A Review of Salinity-Alkalinity Status of Irrigated Soils of West Pakistan

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Irrigated soils of West Pakistan are generally saline (solonchak) in nature. Alkaline soils (solonetz), usually intermixed with solonchak soils, are found in patches but do not exist extensively in this country. In the Northern region (Bari Doab) about 0.02 m.ha. of highly alkaline and saline-alkaline lands exist as a unit. This is one of the reasons that in all the soil surveys conducted till recently the classification of soils has mainly been based upon the degree of soluble salts (TDS), pH and mechanical analysis.

The first soil survey was undertaken in this country in 1941 and during the next 5 years about 6.0 m.ac. had been surveyed mainly by visual inspection supported by laboratory analysis.

In 1953, for the first time soils were started to be classified in groups so that for Northern regions in the Punjab, soils were grouped into five series [2] and this practice has continued to be followed even now in the surveys completed for the whole of the Punjab region. In 1960, the drainage investigations of Sind Region were entrusted to a firm of consultants [6, 7, 9] who too have classified the soils into seven textural divisions.

As regards the salinity and alkalinity status, the estimate has generally been based upon total dissolved solids (TDS), and soils are grouped into five classes depending upon the percentage of the TDS.

Estimation of alkalinity has so far presented some difficulty. In 1937, ASGHAR, PURI and TAYLOR [1] tried to base the alkalinity of soil on pH, on the degree of alkalinity which they defined as the ratio of exchangeable monovalent ions of Na^+ and K^+ present in a soil to the maximum amount of monovalent ions that the soil was capable of holding and on the dispersion coefficient, D. C. (defined as the percentage of total clay which can be brought in suspension on being left in contact with water for 24 hours). It is only very recently that solonetz soils are being classified on the basis of residual sodium carbonate [4, 11] (RSC) and exchangeable sodium percentage (ESP). So far in the published literature and the drainage reports [5, 10, 16], there is no information on the extent of solonetz soils. Maps showing such soils are still to be prepared.

During the last quarter of the century reclamation methods for both the solonetz and solonchak soils have been successfully perfected.

A) Soil surveys

Like many other countries of the world, Pakistan too in the earlier years had never carried out soil survey of land which was to be irrigated. In fact the first soil survey was undertaken in the year 1941 for an area of about

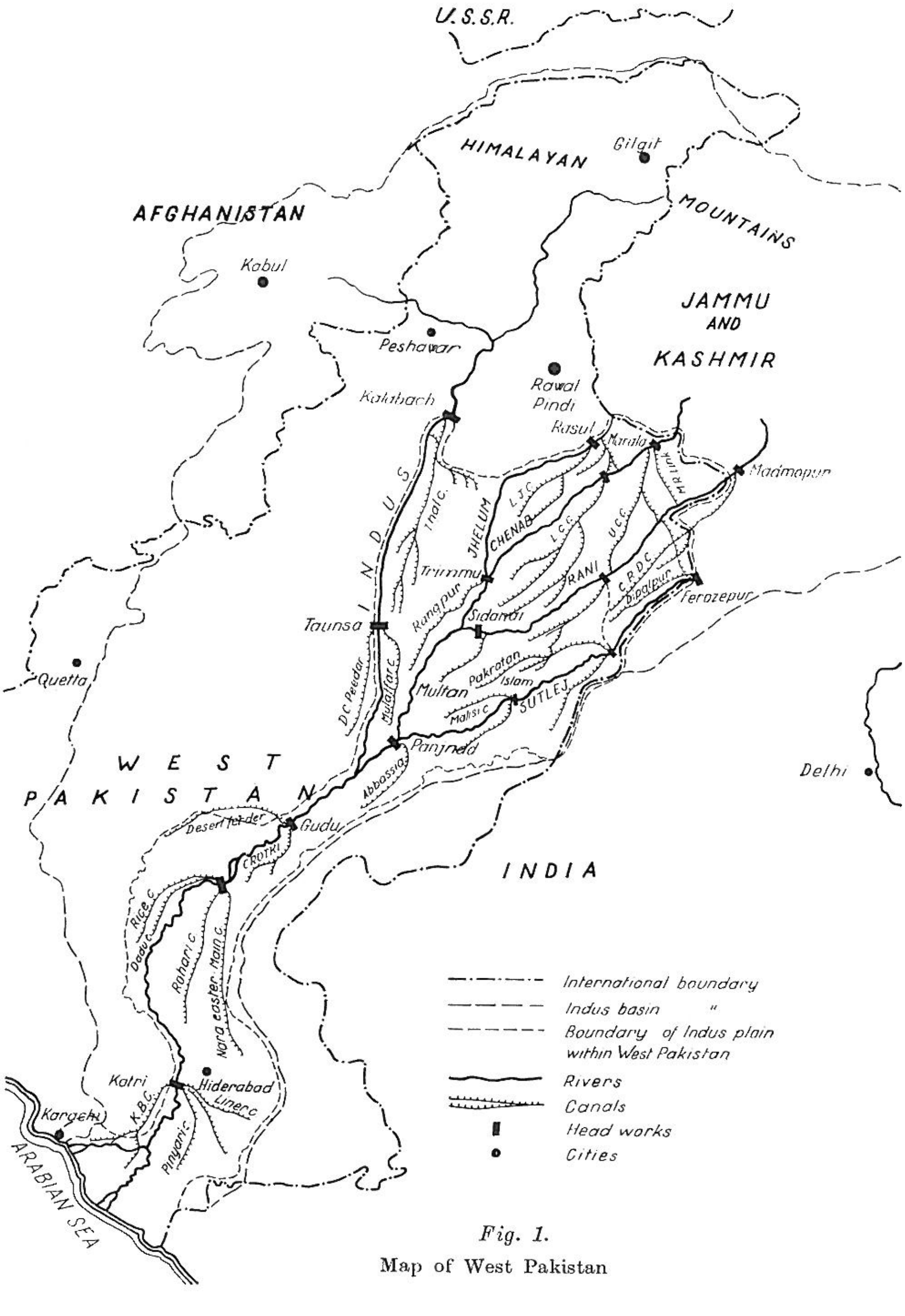

Fig. 1.
Map of West Pakistan

2.655 m.ac. (1 m.hectare) of Thal Doab, a part of the land within the boundaries of Punjab and bounded by the rivers Indus and Jhelum. The survey was limited to the top 10 ft. of soil profile. Besides study of the topography for the existence of sand dunes and other physical features of the area, chemical and mechanical analysis of the soils was also carried out.

This survey gave very useful information, so that during the next five years eight more sites, big and small covering an area of about 6.17 m.ac. (2.5 m.ha.) [12] were surveyed, some in details and others visually.

Soils surveyed

Sites	Year of survey	Area surveyed m. acres	Chemical Analysis		High salts high pH at surface
			low salts low pH in profile	law salts low pH at surface	
		Area in millions of acres			
Thal Doab	1941	2.655	0.502	0.913	1.250
Lyallpur	1941	1.000	—	0.204	0.785
Rakh Miani and Pakhowal	1942	0.002	0.001	0.000	0.001
Ghagh and Darkana	1943	0.150	—	0.104	0.045
Mailsi	1943	0.124	—	0.001	0.124
Jalalpur	1943	0.167	—	0.002	0.165
Rangpur	1944	0.065	—	0.007	0.058
Taliri and Garesh	1944	0.145	0.051	0.064	0.016
Taunsa	1946	1.860	—	0.372	1.400
Total		6.168	0.554	1.667	3.844

In the earlier surveys classification of soils into groups was not attempted. It was in the year 1953 when working in Rechna Doab area, that five series of soil classifications were established. These were:

Soil series (Nomenclature)	Textural Class	Textural Group
Jhang	Sand and loamy sands	Coarse texture
Farida	Sandy loam, fine sandy loam	Moderately coarse texture
Chuharkana	Loam, silt loam, clay loam, silty clay loam	Moderately fine texture
Buchiana	Loam, silt loam, silt	Medium heavy texture
Nokhar	Sandy clay, silty clay, clay	Clayey, fine texture

Each of these series was further sub-divided into five classes.

Recent soil surveys

1. *Punjab area*

Recently an organization called the Ground Water Development Organization a forerunner of the present Wasid Laboratories in association with the American Aids (Geological Survey) was set up which has surveyed the whole of the Punjab and Bhawalpur areas, constituting about 8 m.hectares. Based upon this survey three drainage projects [5, 10, 16] are prepared. The soil textural group existing in the area covered by the three reports for an area of about 1.2 m.hec. are as it can be seen in Table 1. This table shows that

Table 1.

Soils of Punjab Area (in hectares)

Name of the area	Total area	Jhang Group	Farida Group	Buchiana Group	Chuharkana Group	Nokhar Group
a) *Rechna Doab*						
Chichoki-mallian and Shadman ...	160,000	4,800	32,000	116,000	7,200	—
Shahkot	247,200	24,700	165,600	43,300	13,600	—
Chuharkana	10,800	200	2,900	5,000	2,600	100
Pindi-Bhattian	8,300	5,700	1,300	1,200	100	—
Khangah Dogran	121,800	21,900	52,400	39,000	8,500	—
Jaranwala	90,900	10,900	64,400	15,300	300	—
Hafizabad Thatta	131,300	18,700	61,500	46,500	4,600	—
Harse Sheikh	115,400	35,900	39,200	39,400	900	—
Sangla Hill........	150,700	28,600	39,900	76,000	6,200	—
Beranwala	125,900	800	54,200	63,400	7,500	—
Zafarwal	204,200	12,200	85,800	91,900	13,300	1,000
Sub-Total	1,366,500	164,400	599,200	537,000	64,800	1,100
b) *Chaj Doab*						
Lalian	198,000	31,500	46,400	105,500	13,200	1,400
Maggowal	45,400	2,300	7,100	12,500	21,200	2,300
Sub-Total	243,400	33,800	53,500	118,000	34,400	3,700
c) *Thal Doab*						
Muzaffargarh	89,500	7,500	53,600	12,500	14,800	1,100
Excluding Muzaffargarh	1,200,500	416,500	381,400	346,500	10,000	46,100
Sub-Total	1,290,000	424,000	435,000	359,000	24,800	47,200
Grand Total........	2,899,900	622,200	1,087,700	1,014,000	124,000	52,000
Percentage of total	—	21.4	37.5	35.0	4.3	1.8

Chuharkana and Nokhar series of soils which are classed as heavy soils constitute only 6.1%. Light soil of Jhang and Farida series constitute 59% and medium soils are only 35%. Thus the soils of northern regions and the Punjab areas are generally light.

