Irrigation Management in Relation to Waterlogging and Salinity: Precis for a Research Agenda in Pakistan

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Summary: This paper presents an overview of the current state of knowledge on the relationship between irrigation management in Pakistan and the incidence of waterlogging and salinity. It is emphasized that management research should focus on the whole system, including surface and ground water resources. The paper also highlights key management questions that need to be addressed such as salt and water balance and water loss from canals. watercourses and field channels.

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IRRIGATION MANAGEMENT IN RELATION TO WATERLOGGING AND SALINITY

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Foreword

This paper presents an overview of the present state of knowledge about the relationship between management of irrigation systems in Pakistan at both systems and field level, and the incidence of waterlogging and slainity. Special attention is given to field determinations of water and salt balances, and to water losses occurring during transport and distribution of irrigation water.

The conclusion is that systematic research has been carried out in Pakistan on only a few of the related management issues in the context of waterlogging and salinity. The necessity for addressing key management questions is now apparent from the often, and officially expressed objective to increase the productivity of irrigated agriculture by supplying irrigation water in accordance with the variable requirements of the crops.

It is emphasized that management research should focus on whole systems and consider the management of both surface water and groundwater. Five possible research topics with high potential for payoff are identified. They range from examining options for the flexible management of main canals, to evaluating farmers' response to waterlogging and salinity, to the interdependence of the water balance and the salt balance in the field.

Irrigation Management in Relation to Waterlogging and Salinity: Precis for a Research Agenda in Pakistan

INTRODUCTION

WATER MANAGEMENT IN agricultural production in Pakistan is accomplished primarily through a combination of irrigation and drainage. These two activities provide an effective control system for the provision and maintenance of a desired moisture environment for growing plants. The environment has to be defined spatially (e.g., depth of root-zone of the soil), quantitatively (e.g., the volume of water), and qualitatively (e.g., concentration of dissolved solids in the applied irrigation water and in the soil solution). These specifications may be fixed throughout the growing season, or they may vary in time. Under Pakistan conditions, the objective of irrigation management can be regarded as the management of irrigation systems and the available water resources in a manner which would result in sustainable optimum agricultural production and obviation of – to the extent possible – the adverse effects of waterlogging and salinity.

There are a number of physical, social, economic, and institutional factors contributing to waterlogging and salinity. However, in the context of irrigation management, these have to be considered together as interacting factors in an irrigated agricultural system. In this paper, attention has been given to the components of the irrigation system, starting from the irrigated field to the level of main canals.

Because of the wide variety of conditions in the extensive irrigation system of Pakistan, waterlogging and salinity problems occur within different frameworks. The primary frameworks - with particular local relevance - can be taken as: (a) the presence or absence of drainage measures (e.g., Salinity Control and Reclamation Projects), (b) a high or a low watertable, and (c) the presence or absence of fresh groundwater.

The adverse effects of long-tern canal irrigation in **Pakistan** (i.e., waterlogging and salinity), are well documented, although salinity problems in the Indus Basin are not entirely associated with irrigation. Studies of soils over the Indus Basin have revealed **that** most soil salinity is very old, produced in the process **of** soil formation much before the introduction of canal irrigation. This salinity has adversely affected the physical and chemical characteristics of the soils to considerable depths. Undoubtedly, secondary salinity associated with high watertables resulting from irrigation **has** aggravated the problem.

Waterlogging should be attributed to the spreading of water over large areas as a result of irrigation and to impeded surface drainage due to the introduction of an infrastructure for irrigation and drainage, as well as for transport by rail and road. The groundwater tables prior to the construction **of** the extensive canal system were generally very deep (R. Ahmad, et al., 1986).[1]

In both the Seventh Five Year Plan and the Report **of** the National *Commission* on Agriculture it is **stated** that opportunities for expansion of surface water supplies **for** irrigation have been virtually exhausted. Suggestions for better utilization of existing water resourses are made in these reports. With respect to waterlogging and salinity, the reports mention, among other things, the importance of preventive measures for areas not severely waterlogged or saline at present.

