures, can be of great help.

Keywords: Aral Basin, Waterlogging, Salinity, Biodrainage

1 INTRODUCTION

1.1 Irrigation and Drainage Development
A programme to utilise the waters of rivers Amu Darya and Syr Darya for irrigation on a large scale to transform barren desert into productive farm land covering an area of about 8 million hectares was undertaken in the Central Asia in the 1960's. The growth of irrigated area according to Dukhovny and Umarov (2000) was as follows:

Year	Annual Irrigated area (m. ha)
1990	2.5
1960	4.5
1970	5.2
1980	6.9
1990	7.5
2000	80

The five Sea Basin States are Turkmenistan, Uzbekistan, Tajikistan, Kirgizistan and Kazakhstan. The average annual water resource of the basin is estimated as 120 billion cubic metres (bcm). Dukhovny and Yaku Bov (2000) give annual water use figures as follows:

Water Use in Cubic km (or bcm) in Aral Basin		
Year	**1990**	**1995**
Water resource	117.5	110.5
Return water	32.8	30.0

From the total volume of return water (30-36 cu Km.), 55-60% is used for irrigation. The total irrigated area has expanded upto 8 m. ha.

The withdrawal of water from the rivers resulted in progressively reduced inflow into the Aral Sea into which the rivers were ultimately discharging. As a result, the Aral Sea started shrinking in the 1970's; salinity of the Aral Sea rose and several phenomena of environmental degradation such as the destruction of the eco-systems around the sea, extinction of many fish species, and pollution of ground water were discovered. The occurrence of illness among the residents rose because of salty dust sprays in the surrounding areas as high winds picked up salts from the drying bed of the sea. Takano.Y (1994) stated that the cause of the Aral Sea crisis is the same one that destructed the Mesopotamia and Mohenjo-Daro civilizations. The same catastrophic phenomena that mankind experienced those days are recurring today due to inadequate counter measures against salinization and other failures of arid region irrigation. If we fail today to solve the environmental crisis because of our ignorance and arrogance, the next generation will lose their place to live and suffer. The cause of the Aral Sea crisis is apparent and its counter measures technically attainable. We must solve the crisis since it is a crisis universal to us, the human beings.

The ill effects of the extensive irrigation cum drainage programme are not confined to the Aral Sea alone. The ground water table in the irrigated areas is rising progressively along with an increase in the salinity of soils. Dukhovny and Umarov (1990) give the following picture:

Year	Irrigated area (m.ha.)	Depth of ground water level (per cent area)			Degree of soil salinity (per cent)		
		<2 m	from 2 to 3 m	>3 m	Nil	Low	High
1990	7.47	24.8	32.7	42.5	48	29.4	22.6
1994	7.96	31.1	29.9	39	42.2	29.9	27.9

The waterlogging and salinity conditions have caused decline in agriculture produce. As an illustration, Dukhovny and Umarov give the example of Makpaaral zone of South Kazakhstan in the middle reach of Syr darya river, where an irrigated area of 40.6 thousand hectare was a fertile land with cotton yields of 3.2 to 3.5 tons per hectare upto the year 1985 which progressively declined to the low level of 1.9 ton per ha. by the year 1996.

It is estimated that out of an irrigated area of 8 m.ha., 5.7 m.ha. area needs drainage. The drainage measures have so far been carried out over a total area of about 4.5 m ha; an area of 1.0 m ha is provided with sub-surface horizontal drainage, 0.8 m ha with vertical drainage and the rest with "mufriga" and "zauras" which are open drains and canals. It has not been possible to maintain and operate the drainage systems properly as a result of which these have deteriorated and do not provide the intended relief. The main reasons of neglect of drainage systems are high costs, shortage of electric power (for pumping), lack of participation by water users, low land productivity and unavailability of investment funds. Most existing drainage facilities now require reconstruction.

Dukhovny and Umarov (2000) describe to approach the problem in the following three principal directions:

- completion of drainage facilities, where they have not been, as required by design;

- reconstruction of the existing drainage facilities;
- proper maintenance of the existing drainage facilities.