2. *Soils in Sind area*

The Sind area constitutes about 12 m.ac. (4.8 m.ha.). This area is distributed under the command of three irrigation projects which are as under:

Irrigation Projects	*Area under command, m. acres.*
I. Ghulam Mohd Barrage	2.807
II. Sukkur Barrage	
a) Rohri Canal	2.568
b) Nara Canal	2.210
c) Sukkur Right Bank	2.055
III. Guddu Barrage	
a) Left Bank canals	0.788
b) Right Bank canals	1.588
Total:	11.920

Preparation of drainage report for this area was entrusted to Hunting Technical Service [6, 7, 9], a British Firm which instead of following the Punjab classification, found it convenient to classify the soils into seven textural groups. These were:

Texture of soil	*Symbol*
Light	L
Light heavy	Lh
Medium light	Ml
Medium	M
Medium heavy	Mh
Heavy light	Hl
Heavy	H

According to this classification soils of about 3.7 m.ac. (1.5 m.ha.) of Sind are as under:

1. Soil in Ghulam Mohammad Barrage area

Ghulam Mohammad Barrage area of Sind constitutes about 2.807 m.ac. (nearly 1 m.ha.). These soils were classified according to the above seven textural groups. This area lies on both sides of the Indus river. Area on the left side has two perennial portions of Gaja and Tando Bago. The rest of the area is non-perennial. The textural classification is shown in Table 2. It shows that heavy soils vary from 40 to 55% of the total, medium soils constitute 20 to 35% and the light soils occupy the smallest portion. The detail being as it can be seen in Table 2.

The break up of the soils for the two perennial areas of Gaja, 0.13 m.ac. (0.052 m.ha.) and Tando Bago, 0.447 m.ac. (0.19 m.ha.) out of the left bank area of the barrage as depicted above is as it can be seen in Table 3.

Table 2.

Soils of Ghulam Mohammad Barrage Command Area

(in 1000 acres)

	Left bank		Right bank		Total	
	acres	%	acres	%	acres	%
L	346.2	14.4	68.3	11.3	414.5	13.8
Lh	57.2	2.4	2.1	0.4	59.3	1.8
M	161.4	6.7	32.0	5.3	193.4	6.4
Mh	179.6	7.5	45.7	7.6	225.3	7.6
Ml	381.3	15.8	49.7	8.2	431.0	14.3
H	386.2	34.7	219.2	36.4	605.4	35.1
Hl	98.4	4.1	51.7	8.6	150.1	5.0
Complex	346.4	14.4	134.0	22.2	480.4	16.0
Total	1956.7	—	602.7	—	2559.4	—

Table 3.

Soils of Tando Bago and Gaja Area

(in 1000 acres)

	Tando Bago		Gaja	
	acres	%	acres	%
L	78.9	17.6	15.72	12.1
LH	14.8	3.3	0.43	—
M	51.8	11.6	0.16	—
Mh	38.1	8.5	6.83	5.2
Ml	69.4	15.5	21.17	16.3
H	133.5	29.9	62.73	48.4
Hl	10.7	2.4	9.14	7.9
Complex	50.2	11.2	13.18	10.1
Total	447.4	—	129.36	—

II. Soils of Sukkur Barrage Command

Sukkur Barrage commands an area of about 7.0 m.ac. (2.8 m.ha.). Out of this Khairpur area constitutes about 650.000 acres (263.000 ha.) of which 520.000 acres (210.000 ha.) are kept under crops. The soil classification is as it can be seen in Table 4.

III. Soils of Larkana Shikarpur area

This is an other small portion of the land out of Sukkur Barrage canals. It exists on right side of the Indus and lies in the two districts of Larkana and Shikarpur. The gross area constitutes 578.000 acres (234.000 ha.) which is irrigated by three canal systems, Sind and other small inundation channels, irrigate 185.000 acres (75.000 ha.) Rice canal irrigates 99.000 acres (40.000 ha.) and North West including Dadu canal irrigate 294.000 acres (120.000 ha.).

The textures of the soils in this area are enumerated in Table 5.

Table 4.

Soils of Khairpur Area

(in 1000 acres)

Texture	Area in acres	%
L	90.2	14.0
Lh	22.8	3.5
Ml	123.0	19.0
M	75.0	11.5
Mh	97.5	15.0
Hl	100.0	15.5
H	136.2	21.5
Total	644.7	—

Table 5.

Soils of Larkana Shikarpur Area

Group	Area in acres	%
L	75.2	13.2
Lh	15.0	2.6
Ml	139.5	23.9
M	41.6	7.2
Mh	132.0	22.9
Hl	55.0	9.5
H	120.0	20.7
Total	578.3	—

General remarks on soil texture

The soils of West Pakistan Indus Plains are of recent origin. They have no developed genetic characteristics. All along the big and small rivers or flood water disposal streams, there exist active flood plains which get annual deposit of fresh silt and clay. Close to these active flood plains, there exists abandoned flood plain which have been active till recently. Even now every few years whenever the intensity of flood is very high, these do get silt charge which deposits on the land with receeding floods.

The central portion of doab consisting of alluvium deposit, however, continues getting recharge and deposition from the irrigation water which are spread on the surface.

With high intensity rainfall some land is erroded even from the flat plains, to be deposited at some other sites. Thus in the land of the Indus plains fresh recharge of soil continues being deposited. The general land surface seems to be rising about a foot per 100 years.

According to the soil structure, the upper areas of the Indus, in the Punjab, generally contain more of light soils, (about 57%) of Ghang and Farida Series. Soils of medium texture are 34% and those of heavy formation are 6%.

Lower down in the Central Region of Indus within the Sukkur Barrage area, medium grade of soil constitutes 50% followed by heavy soils (33%) and light soils are only 17%. Still lower down in the delta area of Ghulam Mohammad Barrage heavy soils constitute 40—55%, followed by medium soils up to 20—30% and light soils are only 10—12%.

B) Soil salinity

The elevation of the culturable plains of the Indus is roughly a foot per mile, so that at a distance of 800 miles (1288 km.) from the sea, the land elevation is hardly 800 ft. (244 metres) above the sea level. In the Northern Region, the land slope is slightly steep at 2 ft. per mile and in the delta area, the slope is even less than 0.6 ft. per mile. Alluvium deposition took place in the sea water which with time continued to be pushed down and the fresh surface flow continued to wash down tha salts. The sources of soil salts can be enumerated as under:

1. From the original sea water, some minor remanents which may still be in existence particularly at the deeper depths.

2. Those brought down with the soil as a result of disintegration of rocks and deposited along with the alluvium.

3. Salts brought by the irrigation water and spread on the land during agricultural operation.

4. Salts coming up the surface from the under ground formation with rising ground water or by evapotranspiration.

5. Salts accumulation as a result of interchange of radicals and base exchange.

In this section we will discuss the contribution of each component separately. It may, however, be noted that the present status of salinity in West Pakistan is quite different under the innumerable changes brought about during the last 60 years as a result of agricultural operations.

Present status of salinity in West Pakistan

1. An estimate of salt affected land of West Pakistan has been carried out statistically. The work was started in the Northern areas i.e. the Punjab in the year 1944. The data collection was entrusted to the revenue staff. Later on in 1960 four statistical divisions were opened in Bahawalpur, Sukkur, Hyderabad and Peshawar (Table 6) to collect this data. Salinity affected lands as recorded by this organization during 1961—62 were as it can be seen in Table 6.

Table 6.
Salinity affected area in million acres

Region	Area surveyed	Very old	5 years old	New	Partly affected fields	Tirk	Saline areas	% of saline area	Water logged areas
Punjab	17.008	0.704	0.394	0.163	1.663	0.002	3.008	17.6	0.036
Bahawalpur ...	4.081	0.129	0.039	0.028	0.147	—	0.342	8.3	0.015
Sind	12.712	0.900	0.275	0.107	0.600	0.004	1.885	14.8	0.025
Peshawar	0.892	0.015	0.005	0.004	0.009	—	0.033	3.7	0.008
Total	34.693	1.748	0.713	0.302	2.419	0.006	5.268	44.4	0.084

Out of 35 m.ac. (14.2 m.ha.) of West Pakistan, saline area constitutes 5.3 m.ac. (2.15 m.ha.) i.e. 15.1% of the total of which the area having pretty old salts constitute about 2.5 m.ac. (1.0 m.ha.) being 7% of the total area.

2. Estimate of salt affected land according to aerial surveys.

In the year 1954—55, Government of Canada under Colombo Plan conducted a Land Forms, Soils and Land Use Survey [8] of the Indus Plains.

According to this survey (in Table 7), severely saline land constituted 4.82 m.ac. (1.95 m.ha.) and partly salt affected land constituted 11.15 m.ac. (4.5 m.ha.). As this survey was conducted by air the above figures are some times considered rather high.

