History and Magnitude of Water-logging & Salinity Problems in Former Punjab, West Pakistan

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Introduction

Water and Soil problems have existed in the former Punjab ever since an extensive system of irrigation canals was laid out. During the early stages of development of irrigation, the water allowances were quite adequate to meet the consumptive use of the crops as well as leaching requirements of the soils. At the outset the lands were, therefore, fairly productive and free from any soil moisture stresses even in cases where there were concentration of salts near the root zone. Later on, however, increase in population led to more pressure on land and greater intensity of cropping without any revision of water allowances, which remained the same as original. The outcome of these changing conditions was that more and more efforts were directed only towards bringing maximum area under irrigation with minimum possible use of water. Irrigation, thus, actually developed with inadequate water allowances, which failed to meet both the consumptive requirements of the crops and that for maintaining the salt balance in the soil. Over 23 million acres have thus come under canal irrigation during the last 60-70 years with the result that the lands are becoming saline and agricultural production is declining.

Another very important factor in the proper development of agriculture is land drainage, which is highly deficient in the Punjab. As is common in broad, flat valleys, natural drainage, surface as well as sub-surface, is very poor. In the beginning, the water-table was deep and provided enough space below the land surface to contain the percolation from canals and other sources for some years. This space gradually diminished, as the ground water levels rose with the passage of time. The situation today is that ground water is very close to the surface creating water-logging with all its pernicious effects.

The Punjab plain (Fig. 1), where ground water investigations have been completed, is a vast area, about 275 miles long and 150 miles wide, comprising

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about 40,000 square miles. There is a gentle slope in the south-western direction with an average gradient of about one foot per mile. The highest elevation of the plain is 825 feet in the north, near Sialkot in Rechna Doab, while the lowest elevation is 305 feet in the south near Panjnad. The monotony of the flat surface is broken by a few prominent hills near Shah Kot, Sangla Hill, Chiniot and Sargodha. These rock exposures of Precambrian age are high points on the Delhi-Shahpur ridge, which is mostly buried beneath the alluvium.

River Indus is the master stream while Jhelum, Chenab, Ravi and Sutlej are the major tributaries. These rivers originate outside Pakistan in snowy mountains of the Himalayas, in Tibet, Afghanistan and Kashmir. There is a great range in the maximum and minimum discharges of these rivers. In summer, the snow melt from the Himalayas and the monsoon rains provide these rivers with enormous volumes of water. In winter, when the snow melt is minimum and the precipitation negligible, these rivers have a low discharge, chiefly from ground water inflow.

The climate of the plain of Punjab ranges from sub-humid in the north-east to arid in the south-west. The mean annual precipitation in the upper part of the plain is about 36 inches. The precipitation decreases as the distance from the hills increases. There are two seasons of rainfall; the monsoon season from June to September when most of the rainfall occurs, and the winter rainfall season from December to February. The winter rainfall is less than 2 inches in the south, while in the north at Sialkot it may be as much as 5 inches and more.

The summers are very hot with an average maximum temperature of over 105°F from June to August and a maximum of over 112°F persisting for several days. There are frequent dust storms which are usually followed by thunder showers. The winters are moderate with average maximum day temperature of 70°F for December and January and a minimum night temperature mostly within the range of 35°F-40°F but occasionally approaching the freezing point.

HISTORY OF THE PROBLEM

(*a*) Waterlogging

Attention was first drawn to the evils of waterlogging in the Western Jamna Canal district in 1851, when malaria became serious. As a result of investigations then carried out, the Government ordered realignment of the canal and construction of a drainage system. Waterlogging was reported in Sirhind in 1870, in the Bari Doab in about 1880 and in the Lower Chenab in about 1900.

Little data was then available to the investigators. Systematic observations on water levels in wells started in the Sirhind Canal area as early as 1870.

Since then, lines of wells for this purpose have been laid out for each new canal opened; readings being taken in June (end of dry season) and in October (end of monsoon season). Many hydrological stations were set up. River gauges were established, and discharge measurements in the canals were recorded daily. In connection with the investigation of shortage of water in the Jhelum and the Sutlej, a regular system of discharge observation sites on the rivers of the Punjab was established by the end of 1920 under the control of Discharge Division of the Irrigation Department and since then all hydrological data have been compiled in the Division. Studies on the working of storm-water drains in relation to rainfall go back to 1910.