To start these it is necessary to:

- work up a more complete understanding of the present structure of land use;
- improve the methods and assessment criteria of the state of land melioration and fertility, considering the following: condition of irrigation and drainage networks, shortage of water resources and deteriorating quality of irrigation water. Assess lands in Central Asia using the new criteria and methods;
- develop a system to assess the state of drainage. Identify the operational state of existing drainage facilities and necessary rehabilitation measures;
- determine standards for drainage system design with consideration for on-farm irrigation demands, water quality and the transition to new regulations on water and lands use;
- design standards for the operation of drainage systems that will allow responsibility for operation and maintenance to be transferred to Water User Associations.

In principle, the proposed actions will minimize water loss in irrigation network, but require a great capital investments. It will require the following steps:

- implementation of crop irrigation regimes in accordance with planned yields;
- a sharp improvement in the scale of leaching regimes by adoption of intensive methods of crop cultivation (deep soil loosening, chemical ameliorants and organic fertilizers, deep ploughing, crop rotation);
- to secure uniform moistening and desalinization of soil and minimization of groundwater infiltration through optimization of the size of irrigated plots and land leveling;
- revision of crop selection with regard for the environmental, economic and social conditions in the region;
- exclusion of strongly saline lands from cropping;
- raising the efficiency of inter-farm and on-farm irrigation network by anti-filtration lining;
- organizing of the manufacture and large scale introduction of better drainage machinery and improved irrigation technology to achieve a inform supply of water along furrows and consistent moistening of the root zone;
- organization of regular cleaning and maintenance of inter-farm and on-farm collectors and water intakes, to prevent further deterioration of technical conditions of primary drains and the appropriate drainage of irrigated lands;
- to initiate repair and rehabilitation works of on-farm drains, drainage collectors and tube wells, as well as expansion of the modern drainage technologies;
- to definite proper government support to drainage network, especially for vertical drainage and inter-farm collectors;
- to organize local base for maintenance and repair of drainage system on contract base;
- to rehabilitate the local production of tubes and drainage techniques;
- to create the training and education of young specialists in drainage (construction, operation, maintenance).

It would be an uphill task to carry out the proposed measures successfully. A fresh look is needed on the two vital aspects, of water management and drainage methodology to search alternative approaches and methods that may be effective.

2 WATER RESOURCE MANAGEMENT

Assuming that 96 bcm (80 per cent of the available annual water resource of 120 bcm) is used for irrigation and an additional quantity of return water, 18 bcm (55-60% of 30-36 bcm) is also so used, the total water volume of 114 bcm is presently used to irrigate an area of 8 m ha annually. This gives the overall irrigation water use figure of 1.45 m. This is far too excessive and is an important cause of the prevailing problems.

Dukhovny and Umarov mention that in the Makpaaral zone of South Kazakhstan, cotton yields of 3.2 to 3.5 tons/ha were being obtained up to 1970', with irrigation water use (including leaching requirement) of 650 mm. In the Hunger Steppe area, the recommended water delivery for optional reclamative regime is 895 mm against the old practice of delivering water at the rate of 1344 mm.

In the Indus basin in India and Pakistan, irrigation over an area of 26 m ha is based on a water delivery of about 600-mm.

The reasons for the use of excessive water for irrigation appear to be (i) liberal availability of water to the water users particularly in upper reaches; (ii) increasing salinity in the irrigation water as well as in the soils requiring greater fractions of leaching water. The remedial measures should aim to control and regulate irrigation water supply at rates no more than actually needed by the crops.

In case the rate of water application for irrigation is restricted and regulated to 650 mm. then the water use for irrigating 8.0 m ha area would be about 52 bcm (against 114 bcm as at present) resulting in a possible saving of 62 bcm. The volume of return water may reduce to about 10 bcm (20% of 52 bcm), that is 26 bcm less than at present (which is 36 bcm). The net saving in water use would work out to 62-26 = 36 bcm. This quantity of water can then be used for irrigating additional lands or allowed to flow into the Aral Sea or shared between the two options. This arrangement would help to:

- overcome the environmental and other problems being faced due to shrinking of Aral Sea.
- reduce the problem of water-logging and salinity in irrigated areas.
- improve the quality of water in the rivers.
- save water for additional productive use.