3. Estimate of saline lands in Revelle's Report: recently on the request of President of Pakistan, the late President Kennedy appointed a pannel of

Table 7.
Area in 1000 acres

Site	Predominantly severely saline	Area with saline patches	Poorly drained or water-logged
Punjab			
a) Sins Sagar Doab	180	450	510
b) Chej Doab	170	570	650
c) Rechna Doab	1140	2300	2710
d) Bari Doab	100	590	40
Bahawalpur Plain	—	160	500
Sub Total	1590	4070	4410
Sind			
a) Indus Corrider	100	1880	50
b) Upper Sind	1090	2160	3200
c) Central Sind	220	1910	1030
d) Lower Sind	990	860	1850
e) Indus Delta	830	270	680
Sub Total	3230	7080	6810
Grand Total	4820	11150	11220

American Scientists to help Pakistan to overcome its problem of salinity and waterlogging. These scientists have submitted a report on Land and Water Development in the Indus Plain [15].

The estimate of salt affected lands as per that report is reproduced in Table 8.

The data is from the statistical divisions of West Pakistan Agricultural Department. It is based upon the average of ten years from 1947—49 to 1958—59.

It shows that in 30.9 m.ac. (12.5 m.ha.) of culturable lands or 20.6 m.ac. (8.34 m.ha.) of cultivated area or canal irrigated land of 12.2 m.ac. (4.9 m.ha.) the saline and water-logged lands constitute 2.41 m.ac. bout (a1.0 m.ha.) which is 12% of cultivated or 20% of canal irrigated area.

In Bahawalpur region the culturable area constitutes 3.85 m.acre (1.56 m. ha.) of which cultivated area is 2.96 m.ac. (1.2 m.ha.) and irrigated area is only 2.86 m.ac. (1.16 m.ha.). The salinity affected area out of this is 0.5 m.ac. (0.2 m.ha.). If the 11.0 m. cultivated (4.45 m.ha.) acres of Sind area are also included, then the area of salinity affected land rises to 20 or 30% of the total cultivated area.

All these estimates are based upon statistical analysis.

4. Recently some drainage projects have been undertaken both in the Punjab and Sind [5, 10, 16]. For these small areas detailed surveys have been conducted. These reports give more accurate information about the salinity status of the region. Information extracted out of these reports is shown in Table 9. The extent of soils with different orders of salinities (dissolved salts) is given. In 4.56 m.ac. constituting a part of the three Doabs of the Punjab, Rechna, Chaj and Thal, the extent of non saline soils (S-1) with salts percentage less than 0.2 is 55.6% of the total area. These are very good soils having no detrimental effect on the production of crops.

Table 8.

Land use in the Indus Plain and the Potwar uplands, average for 1949—50 through 1958—59

District or Division Punjab and NWFP	Total area	Culturable area	Cultivated area	Gross Area sown	Canal commanded area	Canal Irrigated area	Saline and water logged area	Percent of cultivated area saline and water logged
	Area in Millions of Acres							
Attock	2.67	1.34	1.14	1.05	—	—	0	0
Jhelum	1.77	0.90	0.73	0.70	—	—	0.05	7.3
Mianwali	3.44	2.65	1.41	1.20	0.66	0.13	0.01	0.2
Muzaffargarh	3.56	2.92	0.86	0.80	1.42	0.52	0.22	25.0
Rawalpindi	1.32	0.70	0.58	0.61	—	—	0	0
Gujranwala	1.47	1.29	0.95	1.01	1.01	0.62	0.38	40.6
Jhang	2.17	1.92	1.18	1.02	1.04	0.79	0.30	25.4
Lyallpur	2.25	2.05	1.77	1.86	1.71	1.89	0.18	10.4
Sheikhupura	1.48	1.34	0.94	1.00	1.20	0.88	0.50	52.8
Sialkot	1.32	1.12	1.06	1.10	0.01	0.02	0.01	0.4
Gujrat	1.46	1.20	1.05	1.11	0.52	0.48	0.05	5.0
Shahpur	3.07	2.56	1.90	1.72	1.24	1.25	0.12	6.2
Lahore	1.41	1.15	0.97	0.93	0.97	0.78	0.10	9.8
Montgomery	2.72	2.42	1.97	2.02	2.18	1.98	0.19	9.9
Multan	3.60	3.26	2.42	2.41	2.79	2.47	0.30	12.6
D. G. Khan	3.48	2.42	1.06	0.69	0.71	0.32	0	0
D. I. Khan	2.21	1.66	0.60	0.45	0.10	0.06	0	0
Total	39.40	30.90	20.59	19.68	15.56	12.19	2.41	11.9
Bahawalpur	1.23	0.93	0.70	0.70	N. A.	0.69	—	—
Bahawalnagar	1.74	1.44	1.13	1.14	N. A.	1.03	—	—
Rahimyar Khan	1.75	1.48	1.13	1.11	N. A.	1.14	—	—
Total	4.72	3.85	2.96	2.95		2.86	0.50	16.9
Sind								
Kharipur	9.22	5.51	4.32	3.16	N. A.	—	—	—
Hyderabad	21.01	11.81	6.75	3.76	N. A.	—	—	—
Total	30.23	17.32	11.07	6.92		6.11	2.1 – 306	30 – 52?
Grand Total	74.35	52.07	34.62	29.55		21.16	5.0 – 6.5?	14 – 19?

The soils of salinity class S-2, having soluble salts between 0.2 to 0.5 percent is 23.1% of the total. The lower range of salts percentage has noticeable effect on some delicate crops and higher range of salts has serious effects on many crops.

Intensively saline soils of class S-3 containing the salts between 0.5 to 1 percent are 14% of total area. These soils are unsuitable for all crops. Hardly dates can grow. Such soils need concentrated reclamation efforts before these can grow any crop.

The highly deteriorated land of the class S-4 with salts more than 1.0% constitutes 7.5%. These are all unsuitable for crops. Their reclamation is slow, expensive and often difficult.

Table 9.

Soil salinity in northern Punjab region

S. No.	Name of area	Total area (Acres)	S-1 (Salts less than 0.2 percent)	S-2 (Salts from 0.21 to 0.5 percent)	S-3 (Salts from 0.5 to 1 percent)	S-4 (Salts more than one percent)
	RECHNA DOAB					
1.	Chichoki Mallian Shadman....	160,000	16,000	107,200	36,800	—
2.	Shah Kot	247,200	178,500	49,700	19,000	—
3.	Chuhar Kana	10,800	7,400	2,500	900	—
4.	Pindi Bhattian	8,300	7,200	600	500	—
5.	Khangah Dogran	121,800	74,600	21,800	25,400	—
6.	Jaran wala	90,900	63,800	8,200	18,900	—
7.	Hafizabad Thatta	131,300	81,200	30,200	18,700	1,200
8.	Harse Sheikh	115,400	77,000	9,500	8,900	20,000
9.	Sangl-a Hill	150,700	115,100	8,700	26,900	—
10.	Beranwal-a	125,900	95,800	9,600	9,300	11,200
11.	Zafarwal	204,200	137,000	24,900	42,300	—
	Sub Total	1,366,500	853,600	272,900	207,600	32,400
	CHAJ DOAB					
12.	Lalian	198,000	167,200	16,900	10,900	3,000
13.	Maggowal	45,400	25,700	13,600	3,700	2,400
14.	Rest irrigated area of chaj less item 12–13	1,660,000	830,000	442,000	222,000	166,000
	Sub Total	1,903,400	1,022,900	472,500	236,600	171,400
	Lower Thal					
15.	Muzaffargarh	89,500	65,600	5,000	12,600	6,300
16.	Lower Thal Except Muzaffargarh	1,200,000	600,000	300,000	180,000	120,000
	Sub Total	1,289,500	665,600	305,000	192,600	126,300
	Grand Total..........	4,559,400	2,542,100	1,050,400	636,800	330,100
	Percentage w. r. t. Total	—	55.6%	23.1%	13.9%	7.4%

It may thus be noted, that about 21% of the soils in the Punjab need concentrated reclamation efforts.

In Sind the salinity and alkalinity status of top soils was separated into 5 classes of salinity. The salt percentage, electrical conductivity and salts in tons per acre in these five classes are as under:

Salinity Class	1 Saline	2 Slightly saline	3 Moderately saline	4 Highly saline	5 Ultra saline
Salt %	0.07	0.2	0.37	0.73	1.43
Elec. Cond. m. mhos/cm	0–4	4–8	8–15	15	40
Salts in tons per acre ...	6	18	33	65	111
effect on crop	no effect	noticeable effect	serious effect	unsuitable for crops	difficult to reclaim

Table

Salinity class in

	Total area	1		2	
		area	%	area	%
Left bank non perennial	1,715,800	65,200	3.8	236,780	13.8
Gaja	115,300	25,943	22.5	28,249	24.5
Tando Bago	37,200	2,304	7.0	5,282	14.2
Right Bank	603,800	19,322	3.2	82,117	13.6
	2,472,100	112,769	—	352,428	—
Larkana Shikarpur	578,000	168,200	29.1	165,300	28.6
Khairpur	650,000	192,000	32.0	165,000	27.5
Total	3,700,000	473,000	12.7	683,000	18.4

Data for saline area for Ghulam Mohammad Barrage (2.5 m.ac.), Larkana Shikarpur (0.578 m.ac.) and Khairpur (0.650 m.ac.) is given in Table 10.

The ultra saline lands having salt percentage up to 1.43 or 110 tons per acre constitute about 7 percent in central Sind and about 25 percent in the Delta area of Ghulam Mohammad Barrage. The overall percentage is 20. These soils are very difficult to reclaim. They represent a high order of deterioration of the land and may have high alkalinity, high pH and can be classed as an example of sodic soils of West Pakistan. The next class of highly deteriorated land is that with electrical conductivity of more than 15 m.mhos/cm. possessing 0.73 per cent salts or about 65 tons per acre. These soils are unproductive and nothing can grow in these. These are very difficult to reclaim and another example of saline-alkaline soils. Such soils need great efforts to reclaim but these can be successfully reclaimed. In middle Sind such soils constitute about 20 per cent and in the Delta area about 32 per cent giving an overall percentage of 30.