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[1] Ahmad. Rafiq; Hassan, M. Amjad; Hussain, Ch. Altaf; Ismail, Shoaib. 1986. Salinity and waterlogging problems *in* Pakistan: Land Utilization and Reclamation. Paper submitted for publication in Proceedings of SAARC Seminar on "Reclamation of Problem Soils", Central Soil Salinity Research Institute. **Kamal. India, September 16-19.**

MANAGEMENT ASPECTS AT FIELD LEVEL

A thorough understanding of the effects of irrigation practices on the incidence of waterlogging and salinity involves research, to monitor and evaluate the components of the water and the salt balance at different levels of the system. The basic characteristics of the soil and the cropping system determine the effectiveness of irrigation and leaching. Crop water requirements can be estimated from meterological data with sufficient accuracy. However, soil physical characteristics need to be determined systematically in the field. Other site specific research involves the evaluation of crop rotations for salinity control.

Water requirement studies have been carried out for several crops such as wheat, cotton and sugarcane. Some of these studies were done in lysimeters with watertables maintained at specified depths. Within the stable environment of the lysimeter, the capillary rise from the watertable has been thus determined for several depths of the watertable. However, these studies were done in isolation, without considering the context of managing irrigation to achieve the objective of containing or minimizing waterlogging and salinity.

Recently, the International Waterlogging and Soil Research Institute studied the constraints faced by farmers in adopting reclamation measures. Farmers in Sind and Punjab were asked about their knowledge of reclamation measures and whether they had ever applied any of these measures. The study results may not be definitive as only a limited statistical analysis was carried out and as tenant farmers were excluded in the selection of fanners in Sind. Nevertheless, it can be concluded that many fanners are ignorant of reclamation measures. This type of research could be readily expanded to include an identification of farmermechanisms for coping with excess surface water.

At present, in most situations, it is not possible to accurately inform farmers of the appropriate intervals for irrigation, or of the amounts of water to be applied if irrigation is to be in accordance with the demand of thecrops. One reason for this is that the contribution from the groundwater table has not been quantified in those areas where capillary rise from a shallow, though probably variable, watertable actually contributes to meeting the demand for water by the crops. Hence, studies thus far completed have not led to recommendations with respect to water management at the field level which the farmer can adopt with confidence.

The Water Balance

In general, at the farm level, management of irrigation includes the determination of the allowable water depletion in the root-zone before the date of the next irrigation. For this purpose, crop waterproduction functions relating the amountofwaterapplied and the expected yield are required. Of course, even when fanners know what frequency and what amount of irrigation would be optimal, the present inflexible irrigation system does not permit them to adjust their irrigations accordingly. Similarly. in terms of management related to waterlogging and salinity, the allowable water quality standards which management may accept and still expect to achieve an economic yield need to be established.

Management of water as a scarce resource also needs to consider the effectiveness of rainfall. The irrigation management implications for an effective use of rainfall in conjunction with surface and tube well water supplies have not been studied as yet.

The Salt Balance

For most irrigated agriculture areas in Pakistan, the salt balance in the root-zone is of no less concern than the water balance. The downward movement of water through the soil profile contributes to the maintenance of the desired salt balance. Thus drainage is closely linked with irrigation management as both processes are components of the control system for the maintenance of the desired environment for growing plants. For the prediction of the salt balance in irrigated soils the physical aspects of movement of salts in soils must be considered.

The leaching requirement is often used as an expression for therequired downwardflowofwaterthatwillkeepsaltswithin theroot-zone from reaching a critical level, for instance, as expressed in terms of reduction in crop yields. This concept of leaching requirement, however, assumes a static ionic equlibrium and steady state movement of water through the soil. The inclusion of temporal variations in magnitude and direction of water movement in the soil profile requires field studies.

As a dynamic concept. leaching efficiency has to take account of a number of physical parameters of the soil, for instance, depth of root-zone, unsaturated conductivity of the soil, etc. This means that the physical and chemical parameters which govern the maintenance of the salt balance in the root-zone need to be determined for characteristic soil profiles in Pakistan. So far, that has not been done. The effects of soil amendments such as gypsum on soil structure have been studied at several institutes. Again, however, we observe that these studies have been carried out in isolation and not in the context of the management concerns mentioned above.