3 SALINITY MANAGEMENT

It is reported (Dukhovny & Yaku Bov) that 55 to 70 per cent of return water in Syr Darya basin and 40-48 per cent of that in Amu Darya basin is discharged into the rivers. The total annual return water volume being 30-36 cu.Km.., the net volume of return water being discharged into the rivers is therefore about 18 cu.Kms.

The reported levels of salinity in the return waters for period 1990-97 are as follows:

	Salinity in mg/l
Upper reaches	1500-3000
Middle reaches	3500-6000
Lower reaches	5000-7000

Taking the overall average salinity of the return water discharge into the river as 3500 mg/l, the total salt load discharged into the river annually by the return waters, works out to about 63 million tons.

The volume of drainage water from one hectare of irrigated land in Hunger steppe under the old zone of irrigation (unoptimal reclamative regime) was 7877 cu.m containing 27.57 tons of salt. Under the new zone of irrigation (optimal reclamative regime) the volume of drainage water from one hectare of irrigated land reduced to 2130 cu.m containing 10.22 tons of salt. It was concluded that if irrigation in Central Asia is practised in accordance with the recommended optimal reclamative regime, the salt discharge into the rivers due to return waters would reduce to 40 per cent of the present value. But even under the recommended optimal reclamative regime, discharge of 10 tons of salt from one hectare of irrigated land would result in a total annual discharge of 80 million tons from 8 m.ha. and if 60 per cent of this finds its way into the rivers, the net annual discharge of salts into the river would still amount to 48 m. tons.

Dukhovny and Yayubov mention that in the Syr Darya basins the salt content in the return water in the upper reaches is 1500 to 3000 mg/l and in the lower reaches 3500-7000 mg/l. Similar picture is found in the Amu darya basin. The collector drainage water salinity is 1500-4800 mg/l. While discussing the re-use of drainage water for irrigation they classify the water with salinity 600-1090 mg/l as good (I Class), that with salinity 1000-2500 mg/l as satisfactory (II class), that with salinity 2500-6000 mg/l as weakly satisfactory (III class) and that above 6000 mg/l as bad (IV class).

In the Aral Sea basin an annual river flow of 120 bcm of salinity 250 mg/l and return flow of 18 bcm with average salinity of 3500 mg/l would give total annual salt contribution of 93 million tons. When drainage water is discharged into the rivers, the salinity of the mix water in the river increases. The quantity of increase would depend upon the salinity of drainage water and its volume. The following table shows the average salinity of mix-water in the river corresponding to different salinity levels of the return water and different mix ratios. It is seen that there is manifold increase in river water salinity due to the discharge of saline drainage water into the rivers.

Table 1 Salinity of mix-water in the rivers

Salinity of natural river water (mg/l)	Salinity of return water (mg/l)	Average resultant salinity of mix water of ratio (natural:return) (mg/l)			
		4:1	5:1	6:1	7:1
250	1500	500	458	429	406
	2000	600	542	500	469
	3000	800	708	643	594
	4000	1000	875	786	719
	5000	1200	1042	929	844
	6000	1400	1208	1071	969
	7000	1600	1375	1214	1094

When mix-water from the river is used for irrigation, the need for leaching fraction increases with increase in salinity in the irrigation water. The direct use of saline drainage water for irrigation results in even greater requirement of water for leaching and irrigation. The volume of net drainage water discharged into the river may be reduced but not the quantity of salts. Therefore, the salinity in river water is not reduced. Discharge of drainage water from irrigated fields into the river, can provide relief from salinity to the drained areas on regional or local basis, but in the overall terms it creates more problems than it solves. Horizontal sub-surface or open drainage systems can be no solution to the overall problem being faced in the Aral Sea Basin, unless the drainage water can be safely disposed off into evaporation tanks or discharged into the oceans through dedicated outfall drains without being put into the rivers. The experience on evaporation tanks, so far is not very encouraging. The outfall drains are very expensive and difficult to construct and maintain.

The scenario of discharge of drainage water into the river thereby increasing river water salinity, then using greater volumes of saline river water for irrigation and again discharging back salts into the river results in a vicious cycle in which the demand for irrigation water keeps on growing and the salinity of river water keeps on increasing. The Aral Sea Basin, unfortunately, is caught in this vicious cycle. The traditional drainage measures, the horizontal sub-surface or open drainage systems or the vertical drainage systems cannot solve the problem of the Aral Sea Basin area, in the long term on a sustainable basis. The viable solution can be only that in which the salts from irrigated areas do not find their way into the rivers.