Soils with salinity range of 0.37%, electrical conductivity between 8 – 15 corresponding to 33 tons of salts per acre need reclamation to bring them to full production. These constitute about 14% in Sind. The reclamation is easy to accomplish.

Non saline soils and those possessing salts up to 0.2% constitute about 30% in Sind although in the Delta area their percentage lies between 3 to 14 only. Some sensitive crops may get damaged with salt content of 0.2 percent.. It may be noted that the percentage of land of non saline or those with salinity up to 0.2% is much less in Sind as compared to the Punjab, the proportion being 56 and 31% of the total ultrasaline lands or those with very high order of salinity are much more in Sind than in the Punjab, the proportion of the two being 54 and 20%.

C) Causes of soil salinity

We have already enumerated the causes of soil salinity in West Pakistan. Some soil salts may be the remanents of the period when alluvium were depositing in the sea water.

10.

Sind area

3		4		5	
area	%	area	%	area	%
224,770	13.1	549,056	32	639,993	37.3
22,483	19.5	25,366	22	13,260	11.5
5,840	15.7	14,359	38.6	9,114	24.5
82,117	13.6	224,613	37.2	195,631	32.4
335,210	—	813,394	—	857,998	—
96,100	16.6	84,400	14.6	63,000	10.9
84,000	14.0	170,000	26.5	15,000	4.3
515,000	14.0	1,068,000	28.8	936,000	20.1

Salts might also be transported by alluvium and deposited along with soil. Besides, these salts could also be added from two outer sources, the irrigation water and by upward movement from underground water or soil. We discuss below the contribution from each of these external sources.

1. *Salts deposited by irrigation waters*

Before the present development of irrigation system, the areas kept under crops were the flood plains of rivers. These received annual flood water which infiltrated down washing the land of the salts. The excess water was drained out leaving the soil with sufficient moisture to produce crops. These lands were generally without salinity.

The conditions of land brought under irrigation during the last century were quite different. These were seldom flooded, their ground water level never fluctuated, rather continued to rise regularly since the start of irrigation. The application of irrigation water was so insufficient that it never caused drainage of the land. The result of these defects was that whatever small doses of salts were added to the soil through the irrigation water they remained in the soil.

2. *Salts in water of Indus and its tributaries*

The salinity status of water of the Indus river is very satisfactory. Their salt content varies from 100 ppm. to 250 ppm. The percentage of calcium and magnesium is usually two to three times that of sodium and potassium (see typical chemical analysis of water of river shown in Table 11) bicarbonates are high as compared to sulphates and chlorides. Harmful elements such as boron are generally non-existent. In spite of this property as the annual flows are high, the quantities of soluble salts carried are also high.

In Table 12 and 13 are shown the estimates of soluble salts passed by various rivers and their tributaries [13].

In these tables, the annual flow period is separated into three groups. The periods are six months of winter, 3 months of pre-monsoon when the discharge is from the melting of snow and three months of the monsoon.

Table

Quality of river water samples

Sample No.	Source	Date	Discharge cusecs	EC × 10^6	Total solids ppm.	Boron ppm.	SiO_2 ppm.
22032	Sutlej Suleimanki	March 20.	4,769	284	198	0,06	8
22139	Sutlej 2 Suleimanki	Aug. 24.	259,455	324	573	0.07	14
22033	Rabi Boat Bridge.....	May 12.	4,041	201	148	0,02	11
22144	Robi 2 Shadra..........	Aug. 2.	9,153	207	207	0.05	14
22034	Chenab Marala..........	March 11.	11,380	226	167	0.02	6
22142	Chenab Marala..........	July 29.	70,844	179	102	0.09	6
22141	Jhelum Mangla	Aug. 7.	59,640	231	137	0.03	12
22143	Indus Kalabagh	Aug. 2.	212,500	301	169	0.05	7
22036	Indus Sukkur	Jan. 30.	31,000	370	244	0.19	8
22035	Indus[3] Karachi.........	Feb. 27.	2,751	418	270	0.30	11
22140	Panjnad Panjnad	Aug. 22.	200,598	253	149	0.07	9

Table

Dissolved salts of
Period I = April to June. Period II = July to September.

River & site	I. period				II. period			
	Dis. in maf.	Aver. salts ppm.	Total salts af.	Total salts m.tons	Dis. in maf.	Aver. salts ppm.	Total salts af.	Total salts m. tons
Jhelum at Demel	1.442	225	231	0.404	5.334	224	843	1.484
Nelum at Muzafarabad	2.047	211	307	0.537	2.550	211	382	0.669
Khunor at Ghari Habib-Ullaha	0.836	277	163	0.269	0.916	282	184	0.322
Poonch at Palak	0.650	191	88	0.154	1.340	226	215	0.376
Jhelum at Mangla	10.009	355	2,523	4.115	9.611	402	2,743	4.800
Total	14.984	—	3,312	5.479	19.751	—	4,367	7.651

Note: Jhelum river was previously known as Kishan Ganga.

11.

taken in Spring and Autumn of 1962

Milli-equivalent per litre								
Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-} HCO_3	SO_4^{2-}	Cl^{-}	F^{-}	NO_3^{-}
1.52	0.75	0.75	0.13	2.05	0.43	0.60	0.01	0.01
2.45	0.63	0.48	0.18	2.40	0.36	0.15	0.01	0.04
1.35	0.55	0.19	0.10	1.65	0.36	0.15	0.01	0.00
1.28	0.61	0.28	0.16	1.83	0.07	0.15	0.01	0.02
1.38	0.74	0.21	0.08	1.75	0.48	0.10	0.01	0.02
1.42	0.25	0.12	0.08	1.60	0.21	0.10	0.01	0.01
1.98	0.39	0.15	0.06	2.20	0.20	0.05	0.01	tr.
2.69	0.25	0.22	0.10	3.10	0.02	0.14	tr.	0.01
2.12	0.86	0.88	0.14	3.00	0.25	0.69	0.01	0.00
2.08	0.97	1.04	0.10	2.35	0.81	0.62	0.01	0.00
1.71	0.56	0.42	0.10	2.15	0.33	0.20	0.02	0.02

12.

the Jhelum river system
Period III = October to Dec. and Jan. to March.

III. period				Total of I+II+III. period			
Dis, in maf.	Aver. salts ppm.	Total salts af.	Total salts m. tons	Dis. in maf.	Aver. salts ppm.	Total salts af.	Total salts m. tons
3.942	209	585	1.024	10.718	219	1,659	2.912
0.649	145	67	0.117	5.246	189	756	1.323
0.226	262	42	0.073	1.978	273	389	0.664
0.294	182	38	0.066	2.284	199	341	0.596
5.187	272	1,002	1.753	24.807	343	6,268	10.668
10.298	—	1,734	3.033	45.033	—	9,413	16.163

Table

Dissolved salts in the Indus

Period I = April to June. Period II = July to September.

Name of Site & River	I. period				II. period			
	Dis. in maf.	Aver. salts ppm.	Total salts af.	Total salts m.tons	Dis. in maf.	Aver. salts ppm.	Total salts af.	Total salts m. tons
1. Indus at Durband	11.310	160	1142.7	2.000	35.493	251	6370.8	11.149
2. Kabul at Warsak	5.398	324	1310.8	2.294	5.968	244	103.4	0.181
3. Suat at Munda	1.522	153	166.3	0,291	1,854	146	179,6	0.314
4. Soan at Mukhad	0.138	265	18.9	0.033	0.826	224	137.7	0.241
5. Siran at Thapla	0.233	413	68.3	0.120	0.139	226	22.2	0.038
6. Harrow at G. T. Rd.	0.134	229	21.8	0.040	0.147	260	28.1	0.050
Total item 1 – 6.	18.735	—	2728.8	4.778	44.427	—	6841.8	11.973
7. Indus at Kalabagh	23.817	200	3080.0	5.390	47.496	241	8065.9	14.215
8. Kurram at Kurram Ghari	0.467	389	149.4	0.259	0.372	444	116.8	0.205
9. Gomal at Gulkatch.	0.021	300	4.6	0.008	0.018	193	2.4	0.004
Total of items 7 – 9.	24.305	—	3234.0	5.657	47.886	—	8185.1	14.424

With the annual flow of 148 maf. (173418 m.cu.meter) about 42.5 tons of salts are carried by the rivers.

At present about 70 maf. (86 709 m.cu.meter) of water is being diverted to irrigate about 24 m.acres (9.7 m.ha.) so that about 21 tons of soluble salts or roughly one ton per m. acre is being spread on the land annually. Calcium and magnesium salts are beneficial, but the small amount of sodium may have a cumulative effect of the last 50 or 60 years of irrigation of the land which are without drainage and are never flushed.

3. *Accumulation of salts on the soil surface from ground water sources*

The whole of the irrigated areas of the Indus plains are saturated with water almost to brim. At no place where the irrigation has been practised, ground water is deeper than 30 ft. In the Punjab and Bahawalpur and at many places of Sind, ground water is within 5 or 10 ft. of the surface. According to the recent estimates, areas with different positions of ground water are shown in Table 14.

Extensive irrigation exist in Chaj, Rechna and Bari Doabs, so that in these lands of about 16 m.ac. (6.4 m.ha.) water table in half of the land lies within 10 ft. (3.0 meters). In fact in this area it is fairly high as is shown in Table 15 which gives still closer break up of water table between 0 to 0.92 meters and from 0.92 to 1.83 meters. These are areas where drainage schemes are under way.

13.

river system and its tributaries

Period III = October to Dec. and Jan. to March.