The earliest attempt to study the waterlogging problem was made in 1917 by Schonemann. He examined the results of observations and experiments conducted by Dyas, Beresford, Higham and Kennedy for the absorption losses of Upper Bari Doab Canal in the light of ground water flow theories and evolved his own formula* for these losses. In 1921 Elsdon, too, while endeavouring to review the subject of percolation and waterlogging, assessed the annual volume of water, which ultimately reached the water-table from rainfall and the canal systems. Based on his observations on the Lower Chenab Canal over a period of ten years, he opined that the main cause of waterlogging was the obstruction of sub-surface drainage by the percolation from larger canals and accordingly suggested their lining as an anti-waterlogging measure. Middleton, reviewing the various laws of sub-soil flow and percolation, stated in 1922 that water-logging was caused by insufficient drainage action of the rivers and difference in permeabilities of the sub-strata. Scientifically designed drains were, in his opinion, most effective against waterlogging. Later, May and Iqbal Hussain diagnosed the problem from the data then available and proposed such remedial measures as restriction of irrigation to Kharif only, withdrawal of irrigation, lining of channels etc.

First systematic study was, however, done by Wilsdon and Sarathy in 1927-28. They examined the data of water levels in wells, rainfall and irrigation water applied in Rechna Doab and inferred therefrom that both the rainfall and the irrigation water were responsible for the rise in water-table, the major cause being monsoon rains. On their recommendation the canals

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*$Q = C\,a\,d$

Where Q=absorption losses in cusecs.

a=reduced area of wetted surface.

d=depth of water on bed.

C=a coefficient varying with the capacity of the channel and which takes into account the variation of the temperature with the size of the channel it flows in.

were closed periodically, but subsequently this practice was stopped, as it caused grave dislocation to the irrigation system. In 1933, Taylor, Malhotra and Mehta carried out exhaustive statistical studies of the well observation, rainfall and irrigation data for the Upper Chenab Canal and thereby maintained that the monsoon rainfall was the only factor causing rise in the watertable, which had no relationship with the amount of irrigation water applied. As a remedy they suggested constructing storm-water drains for rapid disposal of monsoon rainfall. Later in 1937 Midha, Luthra and Vidianathan grappled with the problem in a different way. They conducted experiments along Jhang Branch and Lower Chenab to calculate the leakage to the water-table from canals which, they considered, was the major reason for rising ground-water levels. In 1937 R. B. Natha Singh, while reviewing the effects on the watertable of the seepage and storm-water drains, lowering of the full supply levels in main canals, tubewell pumping, and restriction of irrigation supplies, advocated the provision of a suitably designed system of seepage and storm-water drains to combat waterlogging. He opposed restriction of irrigation in any form. Since, in his opinion, the rise of watertable in the upper regions also affected the watertable in the lower reaches, he recommended tubewell pumping in the upgradient areas to attain its lowering in the down-gradient areas.

In 1938 Mehta carried out experiments to determine accretion to the watertable from rice and cotton crops and stated that 11.3 per cent of the total water used for rice and 3.5 per cent of the total water used for cotton was added to the watertable. In 1940. Sharma conducted investigations of the pressure gradients associated with the movement of ground waters. He utilized this technique in measuring the height of capillary fringe, transmission constant, soil evaporation, effect of rainfall and irrigation, effect of sources and sinks on watertable and transpiration etc. The results obtained were very rough and involved complicated corrections. Hence, the technique could not make much headway. During the same year Blench worked out the actual seepage loss in cusecs for Lower Chenab Canal system on the basis of record of the rise of sub-soil water in wells as published in his "Waterlogging Investigation Report 1940". On the other hand Khangar based his calculations of the seepage loss on discharge data of the Lower Chenab Canal system as given in his Paper read at the Punjab Engineering Congress Session 1947. The results of both these investigations showed that the seepage loss from the whole system of main canal and branches ranged from 40 to 47 per cent of the total discharge indicating thereby that canal leakage was the most significant factor in the rise of watertable. The conclusions drawn by Khangar on the basis of Benton's data for Upper Bari Doab Canal system showed the seepage losses to be of the order of 45 per cent.