MANAGEMENT ASPECTS AT SYSTEMS LEVEL

Reliable data on seepage losses from canal systems are considered essential for the determination of the water balance of canal command areas. Estimates of such losses have been made throughout this century, based on various techniques and expressing the results in various quantities. A review of these early studies is presented in a 1981 publication by the Water and Power Development Authority's Planning Division: ***Groundwater development and potential in canal commanded areas of the Indus Plain.***

Water Losses from Watercourses and Field Channels

The conveyance efficiency of a watercourse depends on its proper construction and maintenance. Water losses occur through seepage, evaporation, overtopping of the banks, leakage through ratholes, leakage through bunds near junctions and earthen *nakkas* (field inlets from watercourse), and in general from degraded sections of the watercourse. Moreover, any system of irrigation on demand is likely to increase the transitional losses in watercourses compared with those losses occurring in the regular *warabandi* (distribution of water in a fixed rotation) turn system. Therefore, it is to be expected that the conveyance efficiencies of watercourses can vary a great deal: hence, an average value is of little use.

The exact magnitude of the water losses from irrigated fields is also not known at a very precise. level. The efficiency of surface irrigation is known to depend on the method of irrigation, the extent to which fields have been leveled or graded uniformly, the length of run of water over the field. and the relation between water application and infiltration rate. In case of rice, for example, the method of irrigation – the so-called punchu system in Sind – where water is left flowing from one field to the next, may be particularly wasteful.

Recharge of groundwater is affected by the efficiency and effectiveness of field irrigation practices. Thus, it is important to know the degree to which water is applied in accordance with the water requirements of the crop and the storage capacity of the root-zone, and to know whether the field has been over-irrigated or under-irrigated. Spatial variability of application over the field in relation to requirement is usually substantial and also would affect water losses from the field.

Water Losses Rom Main Canals and Distributaries

Estimates of the seepage losses in main canals, branch canals and distributaries range between 600 and 15,000 liters/sec/million square meters (2 and 48 cusecs/million square feet) of wetted area. Most values, however, appear to fall between 900 and 4,500 liters/sec/million square meters (3 and 15 cusec/million square feet). The percentage of the total flowrate lost through seepage also varies greatly, as does the loss rate expressed as cusec per canal mile. This is not surprising because discharge is not directly proportional to wetted perimeter since that relation is affected by the velocity of the water and the shape of the cross-sectional area. These relationships are not the same for all canals and distributaries. More importantly, seepage rates can be expected to vary according to the permeability of the canal beds and to depend on whether the canal was built in cut or fill, as well as on the presence or absence of silt deposits and scouring. At present, the proportion of conveyance losses that goes to recharge the groundwater – and that is evaporated or transpired by vegetation – is not known, other than that it is dependent on the depth of the watertable.

Management Aspects of Water Losses in Canal Systems

It can only be concluded that reliable information on seepage losses from various parts of the canal system in Pakistan is still not available. Nevertheless, it should also be remembered that it is difficult to obtain these data for the entire contiguous irrigated area of the Indus Basin. It could even be reasonably argued that seepage losses are expected to vary greatly and are inevitable in any event. From a management point of view, therefore, one should not worry too much about the exact magnitude of such losses.

In response to changes in cropping pattern, for instance, increase in area under sugarcane (even in non-perennial canal commands), the Provincial Irrigation Departments have been under pressure to divert more than the design capacity into some canals and, in fact, have done so. This in turn has led to further changes in cropping patterns and/or cropping intensities and, in some instances, to increased water allowances. Since conveyance losses increase with an increase in flow, the questions "how effective is it to provide additional diversions of water in excess of the design or authorized discharge?" and "how much increased discharge can be expected to reach the farmers at the tail end of the system?" should be evaluated. The management of excess water, whether it be from extra flows in the canals, distributaries or watercourses (which could be localized because of inequity of water distribution), or discharges from tube wells, or from rainfall, deserves particular attention in any irrigation management research related to waterlogging and salinity.