III. period				Total of I+II+III.			
Dis. in maf.	Aver. salts ppm.	Total salts af.	Total salts m.tons	Dis. in maf.	Aver. salts ppm.	Total salts af.	Total salts m.tons
5.985	249	1055.8	4.539	52.788	220	8569.3	17.688
0.966	503	350.7	0.614	12.332	363	1764.9	3.089
0.461	269	88.5	0.155	3.837	189	434.4	0.760
0.052	266	7.8	0.014	1.016	235	164.4	0.288
0.134	323	30.7	0.054	0.506	321	121.2	0.212
0.112	319	27.6	0.050	0.393	270	77.5	0.140
7.710	—	1561.1	5.426	70.872	—	11131.7	22.177
11.705	168	1416.4	2.479	83.018	203	12562.3	22.084
0.491	192	178.0	0.312	1.330	442	444.2	0.776
0.009	914	4.2	0.008	0.048	469	11.2	0.020
12.205	—	1598.6	2.799	84.396	—	13017.7	22.880

Water table in about 40% of the areas of Rechna, Chaj and Thal Doabs lies within 1.83 meters from the surface. Khairpur is also an area of high water table in 238 000 hec. of Larkana—Shikarpur fluctuates between 2.14 to 2.75 meters during rice cultivation and dry season. Thus there are large areas with high water table in which the water constantly continues to rise to the surface when salts of the ground water are deposited after the water has evaporated.

Table 14.

Table showing areas in acres of water-table depth in various regions of West Pakistan (June 1959)

Regions	Total area	0′—5′	%	5′—10′	%	10′—15′	%	Beyond 15 feet.	%
Peshawar Region ...	17,623,040	20,787	0.118	182,067	1.03	106,496	0.607	17,313,690	98.24
Chaj Doab.	3,229,000	432,200	13.3	1,926,400	58.42	442,000	13.68	428,400	13.26
Rechna Doab	6,916,000	483,400	6.9	2,982,800	43.12	1,886,400	27.27	1,563,400	22.59
Thal and Derajat ...	12,786,173	250,000	0.019	1,650,000	12.90	950,000	7.42	9,936,173	77.71
Bari Doab .	6,553,600	16,783	0.25	1,365,903	20.84	1,780,838	27.17	3,390,076	51.72
Bahawalpur	10,667,187	240,000	2.24	990,000	9.28	1,210,000	11.34	8,227,187	77.12
Sind.......	35,926,080	572,621	1,59	3,346,152	9,33	1,286,349	3,58	30,720,958	85,51
Total......	93,701,080	2,015,791	2.14	12,443,322	9.89	7,662,083	8.16	71,579,884	76.22

This order of salts deposition is fairly high as the salt percentage in ground water is also high

a) *Salts in ground water :* The quality of ground water is nowhere as good as that of the rivers. Even within the flood plains, the range of salinity is nearly double that of the rivers. In fact the infiltration from the rivers, rain water and flood spills, has washed down the saline water and improved the ground water in extensive areas in the Northern regions. There are evidences that salts have been washed down to be accumulated in depressions [14]. This process has continued for ages. All the former depressions have now saline water. The flood plains or the regions below foot-hills have all good quality water which has replaced the saline one.

When the irrigation practice was undertaken about 60 to 100 years back, the infiltration from canals and fields etc. continued to be added to the underground formation. Consequently the ground water rose. The infiltering water had good quality, so that it depressed the saline water downwards.

At present generally within a depth of 100 ft. (30.5 meters) and in some cases up to 200 ft. (61 meters) the ground water of low salt content is floating on saline water at the bottom. There are a few exceptions where saline water is held up in pockets and has not been washed down. This is the condition of area which has deep saline water. The regions from which salts were washed down have good quality water often to a depth of 600 ft. (183 meters).

In the South i.e. Sind region, the conditions were different. Here the rainfall was low, soil crust was thick and heavy, irrigation was insufficient with the result that ground water has generally remained very saline. Only those areas which constituted the flood plains or where intensive rice cultivation was practiced or in the vicinity of big canals, the top ground water has improved by depressing the saline water downward.

In the big delta areas of Ghulam Mohammad Barrage and tail of Sukkur Barrage, the ground water is too saline within shallow depths.

b) *Extent of areas with saline ground water :* In the Northern regions of the Punjab saline ground water lies within one quarter of the total area (Fig. 3). In the four Doabs its extent is as under:

Region	Total area	Saline area salts above 1000 ppm.	Good water quality area salts less than 1000 ppm.
	Area in millions of acres		
Rechna Doab	4.70	0.70	4.00
Chaj Doab	2.00	0.42	1.58
Thal Doab	5.30	1.48	3.82
Bari Doab	4.40	1.76	2.64
Total	16.40	4.36	12.04

The saline water also lies at deeper depth. In case of Chaj Doab, for instance, (see below) which had before the start of irrigation in 1900, water table at 60 ft. (18.3 meter) at present the depth of good quality water is within 100 ft. (30.5 meter) from surface.

Chaj Doab

Zone	Depth of ground water	Salts ppm.	Condition of ground water
A	Up to 600 ft.	250 to 1100	usable
B	less than 200 ft.	500 to 2000	usable with dilution
	200 to 600	2000 to 15 000	not usable
C	less than 100 ft.	1000 to 4000	top 50 ft. usable
	100 to 600 ft.	3000 to 20 000	not usable
D	less than 100 ft.	1000 to 8000	top less than 50 ft. usable
	100 to 600	3000 to 20 000	not usable

In Lower Thal in an area of 0.48 m.ha. (1.2 m.ac.) saline water is limited to very small area and that too is deeper than (100 ft.) 30.5 meter. The range of salinity is:

Lower Thal

Zone	Depth of ground water	Salinity range ppm.	Area m. ac.	% of area
A	less than 200 ft.	$<$ 1000	0.985	77
B	less than 200 ft.	1000 to 2000	0.139	11
C	less than 200 ft.	$>$ 2000	0.164	12
			1.288	

Ground water in the Delta area : In case of the Delta area at many places, the ground water from the very top is very saline. An example is given below which shows the percentage areas which have ground water of various ranges of salinity.

Site	EC in mmhos./cm.						Total m. ac.
	0–5	5–10	10–15	15–25	25–50	>50	
Gaja % of total area	49	12	11	9	12	7	0.130
Tando Bago % of total area	17	9	11	8	21	34	0.398
Whole G. M. % of total area	21	10	5	8	12	44	2.800

Detailed chemical analysis of deep and shallow ground water of each Doab has been carried out. All waters contain different proportions of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, bicarbonate, sulphate and chloride. Other radicals are either non-existent or exist in minute proportion. A few typical cases of detailed chemical analysis of ground water are shown in Table 16.

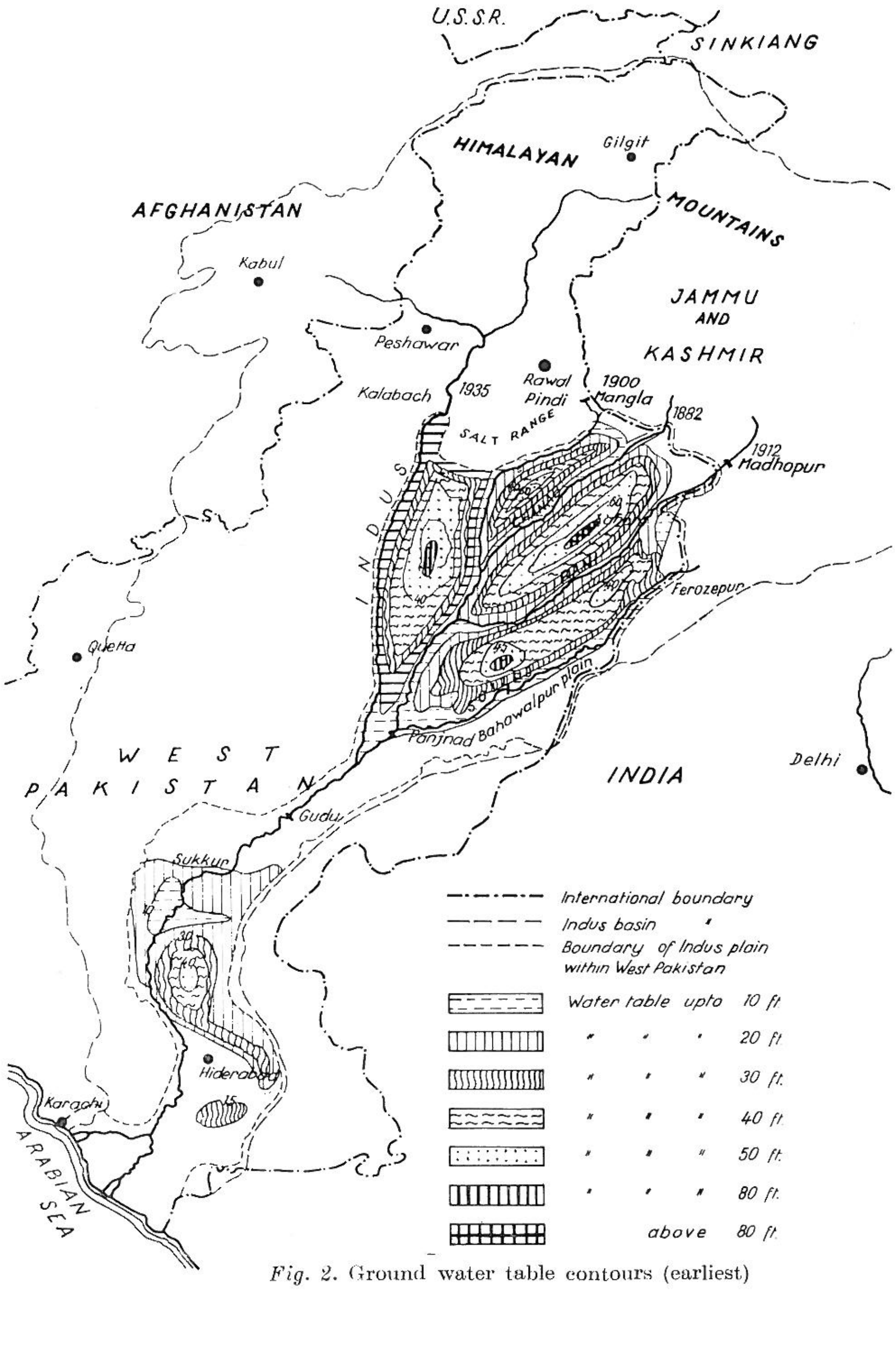

Fig. 2. Ground water table contours (earliest)