The first comprehensive study of the problem of subsurface drainage was made by Carlston (1953). He examined all available hydrologic and geologic data for Rechna Doab and concluded that canal leakage was the major factor involved, but he recommended that further detailed studies should be made to determine which methods of reclamation were most appropriate for the Punjab to provide an adequate basis for planning reclamation programmes. More recently, it was expressed in some quarters that the buried Shahkot-Delhi ridge, which runs at right angles to the Jhelum, the Chenab and the Ravi along the centre of the doabs, served as an underground dam which accounts for the great difference in the levels of watertable on either side of the submerged barrier. This opinion was shared by Karpov and Nebolsine, Consulting Engineers, Hydrotechnic Corporation, New York, who even suggested, as a solution to the eradication of waterlogging in the north-east of the ridge, lowering of the high watertable by means of tubewells and transferring the pumped supply to the south-west of the barrier. However, extensive test drilling carried out by WASID in the buried ridge portions of Rechna, Bari and Chaj Doabs revealed that except very close to the out-crops at Shahkot, Sangla and Chiniot the greater part of the ridge was buried by over 400 to 600 feet of alluvium. As such it could not exercise any significant influence on the movement of ground water to that depth.

Generally, open surface and seepage drains were also constructed to relieve some areas of the adverse effect of waterlogging. Large scale construction programme of such drains was taken up in 1933. By 1947 about 2300 miles of these drains had been laid out, mostly in Rechna and Chaj Doabs. The construction and maintenance of drains in waterlogged areas was, however, a difficult operation. Since the country is flat, drains silt up and are choked by weeds. Out-falls are poor and ineffective during the Monsoon. Seepage drains along the canals could not achieve any general lowering of the watertable. The effect of the drains, which were laid away from the canals, was very insignificant. It was found that these could intercept only a very small percentage of the total infiltration to the ground water reservoir.

Enthusiasm for constructing drains soon began to wear out and lining of canals was started in earnest in 1938. It was decided that all the main canals and feeders should be lined. Lining of the canals was first tried in 1943 over a portion of Jhang Branch below Nanuana. It was decided to construct a parallel canal and line it with double layer of bricks. Construction of this line canal, however, presented many difficulties. The operation was expensive. As this experiment of lining of the existing canals did not prove very successful, further lining of the canals was not taken up for quite some time. New channels such as Haveli Canal, Bombanwala-Ravi-Bedian and Balloki-Suleimanki Links were, however, later on all constructed as lined canals.

In small areas, tubewells as means of lowering the waterable, were tried under Amritsar Tubewell Scheme, but the attention towards them was directed more for development of irrigation on the pattern of U.P., Tubewell Scheme (India) when Mr. Montague submitted his report on effecting irrigation in the Punjab from Tubewells in 1939. Attention was diverted to sub-soil drainage by means of tubewells in the early forties, when it was found that excessive seepage from the canals had raised the watertable to such an extent that the water in the canal had come in direct contact with the sub-soil water. It was considered that this contact could be broken and the seepage reduced considerably, if the watertable was lowered. With this object in view, a large tubewell pumping project known as Rasul Tubewell Project envisaging installation of 1860 tubewells in Rechna and Chaj Doabs was undertaken. In the beginning, tubewells were sunk at a distance of 60 feet from the canals and thereafter at 600 feet. The idea was to intercept leakage from the canals and deliver the discharge back into the canals to augment their supplies. It was, however, found that the tubewells were so close that they pumped water directly from the canals without lowering the watertable. Many tubewells were never put in operation for want of electric energy. Estimates of available supplies or safe yield for installation of tubewells had been made on empirical methods and needed correlation with thickness of aquifer, storage coefficients and transmissibility constants. Analysis of the hydrologic data was needed to determine the net recharge and discharge of the ground water reservoir.

(*b*) **Salinity**

Rehabilitation of lands is not confined to lowering of the watertable. In fact, the major problem in this connection has been reclamation of saline and alkaline lands. No extensive soil survey was made in the Punjab till 1954. Some work had previously been done, however, to ascertain the suitability or otherwise of such areas for crop production under specific schemes like the million acre soil survey in Lyallpur district, Rangpur Crown-wasteland survey, Mailsi Canal Circle Soil Survey, Jalalpur and Thal.