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CONCLUDING REMARKS

Systematic research has been carried out in Pakistan on just a few of the management topics briefly discussed above. The available information, in most cases, has not reached the farmers. In this sense, the topic of management of irrigation in relation to waterlogging and salinity differs from other more technical topics such as surface drainage, which led more directly to tangible results applicable to the irrigation community. Probably the type of questions raised at present were less relevant in the context of operating irrigation systems with a constant flow regime, where any shortage in supply was assumed to be distributed in an equitable manner to the many users. Administrating a scarce resource is substantially different from managing it.

Now, in parts of Pakistan, there is more water available to irrigation systems because of groundwater development and additional diversions from the rivers. Moreover, it is increasingly evident that in order to improve agricultural production, it is necessary to supply water in accordance with the variable requirements of the crops throughout the season, with due regard to the sensitive stages of the crops grown. Whereas Pakistan irrigation systems originally tried to provide a reliable, albeit limited, source of water, in addition to the unreliable rainfall to the same crops that were produced before the introduction of irrigation, nowadays with different and more valuable crops produced under irrigation, management of the scarce water resource has become imperative.

This may require a change in focus by the Provincial Irrigation Departments. At present. the main concern of these departments appears to be to divert the design volume of water (or more, as the case may be) into the main canals and feeders without consideration of its use below the *mogha* (outlet from distributary channel to watercourse). Managing irrigation systems as discussed here implies concern for the ultimate use of the water that was delivered, in close collabnoration with the end users. In other words, in the past, it may not have been necessary to think conceptually in terms of irrigation management. Now, a holistic context of which management issues are part and parcel is essential for irrigation research.

Within the frameworks for management options related to waterlogging and salinity identified in the introduction of this paper, emphasis on research should be given to both management options and to structural improvements. The compatibility and interdependence of the two types of research endeavors should, of course, be realized.

GAPS IN THE PRESENT STATE OF KNOWLEDGE

At present, it is not known how main canal systems can be operated to make the best use of additional supplies of water. The main canals have a small number of regulating structures, considering the length of the average main or branch canal and its design discharges. Hence, from a management point of view the flexibility of the canal systems in Pakistan is low, which results in additional water from rainfall most often being lost to the groundwater.

The question of in which part of a distributary, maintenance and desiltation should be carried out, if financial constraints preclude rehabilitating the entire channel, in order to have maximum effect on equity in water delivery, presently remains unanswered.

Conjunctive use of groundwater and surface water remains an ideal, which so far has not been translated into operational rules. However, this is a critical issue if water resources are to be managed such that the undersirable effects of irrigation are prevented and, simultaneously, the system is operated with the aim of supplying (more) water in accordance with crop water needs. (Refer to suggested research topic No.1)

At watercourse and farm level it is not known how supplies can be managed when water for irrigation is to be delivered to the farmer according to the needs of the crops (an "on demand" system). The effects of watercourse improvement and lining on the equity of distribution and the reliability of water supplies at head and tail reaches of watercourses remain poorly understood. Water and salt balances in different reaches of watercourses have not been determined. although it is argued that a substantial part of the water loss from the system takes place at this level.

In terms of managing the irrigation system as a whole, the implications of management decisions at one level for the remaining management options at a lower level in the system should be carefully studied. The role of the irrigator (farmer-owner or tenant) needs to be studied and ultimately improved with a view to expanding his contribution to the prevention of waterlogging and salinity. (Refer to suggested research topic No. **2).**

The physical information for calculating leaching and capillary rise for the irrigated areas in Pakistan is insufficient. Estimates have been made based mainly on steady state conditions in lysimeters. However characteristic data are lacking on soil water retention, infiltration rates, and mobility of solutes in the soil profile. These parameters need to be known, which is presently not the case, to describe salt and water movement in a quantitative manner. (Refer to suggested research topic No **3).**

Management in relation to waterlogging and salinity requires decision making with respect to allowable water quality standards. With a decrease in water quality, yields are expected to decrease, but what is the allowable water quality the irrigator may accept and still expect an economic yield? To answer this question, crop water production functions **for** different qualities of water need to be determined. When good quality surface water is to be used in conjunction with tube well water of lower quality, irrigation management requires an understanding **of** the effects of sequential use of waters of different qualities versus the use of blended water. Information on these issues **is** presently not available for Pakistan conditions. (Refer to suggested research topic No. **4)**