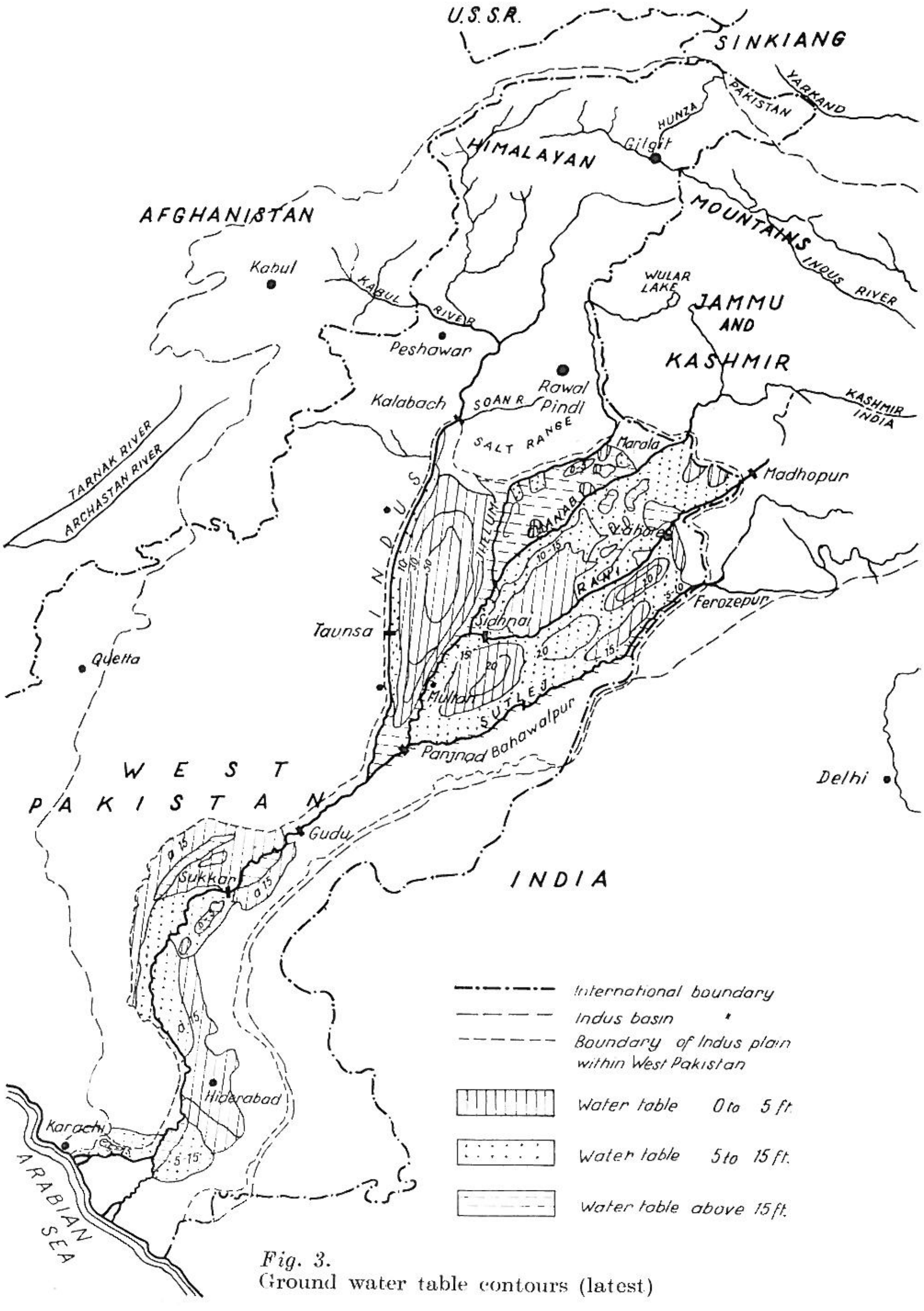

Fig. 3.
Ground water table contours (latest)

Table 15.

Areas of depths to water table			Water table (feet below land surface)				
No.	Name of area	Total area (acres)	at surface	0–3	3–6	6–10	more than 10 feet.
	Rechna Doab						
1.	Chichoki Millian Shadman	160,000	—	17,100	82,000	56,800	4,100
2.	Shah Kot	247,200	1,600	15,100	67,400	86,000	77,100
3.	Chuharkana	10,800	100	6,700	3,200	700	100
4.	Pindi Bhattian	8,300	—	200	400	700	7,000
5.	Khangah Dogran	121,800	1,800	11,900	66,800	30,400	10,900
6.	Jaranwala	90,900	—	600	8,700	36,300	45,300
7.	Hafizabad Thatta	131,300	600	19,600	74,400	32,400	4,300
8.	Harse — Sheikh	115,400	1,700	13,300	31,900	23,500	45,000
9.	Sangla Hill	150,700	1,600	23,600	72,600	49,900	3,000
10.	Beranwala	125,900	700	23,100	38,600	35,900	27,600
11.	Zafarwal	204,200	1,600	2,400	19,900	48,700	131,600
	Chaj Doab						
12.	Lalian	197,600	3,700	5,000	29,600	56,300	103,000
13.	Maggowal	45,400	—	2,200	16,600	21,600	5,000
	Thal Doab						
14.	Muzaffargarh	89,500	5,100	13,400	65,200	5,700	100
15.	Lower Thal Excluding Muzaffargarh	987,200	15,000	56,600	356,800	538,300	20,500
	Total	2,686,200	33,500	210,800	934,100	1,023,200	484,600
	Sind area						
16.	Khairpur area	339,000	—	76,000	263,000	—	—

Table 16.

Typical quality of ground water

Test hole number	Depth (Ft.)	Milliequivalents per Litre: Calcium Ca^{2+}	Magnesium Mg^{2+}	Sodium + potassium $Na^{+} + K^{+}$	Carbonate CO_3^{2-}	Bicarbonate HCO_3^{-}	Chloride Cl^{-}	Sulfate SO_4^{2-}	Total cations anions	Total dissolved ppm.	Specific conductance mmhos/cm.	pH	Sodium adsorption ratio.	Residual sodium carbonate (me./l)
						a) Lower Thal Doab								
TTIG—24	90	2.88	0.69	3.00	—	3.70	0.89	1.98	6.57	410	620	7.9	2.2	0.13
,, ...	170	3.25	0.56	4.45	—	2.83	1.88	3.55	8.26	510	770	8.0	3.2	0
,, ...	250	3.62	1.14	5.20	—	3.16	2.67	4.13	9.96	630	940	7.9	3.4	0
,, ...	330	2.87	1.41	4.47	—	3.16	2.18	3.41	8.75	550	830	7.8	3.0	0
TTLK—1	100	2.44	0.23	4.89	—	4.08	1.27	2.21	7.56	500	730	7.7	4.2	1.41
,, ...	250	2.53	0.14	3.31	—	4.08	0.78	0.94	5.80	390	580	7.9	2.7	1.41
,, ...	400	2.21	0.10	1.16	—	2.55	0.58	0.43	3.56	220	320	7.8	1.1	0.24
TTIM—2	80	2.73	1.91	5.26	—	2.84	1.19	5.87	9.90	644	970	7.6	3.4	0
,, ...	274	2.10	1.31	3.39	—	3.90	0.69	2.21	6.80	404	620	7.6	2.6	0.49
	358	2.31	1.91	7.41	—	3.39	2.52	5.72	11.63	732	1100	7.7	5.1	0
						b) Chej Doab								
CTLA—3	73	2.19	1.20	5.33	0.00	7.50	0.38	0.83	8.71	490	800	—	4.0	
,, ...	178	1.77	1.30	5.09	0.00	7.25	0.38	0.53	8.16	360	600	—	4.1	
,, ...	283	1.98	1.10	4.16	0.00	6.00	0.57	0.67	7.24	380	640	—	3.3	
CTLA—10	90	0.83	1.10	4.54	1.00	4.50	0.28	0.69	6.47	370	600	—	4.6	
,, ...	180	0.83	0.40	7.09	1.00	5.33	0.38	1.61	8.32	530	800	—	0.9	
,, ...	235	1.25	0.30	5.73	0.50	5.33	0.47	0.98	7.28	480	700	—	6.5	
,, ...	410	1.14	0.90	5.12	0.00	5.20	0.19	1.77	7.16	450	650	—	5.0	
CTLC—4	72	0.51	0.17	10.01	—	8.62	0.79	1.28	10.69	630	940	7.7	1.7	
,, ...	142	0.71	1.62	6.69	—	6.81	0.84	1.37	9.02	504	920	7.8	6.1	
,, ...	222	0.81	3.12	4.37	—	6.18	1.18	0.94	8.30	496	750	7.8	3.1	

c) *Accumulation of salts in the soil profile from ground water.* From a bare soil evaporation takes place. The order of evaporation with watertable at various depths is as under:

Depth of watertable in ft.	% evaporation with respect to free water surface		
	Sand	Silty Soil	Clayey Soil
0.5	65	82	93
1	45	62	76
2	27	35	50
3	18	22	31
5	9	9	12
10	1.3	1.3	1.3

Watertable at (6.0 ft.) 1.83 meter is within the capillary range, so that water continues rising up and on evaporation leaves the salts at the surface. In large areas the ground water possesses salts between 500 to 1000 ppm, so that from an area of 0.2 m.ac. with watertable at 3.0 ft. and from 1.0 m.ac. with watertable at 6.0 ft. the annual water lost by evaporation is 0.8 and 2.0 m.aft. Thus 1.2 m.ac. of land losses 2.8 m. af. of water, which is 2.33 times the area on that salts were deposited (so one acre is equal to 145.2 lbs. per year assuming the ground water salts equal to 1000 ppm). There are areas in Sind particularly in the Delta, where the ground water salinity is 10 to 40 thousand ppm. If these order of salts are allowed to rise to the surface, in one year these may add 1452 lbs to 6808 lbs of salts on an acre.

d) *Base Exchange in Solonchak and Solonetz Soils. Solonchak soils :* These contain enough soluble salts in the soil profile to interfere with the growth of crops. Soils of Pakistan are usually alkaline in reaction with pH between 7.4 to 8.5. Saline soils contain little adsorbed sodium. Such a soil usually shows white incrustation particularly during winter and efflorescence on the surface during summer. Some soils of this type appear oily damp, slightly dark brown and are devoid of any kind of vegetation. The degree of their salinity is estimated by the determination of the concentration of soluble salts.