The reclamation of saline soils was for the first time stressed in 1917 in a war-time report on the possibilities of increased food production in the Punjab and the rapid spread of waterlogging in irrigated tracts, particularly the Chakanwali area, was brought to the notice of the Government. A Drainage Board was set up in 1917 in order to investigate the causes and effects of waterlogging and suggest suitable remedies for a successful attack on the problem. With the passage of time, it was felt that organizational improvements were required in the set-up of the Board. Accordingly, in 1925, the Drainage Board was split up into the Waterlogging Enquiry Committee and the Rural Sanitary Board. Each of the two bodies was given separate responsibilities. In the same year an experimental station to investigate the causes of infertility of waterlogged lands, changes in chemical and mechanical composition of soils and methods for treatment was set up at Chakanwali. The Waterlogging Enquiry Committee instituted systematic surveys of saline and waterlogged lands based on crop yields as determined from land revenue assessment; yield below one-fourth of the assumed normal for the tract being taken as the measure to denote "severely affected" areas. In 1931, the Central Board of Irrigation recorded its provisional opinion that the reclamation of waterlogged and alkaline soils was possible by lowering of the sub-soil watertable, if a hard and impermeable crust had not been formed. In the triennial review of Irrigation in India for 1930-33 it was reported that in the Punjab there was an area of about 26,000 acres affected by waterlogging and a further 322,000 acres affected by salts. Well records showed insignificant fall in the watertable in spite of such preventive measures as gravity drains and drains with pumped outfalls, lowering of canal beds and remodelling of distributaries.

During the period 1926-39 some basic work on diagnosis and reclamation of saline and waterlogged areas was done in the Irrigation Research Institute.

Results achieved in the Irrigation Research Institute: The results achieved in the laboratory as well as on the experimental farms were applied to the affected areas. In 1939, it was considered that the technique of land reclamation by leaching down of salts had passed the experimental stage and that the reclamation of saline lands could proceed depending on the amount of extra water supplied. A Land Reclamation Board was constituted in 1940 to give a fillip to reclamation operntions. By 1943, the supply of water for leaching salts and reclaiming lands was controlled with the Canal Circle as unit, and reclamation units were set up for each distributary canal. A separate organization known as Directorate of Land Reclamation under the control of the Irrigation Department was opened for the purpose in 1945. Director Land Reclamation was charged with the responsibility of coordinating the field work in various Canal Circles and providing scientific guidance. Such reclamation activities are still in force in different Canal Circles. Soil and Chemical Laboratories of the Irrigation Research Institute were subsequently transferred to the Directorate, thus integrating the work on fundamental and applied research on soil and water problems under the competent direction of a single entity. Standards were laid for assessing soil salinity, exchangeable sodium percentage, and their relations with crop yields, having direct bearing on economic aspects. Methods for reclamation and development of salinised and waterlogged lands have been developed at the reclamation experimental farms representing varying soil and climatic conditions and have been adopted with success. The results achieved so far are available in the annual waterlogging reports and publications of the Directorate of Land Reclamation. The pace of reclamation, however, remained slow and led to the establishment of Soil Reclamation Board in 1952 for undertaking these activities on broader lines and under a long-term programme. To ensure success and achieve lasting results it was armed with adequate powers in all the fields of its operations.

The Problem of Soil Salinity

The sediments which now fill the Indus Valley have been derived mostly from the Himalayan Mountains and foot-hills. All available geological evidences indicate that the deposition has taken place in environments as exist today. The salts resulting from the mineral decomposition were carried by rivers as a part of the sediment load to be deposited later in the plains. Depending upon the type of rock material from which the sediments were derived, the salts within the alluvial soils have a heterogeneous pattern of concentration, composition and distribution. These sediments have been subjected to evaporation in an arid to semi-arid type of climate, which left a varying degree of salt distribution within the alluvial deposits. In addition to this inherent salt distribution, the soils have further received large quantities of salts through applied irrigation water, which being in inadequate quantities, could not provide effective leaching.