4 BIO-DRAINAGE

Dukhovny and Umarov classify reclamative regimes as follows:

automorphous regime	-	irrigation water not connected with ground water. Infiltration is free.
semi automorphous regime	-	ground water backs up irrigation water but almost doesn't feed plants
semi hydromorphous	-	ground water feeds plants prevailing over irrigation water
hydromorphous	-	plants are mainly fed by ground water

Under the bio-drainage scheme, the irrigated crops (cotton etc.) would grow under automorphous regime while the tree plantations to provide drainage would be under the hydromorphous regime. The tree plantations are to be raised in blocks and strips adjacent but outside the blocks of irrigated areas.

4.1 Water balance

Dukhovny and Umarov, for the optimal reclamative regime in respect of Hunger Steppe estimate the volume of drainage water as 2130 cubic metres corresponding to total water application of 11530 cubic metres. The volume of drainage or recharge water is approximately 20 per cent of the applied water. They give the figure of annual potential evaporation as 1200-1700 mm.

Kapoor (2001) suggests that tree plantations can transpire quite large volumes of ground water at shallow depth. To estimate the area required for tree plantations for transpiring as much quantity of ground water as is added in the form of recharge from irrigated area, he gives the following relationship:

$$P/C = \frac{R_F x A_F x I_R}{k \text{ x } A_{pan}}$$

Where P/C	represents the fraction of culturable area that must be under afforestation
R	is the recharge factor i.e. ratio of net recharge (to ground water) to total

F

	irrigation water supply
A_F	is the area intensity factor of irrigated agriculture
A_{Pan}	is surface evaporation from a standard pan
k	is adjustment 'factor' to account for canopy cover, tree species and salinity of ground water.
$k \times A_{pan}$	represents the quantity of Tree Water Use

For the Aral Sea Basin, if $R_F = 0.2$, AF = 1.0, $I_R = 650$ mm and $k \times A_{Pan} = 1300$ mm, then P/C = 0.10, that is, tree plantations over 10 per cent of the area can provide the needed bio-drainage to check the rise of ground water table and stabilise it at safe deep level. Tree plantation in blocks or strips, suitably distanced and dispersed in the irrigated area can help achieve a water balance to overcome the threat of water logging.

Kapoor (2001) recommends the use of Donnan equation to decide on the spacing of plantations:

$$L^2 = \frac{8KY_oh}{R} + \frac{4Kh^2}{R}$$

Where	L	is distance between plantations
	R	is rate of recharge
	Y_o	is height of water level above barrier layer underneath plantations
	K	is hydraulic conductivity
	h	is head difference

4.2 Salt balance

The annual salt input with 650 mm of irrigation water containing 250 mg/l salts would be 1.65 tons/ha/yr.

The harvested raw cotton produce of 3 tons/ha along with 7 tons/ha of foliage containing 3.33 per cent average minerals (cations – Na + Ca + K + Mg), would enable extraction and removal of salt compounds to an extent of 1.0 ton/ha/year (The weight of salt compounds of sodium, calcium etc. is on average about three times the weight of cation elements found in the plant by ash analysis). The data of cotton/foliage produce and mineral content in them is to be checked for the relevant site and if it is different from the figures given above, then the actual field data should be used to estimate mineral removal by harvested agriculture crops.

Tree plantations over 10 per cent area with utilizable bio-mass produce of 30 tons/ha/year, containing 2.5 per cent minerals (cations), would enable evacuation of another 0.2 tons of salt compound per ha per year.

Total extraction and removal of salts by crops and plants would be about 1.2 tons/ha/year. This would be 0.45 tons/ha/year less than the salt input of 1.65 tons/ha/year. This would result in an increase in the salinity of ground water. Kapoor (2001) describes a method of estimating the rate at which the ground water salinity may be expected to increase and shows that this rate while using irrigation water of low salinity is likely to be too slow to be a matter of concern.

There can be methods to achieve full salt balance. Cervinka et al (2001) describe experiment on growing Salicornia plant giving a bio mass produce of 10.5 tons/ha with as much as 43.5 per cent mineral content. Growing of Salicornia plants on one hectare area by irrigating from pumped ground water can help remove about 4.5 tons of salts from the ground water. Such plantations over relatively small areas can help in achieving a total salt balance.