The adsorbed ions in such soils are principally calcium and magnesium. Such soils flocculate in water and can easily be worked into granules and crumbs. Their permeability is usually as much as that of non saline soils and in some cases even higher and can easily be freed of the excessive salts by proper leaching and can be brought to the desirable textural condition for normal plant growth.

Solonetz Soils : An alkali soil contains sufficient amount of adsorbed or exchangeable sodium to interfere with the growth of most plants. Such soils are impervious to water, manifest phenomenon of mirage and give metallic sound on tapping.

In the Punjab, such soils have a highly alkaline top layer but the soluble salts are not excessive. Below the top layer there occurs a zone of medium alkalinity, containing calcium carbonate nodules varying in size from a few mm. to 4 or 5 cm.

Below these two layers there exists generally a layer of high permeability sand.

In these soils, sodium is the dominant cation. Soil particles are electrically charged so that these can adsorb and retain cations of sodium and calcium. These are firmly held as a result of this charge but they can freely interchange with other ions of the soil particles. This reaction is called the cation exchange. The greater the concentration of various types of cations, the greater is their concentration in the exchange complex of the soils. The bond between sodium cations is not so strong as it exists between calcium and magnesium so that for reaction of sodium with soils its concentration should be fairly high. Sodium is a medium which disperses soils and thus makes them impervious to both water and air. This property effects the seed germination and the plant growth.

In order to bring these soils back to production, it is necessary to replace adsorbed sodium, create good physical condition of soils by rearrangement and aggregation of soil particles to form granules and produce good tilth. The measures of improvement for such soils are discussed under soil reclamation.

Saline-alkali soils: These soils possess the properties of both saline and alkali soils independently. There are both high soluble salts and high order of adsorbed sodium. Such soils are not highly alkaline with pH generally lower than 8.5. If somehow soluble salts are leached out, the soil becomes alkaline.

c) *Sodium Hazard of Ground Water:* For removing salinity and saline-alkalinity of soils, the removal of deposited surface salts, mixing of salt free silt or soil, growth of salt resistance and salt removing plants, have been tried but without much success.

The only effective measure is the washing down of salts by water with effective drainage and by the use of chemical amendments and green manuring. The last two measures are necessary for alkaline soils. Many techniques of paddy cultivation for leaching the salts and proper crop rotations have been developed and are described in many publications of Irrigation Research Institute and Land Reclamation Department but the main limiting factor is the water. Soils of the Indus plains contain sufficient lime and gypsum. Even gypsum is locally available but the main commodity for soil reclamation is the water, the supply of which is very limited. Some attempts have been made to utilize the excess summer water. The other source is the ground water, the use of which needs very careful analysis and knowledge of the reaction of these waters with the soils.

ASGHAR, PURI and TAYLOR [1] in 1936 put forth a Salt Index Method for determining the suitability of irrigation water. The relation was:

Salt index = $(\text{Total } Na^{+} - 24.5) - (\text{Total } Ca^{2+} - Ca^{2+} \text{ in } CaCO_3)\,4.85$.

All quantities referred to are in parts per hundred thousands. The degree of goodness was equivalent to the magnitude of the negative factor. The salt index varied from 24.5 to zero for all good water and is positive for all bad water.

The present practice is to base the determination of sodium hazard of water on the basis of sodium absorption ratio (SAR), residual sodium carbonate (RSC) and calculated exchangeable sodium percentage (ESP).

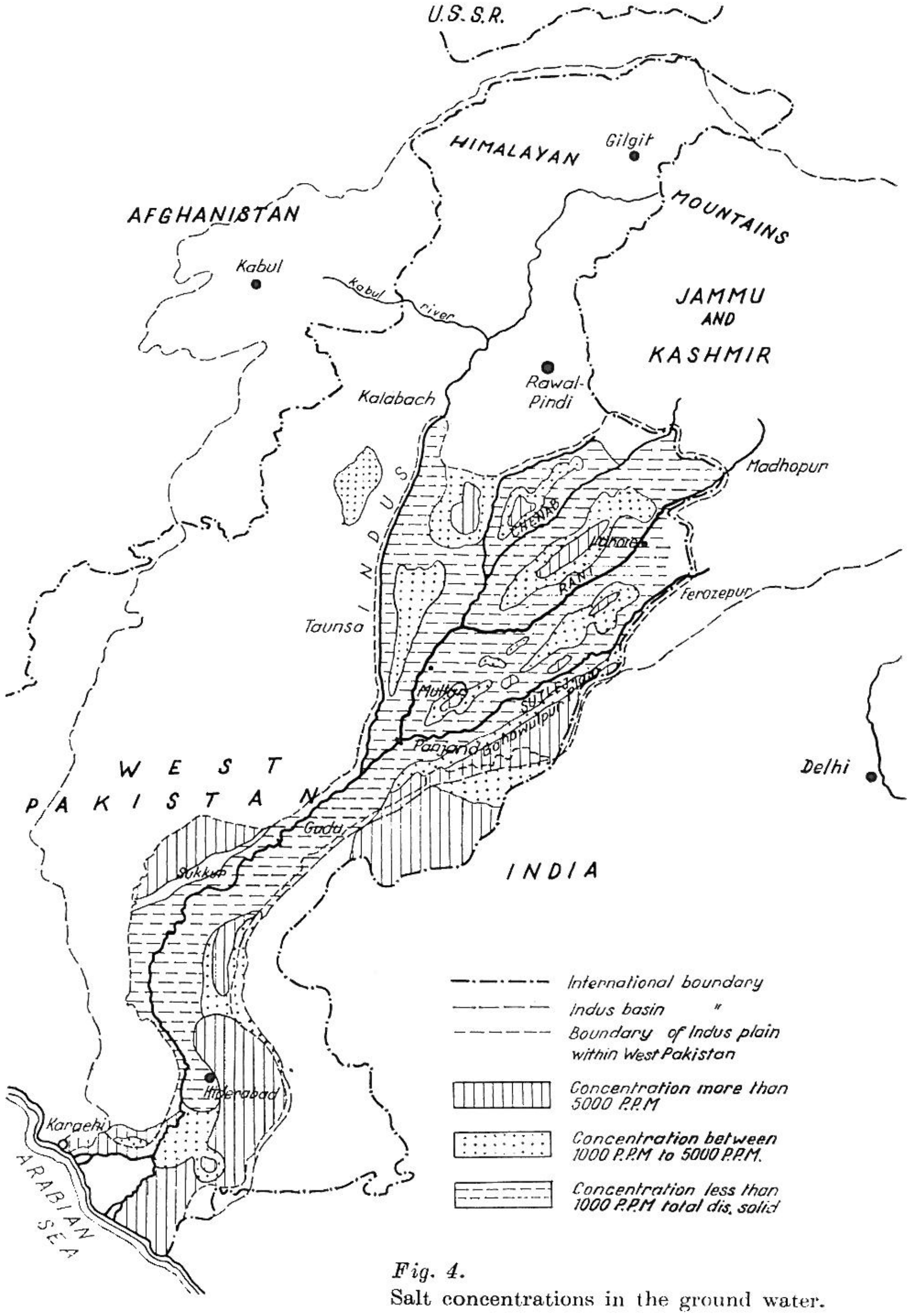

Fig. 4.
Salt concentrations in the ground water.