A saline soil is defined as the soil, which has excess of salts sufficient to adversely affect the crop yield. Different standards exist in different countries to identify the salinity status of soils. In Pakistan it is mostly indicated by the presence of white crust of salts on the land surface, which has caused decrease in yield to such an extent that it cannot produce a 'four anna crop'. In U.S. a saline soil is defined as having a conductivity of the saturation extract of more than 4 m. mhos/cm at 25°C and the exchangeable sodium percentage of less than 15. In WASID the salinity classification is made by a combination of field observations and laboratory tests. The latter include the above U.S. methods and a salt content percentage on a dry soil; a soil having salt contents of more than 0.2% is classified as slightly saline and a soil having salt contents of more than 1.0% is classified as highly saline.

Soil salinization is characteristic of the arid and semi-arid regions. Due to intense heat such regions are subjected to rigorous evaporation losses, particularly if the area has a high water-table. Water in such areas is brought to the surface by capillary action, where it is evaporated from the soil by excessive heat and transpired by plants. Therefore, most of the dissolved salts present in the water are deposited at the surface or within the upper few inches of the surface in solid form. When this process goes on for a long time, a stage is reached where the soil becomes highly saline.

Evaporation causes salts to come over the surface in another way. Where salts are present in the coil at very shallow depths, natural precipitation or insufficient applied irrigation water may penetrate to the level of saline layer and dissolve it. On subsequent evaporation direct, or through capillarity, the salts will appear on the surface. Salts are also present in irrigation water even though in small quantities (150-300 ppm). Continuous application of irrigation water in time may add salts in the soil profile.

An alkali or sodium saturated soil (Sodic) is defined with reference to its capacity to absorb exchangeable sodium. A soil in which the percentage of exchangeable sodium is 15 or more is alkali soil. The figure of 15 per cent was adopted after experiments were made on the effects of exchangeable sodium percentage on crops. Below 15 per cent the crops were not affected.

The alkalization of soil is the last stage of salinization. In the normal soils of arid or semi-arid regions calcium and magnesium are invariably the principal cations on the exchange complex. But due to excessive accumulation of soluble salts sodium frequently becomes the dominant cation. The greater concentration of sodium ions causes a corresponding release of calcium or magnesium ions which are precipitated as carbonates or sulphates. With the increase in percentage of exchangeable sodium the soil becomes progressively more alkaline in reaction. This is why the process is termed 'alkalization'. The higher the exchangeable sodium percentage the more alkaline the soil will be.

The sodium saturation causes deflocculation of soils, a decrease in the permeability of the soils and a tendency in the soil to become puddled and hard. Sodium also casts a toxic effect on the plants. The alkalinity survey conducted by WASID in Punjab has revealed a relatively small percentage of sodium saturated soil. Consequently alkalinity of the Punjab soil is presently not considered a serious problem. However, a close watch is imperative on this aspect of soil problem.

MAGNITUDE

Water-logging and salinization of agricultural land is the most serious problem now being faced by West Pakistan. In recent years the progress that was made in the extension of the country's irrigation by opening barrages, canals etc. bringing a large area under cultivation, has been completed offset by an almost equal amount of land going out of cultivation each year or reduction in crop-yielding capacity of the land due to water-logging and salinity. The magnitude of the problem can be gauged from the figures of land acreage affected by waterlogging and salinity, which departments like Land Reclamation, Soil Reclamation Board, G.W.D.O. (now WASID), and others have given from time to time. Some of these statistics are given below :

(*i*) An assessment made in 1950 about the extent of damage by water-logging and salinity in the former Punjab revealed that about 3 million acres of land showed poor drainage/waterlogging conditions while about 1.6 million acres were affected by the salinity of varying degree intensity.

(*ii*) The assessment made in (1951-52) by the Pakistan Agricultural Inquiry Committee puts the figure of land affected by water-logging and salinity at about 2.5 million acres.

(*iii*) The survey carried out by the Directorate of Land Reclamation in 1955-56 showed that about 3 million acres in the former Punjab had been affected by salinity, out of which about 1.3 million acres had gone out of cultivation.

(*iv*) The Directorate of Land Reclamation gave a figure of 2.8 million acres for 1960-61 as the area affected by Thur in the canal colonies of Rechna/Chaj/Thal and Bari Doabs.

(*v*) The salinity survey carried out by WASID in various areas of Rechna/Chaj and Lower Thal Doab during the period 1958-61 revealed a figure of about 2.9 million acres affected by partial and severe soil salinity.