An acceptable salt balance is feasible with the help of crops and plantations so long as the irrigation water is of good quality. Therefore, a feasible approach, for overcoming the problem being faced in the Aral Sea Basin, is to prevent the pollution and increase in salinity of the river water. If the discharge of drainage water from irrigated lands is totally stopped along with elimination of discharge from other polluting sources, the salinity level in the river waters can be restored to the original natural level of 250 mg/l or even lower. Bio-drainage can help to achieve this.

5 OTHER BENEFITS:

In addition to providing drainage, the tree plantations would give economic and environmental benefits of great value, so much so that the net cost of providing drainage may be near zero. Good deal of data is available on suitable plantations for different conditions of soils and climates. A start can be made on the basis of available information and experience. Further research for improvements and finding answers to gaps in knowledge may be needed.

6 CONCLUSION:

In the Aral Sea Basin the annual irrigated area has increased from 2.5 m.ha at the beginning of the century to 8 m. ha by the year 2000. The salinity of the water of the rivers Amu Darya and Syr Darya, which earlier used to be about 250 mg/l in the upper watershed has been progressively increasing. The salinity levels in the lower reaches of the rivers are much higher. The major contributory source to the progressively increasing salinity is the discharge of saline drainage water from irrigated lands into the rivers. The water salinity of return water in the upper reaches is 1500-3000 mg/l, in the middle reaches 3500-6000 mg/l and in the lower reaches 5000-7000 mg/l.

The waterlogging and salinity are on the increase in the irrigated land causing loss in agriculture productivity. The problem is proposed to be overcome by cutting down on the volume of water that is excessively used for irrigation and by extension and reconstruction of the horizontal sub-surface and open drainage systems.

There is no doubt that better water management to reduce the quantity of water being used for irrigation would help and is a step in the right direction. But it is doubtful whether horizontal sub-surface and open drainage systems can be sustainable in the long term for the entire basin taken as a whole. The discharge of saline drainage water from irrigated lands into the rivers is the major cause of the problem. How can then it be a part of the solution? The right approach should be to reduce and ultimately stop altogether the discharge of saline drainage water into the rivers. This cannot be achieved by reconstructing and extending the horizontal sub-surface and open drainage systems. This may further aggravate the situation.

The vertical drainage systems can be effective where the ground water is of good quality and where assured electric power is available for pumping. But in this system the salts are merely recycled and not removed from the system.

Bio-drainage, in which excess groundwater is removed from the soils by tree plantations by transpiration can be a feasible option. They can prevent the flow of saline drainage water into the river and restore the salinity levels in the river waters to the original natural levels of less than 250 mg/l. This in turn can help in achieving salt balance by removal of enough salts through the harvested crops and foliage.

7 REFERENCES

Dukhovny V.A. & Uma Rov PD et al (2000). "The land salinization and drainage problem in Central Asia" paper presented at the 8th ICID International Drainage Workshop, New Delhi - Vol. I – p. 71, 79-84

Dukhovny V and Yaku Bov KH (2000). "Return waters of the Aral Sea Basin and possibilities of their utilisation on the base of "Green Desert" programme" paper presented at the 8th ICID International Drainage Workshop, New Delhi – Vol.III – p. 329-331

Takano Yoshihiro (1994) GIF Japan. "Our actions towards the rehabilitation of the Aral Sea" Paper presented at the Special Sessions programme on Aral Sea Basin, Bulgaria (19th May 1994) ICID Report p. 35.

Kapoor AS (2001). "Bio drainage A biological option for controlling water logging and salinity" Tata McGraw Hills Publishing Co Ltd.p.210-212

Kapoor AS (2001). "Bio drainage A biological option for controlling water logging and salinity" Tata McGraw Hills Publishing Col Ltd. New Delhi p. 146-147

Kapoor AS (2001). "Bio drainage, A biological option for controlling water logging and salinity" p. 71-74, Tata McGraw Hills Publishing House

Cervinka V. et al (2001). Drain water, salt and salinium management utilising IFDM/Agroforestry systems – Report prepared for USBR – p. 21

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