One expects that the ability of a farmer to cope with the adverse effects of high watertables and surface or profile salinity improves with knowledge of the evasive measures he may take at farm level. However, the possibility for a farmer to apply these measures (e.g. on-farm drainage works, changing crops or cropping calendars, land leveling, application of gypsum, etc) may well be governed by the size and layout (or degree **of** fragmentation) of his holding. For example, transient water losses may be reduced when field channels are shortened by laying out fields as long narrow border strips, instead of rectangular grids. However, the gains from reducing water losses in the field channels may be offset by an increase in variability (lower efficiency) of field application. Presently, no information on these issues in the Pakistan context is available. (Refer to suggested research topic No. 5)

SUGGESTED RESEARCH TOPICS

A distinctive characteristic of research on irrigation management in relation to waterlogging and salinity is that the inter-relations of different components or elements, namely, infrastructural, physical, chemical. socio-economical and agricultural aspects. should be studied and analyzed. In the following brief descriptions of suggested research topics no justice is done to that principle, because the objective here is to primarily stimulate further consideration of such research topics rather than to delimit them definitively. It should be understood. however, that in the implementation of research projects on irrigation management related to waterlogging and salinity, a more holistic approach must be followed. Various agencies and institutions should study (parts of) irrigation systems simultaneously. each from its own discipline and expertise. The results then should be collated and interpreted in terms of their management implications.

1. Evaluation of irrigation system performance – a simulation approach.

Objective: to evaluate the effect of varying discharges in main canals on equity of supplies to distributaries in order to establish more optimal operational rules for managing excess water supplies.

Implementation: data collection on present operation of selected canal systems and development of a computer model to evaluate the effect of alternative operational modes.

Time frame: two to three years.

2. Evaluation of watercourse performance.

Objective: to evaluate the effect of varying discharges, as dictated by the water requirements of the crops, on the efficiency of water delivery to farm intakes along selected watercourses in order to minimize seepage losses and maintain the salt balance in the tertiary unit

Implementation: field study in two phases; first phase to establish benchmark data on present watercourse performance: second phase to measure effect of management interventions (including maintenance and desiltation) on watercourse performance.

Time frame: four years.

3. *Determination ofphysical and chemicalparameters governing the* flow *of water and salts in the profiles of characteristic irrigated soils.*

Objective: to describe the flow processes of water and solutes in characteristic soil profiles in a quantitative manner in order to evaluate trends in waterlogging and salinity in irrigated areas.

Implementation: field and laboratory study in which soil samples from soils considered to be characteristic or representative on the basis of soil survey data are examined for their chemical and physical properties.

Time frame: three years in twophases. Phase 1: selection of characteristic soils through analysis of soil survey data (one year); and phase 2 collection of soil samples and performing the chemical and physical tests (two years).

4. *Optimal ratios of saline and non-saline irrigation water for crop production.*

Objective: to developaquantitativemethod for determining the optimal or cost-minimizing mix of saline and non-saline water for crop production in order to establish operational rules for conjunctive use of surface water and brackish groundwater.

Implementation: collect data on tolerance to salinity for major crops, revenue that can be obtained for these crops, prices of water and non-water related variable inputs and the relative prices of the various waters; establish the extent to which waters of two qualities can be substituted when constant yield is sought: develop a linear programming model to assess the effects of various policies.

Time frame: two or three years (provided salt tolerance of species of major crops is known).

5. Evaluation of existing farm layouts.

Objective: to evaluate the effects of fragmentation of farmers' fields and of the length of fanner channels on the efficiency of water use; to assess existing constraints at fanners' level on the implementation of measures to cope with high watertables and salinity.

Implementation: field study involving a representative survey of fanners' fields and measurement of water loss in field channels, statistical analysis of these data, supplemented by a study of fanners' response to waterlogging and salinity questions.

Time frame: three years.