The rate of productive land being damaged by salinity each year estimated in 1945-46 was about 40,000-50,000 acres. The present estimates put this figure now at about 100,000 acres per year.

The dwindling cultivated acreage, reduced crop yields and increasing population culminated in creating a serious food shortage lending singular importance to the dire need of vigorous remedial measures against this twin cancer. Various remedies that were tried in the past, as mentioned above, were only half-way measures and not being soundly based on hydrologic data and principles, were neither extensively applied nor as intensively pursued as the nature and magnitude of the problem demanded. Foreign experts, who occasionally paid visits to the Punjab, had little time to investigate the ground water and soil problems extensively. Their suggestions generally followed the pattern adopted in the countries of their origin. It was realised finally in 1954 that both waterlogging and salinity were related to the ground-water regimen and that a solution to these problems could only be had through a complete knowledge of the conditions of occurrence of ground water. Ground Water Development Organization, now renamed as Water & Soils Investigation Division, was, therefore, set up in August 1954 in cooperation with the International Cooperation Administration (now Agency for International Development) of U. S. A. in order to start such investigations on proper scientific lines. Specific objectives of these investigations are :

1. Determination of the physical character, distribution and continuity of the soils and water-bearing material through soil survey, land classification, aerial and sub-surface geology.
2. Determination of the vertical and lateral extent of the water-bearing materials and their ability to transmit and store water through geophysical exploration, test drilling, tubewell drilling and aquifer tests.
3. Determination of the amount of change in the amount of ground water storage through the movement of ground water levels.
4. Determination of recharge and discharge to and from the ground water reservoirs through the movement of gains and losses to and from rivers, canals and drains, evaporation, transpiration and consumptive losses, infiltration of rainfall and applied irrigation water.
5. Determination of distribution and chemical character of all waters.
6. Preparation of ground water inventory.
7. Determination of the safe yield in areas compatible with economy drains, irrigation and reclamation programme by pumping from tubewells.
8. Determination of the extent of saline and alkaline lands.

The investigation programme was primarily meant for the three doabs of Rechna, Chaj and Thal between the Indus and Ravi Rivers but was subsequently enlarged to cover selected parts of the former states of Bahawalpur and Khairpur. The Organization previously known as G. W. D.O. had been under the administrative and technical control of the Irrigation Department from August 1954 to April 1960, when it was transferred to West Pakistan Water & Power Development Authority. Soon after, it was re-named as Water & Soils Investigation Division and its set-up reorganized in keeping with the goals of investigations. Its scope of activities was further extended to cover all other areas such as Bari Doab, Bahawalpur, Districts of D. G. Khan, D. I. Khan, Hazara, Bannu and other areas in the Northern Region. Intensive investigations started towards the close of 1955, when the necessary drilling and other equipment arrived from abroad.

The accompanying Table I summarises the physical progress of work achieved by WASID till June 1963 in various areas of the former Punjab in the field of Geology, Hydrology, Soil Survey, Water Chemistry, etc. In addition WASID has produced 26 publications exclusive of a large number of periodic publications of Surface Water Circle of WASID. Based on the data collected as a result of these investigations by WASID, a number of development projects for utilization of ground water for irrigation, anti-waterlogging and salinity control measures have been framed by Ground Water Reclamation Division of WAPDA. These projects provide large number of tubewells all over the affected areas for depressing the water-table and reclaiming the water-logged and saline lands. Project No. 1 in Rachna has been completed and installation work of tubewells in Project No. 2 in Chaj Doab has since started.

TABLE I—PROGRESS OF WORK OF WASID UP TO JUNE, 1963

Sr. No.	Particulars		Rachna	Chaj	Thal	Bari	Total
1.	Test Drilling No. of test holes drilled		311	259	212	139	921
2.	Depth drilled in feet		186,600	150,190	139,787	103,270	579,867
3.	Test Wells Installed.	Number	44	27	29	21	121
4.	Well Inventory.	Number	78,678	28,052	39,905	..	146,635
5.	Well Observation.	Number	176	109	103	..	388
6.	Aquifer Tests	Number	61	45	47	21	174
7.	Tests analysed.	Number	61	45	47	21	174
8.	Soil Survey in Million Acres		6.3	3.4	6.4	1.6	17.7
9.	Water Chemistry Survey No. of samples analysed.		27,075	5,029	4,526	7,369	43,999

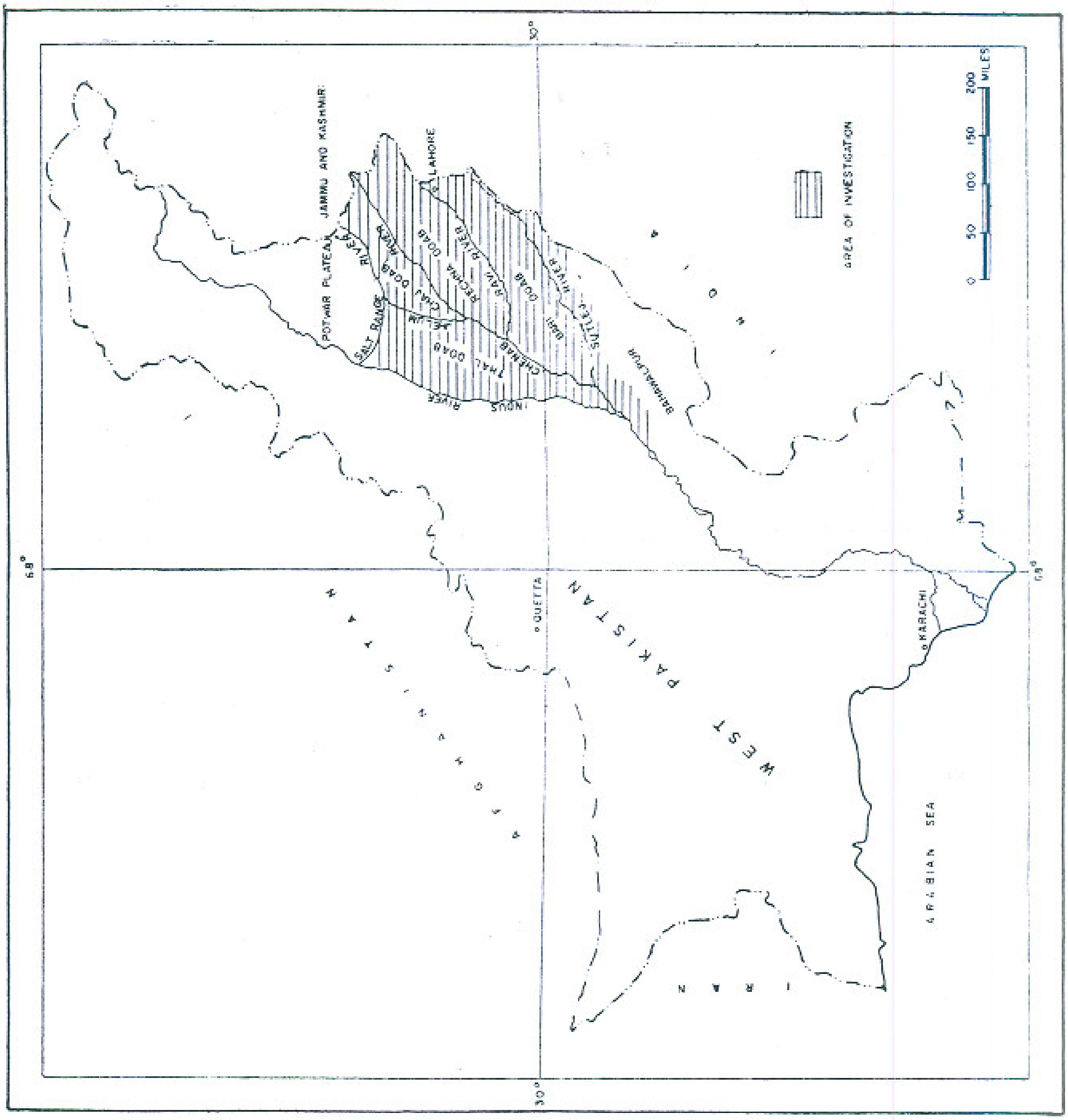

FIGURE I MAP OF WEST PAKISTAN SHOWING AREA OF INVESTIGATION

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