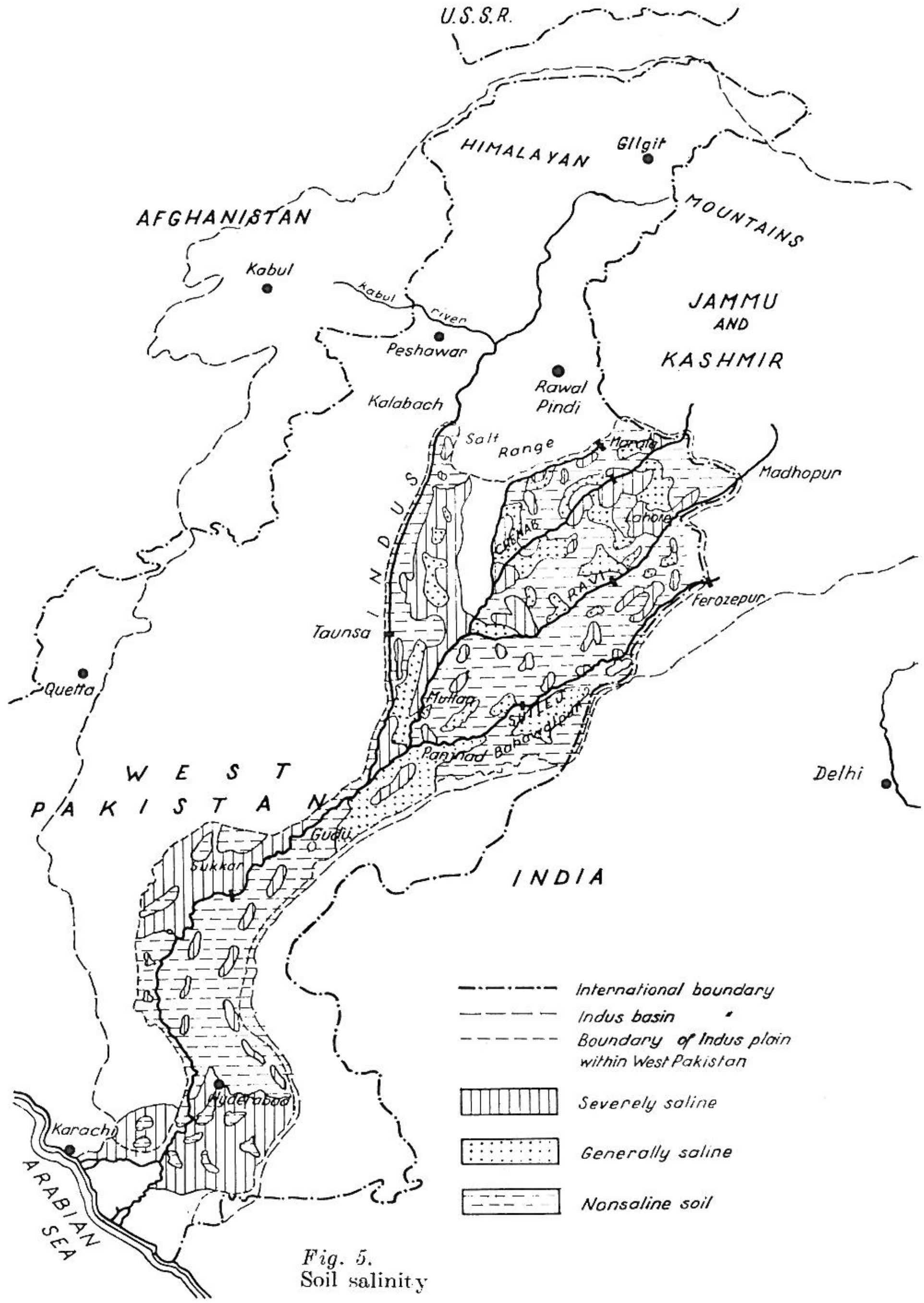

Fig. 5.
Soil salinity

If the ratio of soluble sodium (Na^+) to that of soluble calcium (Ca^{2+}) plus magnesium (Mg^{2+}) is high, the order of this factor increases, and the sodium hazard tends to increase. The expression for sodium adsorption ratio is

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} - Mg^{2+}}{2}}}$$

The concentration of the three soluble cations is given in milli-equivalents per litre (me./l.). The critical value of SAR depends to a certain extent on the texture of the soils. For permeable, or sandy soils of the Indus plains, a limit of SAR equal to 20 has generally been accepted and for fine textured soils the limiting value is close to 10.

Residual sodium carbonate (RSC). Irrigation water contains carbonate plus bicarbonate. If they are excessive in relation to calcium plus magnesium, this excess is called the residual sodium carbonate. The effect of this high concentration of carbonate and bicarbonate is, that calcium and magnesium tend to precipitate as insoluble carbonates. This happens particularly at high order of concentration.

Removal of Ca^{2+} plus Mg^{2+} increases the proportion of Na^+, so that there becomes a greater tendency for Na^+ to be adsorbed and the soil acquires the properties detrimental to the growth.

The generally accepted limit of RSC values of water not suitable for irrigation is 2.5 me./l. Water marginal for irrigation possess RSC below 1.25 to 2.5 me./l.

Recently BOWER and MASSALAND [4] have proposed an equation to determine ESP for water containing high amount of carbonates and bicarbonates but having no residual sodium carbonates. The equation being:

$$ESP = 2\,SAR + 2\,SAR\,(8.4 - pHc)$$

where pHc is the calculated value for water in equilibrium with $CaCO_3$. This is based upon Langelier's conception of saturation index expressed as

$$\text{Saturation index} = pHa - pHc$$

It was concluded that waters for which ESP is found to be 10 or less, are safe for direct use. Water with ESP between 10 to 20 are marginal and those with ESP more than 20 are hazardous.

On the basis of these studies, the limits of safe marginal and hazardous waters has been fixed as under:

	Safe	Marginal	Hazardous
TDS	$<$ 1000 ppm.	1000 – 2000	$>$ 2000
SAR	$<$ 10	10 – 20	$>$ 20
RSC	$<$ 1.25	1.25 – 2.5	$>$ 2.5
ESP	$<$ 10	10 – 20	$>$ 20

Appendix to the review on salinity-alkalinity status of irrigated soils of West Pakistan

Pakistan is the fifth largest state of the world in which reside about 100 million peoples. It has two parts. East Pakistan and West Pakistan, separated by nearly 1000 miles (1610 km.) of Indian territory. The two wings of Pakistan are quite different, climatically and in the intensity of population. In East Pakistan, in an area of about 55,126 sq.miles (143,27 sq.km.) reside nearly 50.84 m.people. Its climate is humid. It gets 100 to 200 inches (2540 mm. to 5080 mm.) of annual precipitation generally within the summer monsoon months.

West Pakistan on the other hand is arid or semiarid. Its annual precipitation varies from 40 to 4 inches (1000 mm. to 100 mm.). It constitutes about 310.000 sq. miles (806,000 sq.km.) or 198 m.acres (80 m.ha.) in which reside 43.00 m.persons. West Pakistan can be divided into two distinct hydrological units. An arid dry plateau of about 100,000 sq.miles (259,000 sq.km.) adjacent to the arid regions of Persia and Afghanistan. It is called Blauchistan. The area has little water, having hardly 4 inches of precipitation annually. It is sparingly populated, is undeveloped waste land, except for one or two small valleys.

The second hydrological unit is the catchment of the Indus and its tributaries. A very large portion of this constitutes flat fertile plains. It is one of the biggest single culturable units of land watered by the great rivers considered to be a major natural resource of the world. The Indus and some of its Eastern tributaries rise in Tibet and Kashmir. Its Western tributaries rise in Afghanistan and flow into West Pakistan. Total catchment area of the Indus and its tributaries is estimated to be 348.000 sq.miles of which 204.000 sq. miles lie in West Pakistan. The rest of the catchment lies in India, Jammu Kashmir, Afghanistan and Tibet. Its approximate distribution is as under:

Country	Drainage	Area		
	sq. miles	sq. km.	m. hec.	m. acres
West Pakistan	204,000	530,400	52.5	130.5
India	29,000	75,400	7.6	18.5
Jammu Kashmir	52,000	135,200	12.5	33.2
Afghanistan	63,000	163,800	16.5	40.3
Total	348,000	904,800	89.1	222.5

Nearly half of the catchment within Pakistan is hilly, unculturable waste land with small valleys wherever water is available. The rest of the land is a flat plain about 800 miles (1,288 km.) long and its broadest end is about 300 miles (483 km.). In the Northern portion separated by Pothar plateau is another small valley of Peshawar nearly 100 miles (161 km.) long and 30 miles (48.3 km.) wide. It is irrigated by Western tributaries of the Indus. The culturable commanded area of the region is 0.681 m.ac., land slope is high, rainfall occurs both in summer and winter. This region has no problem of salinity and alkalinity except in small patches. The wide Indus plains lie in a region called the Punjab and Bahawalpur. It is a flat land of about 300 miles (483 km.)

in width and 450 miles (725 km.) in length. It is watered by the eastern tributaries of the Indus and constitutes about 44.0 m.acres (17.6 m.ha.). Next to it lies the Sind, through the heart of which flows the Indus. It is nearly 350 miles (563.5 km.) long and 100 miles (161 km.) wide. It constitutes about 12.6 m.acres (5 m.ha.). This extensive culturable flat unit of land of about 62.0 m.ac. (25 m.ha.) is watered by withdrawals from the Indus and its tributaries which have an annual run off of about 135.7 m.a.ft. (168,092 m.cu.meters). The annual flow of the three rivers being:

	Discharge in M. A. Ft.		
	Max.	Min.	Average maf.
Indus	115	69	92.25
Jhelum	29	15	22.00
Chenab	29	19	24.25
Total			138.50

Originally about 6.5 m.ac. of the Punjab and Bahawalpur used to receive about 24 m.a.f. from the rest of the three Eastern tributaries. Their annual flow is as under:

	Discharge in. M. A. Ft.		
	Max.	Min.	Average
Ravi	9.30	4.25	6.73
Beas	20.20	6.25	13.23
Sutlej..........	17.40	10.25	13.83
Total			33.79

According to a recent settlement with India the water of these three rivers is now to be used by India and Pakistan is to divert a part of the flow of the Indus and the Jhelun after conserving the flood water flow which goes waste into the sea during the two and half summer monsoon months.

The Land of the Indus Plains

In geological times the present Indus plains were occupied by sea. This portion was filled in by alluvium brought in by the geological rivers so that at present the thickness of the alluvium varies from 1000 to 10,000 ft. (305 to 3050 meters). The thinnest deposit is a few 100 ft. The rivers meandered moving from one place to another. Within the historic times there are instances of rivers moving from one site to another. There are still dry river beds. There must have been frequent changes in the rivers when the plains were being built in. Exploration of the formaton profile to a depth of 600 to 1000 ft. shows predominance of alluvium sand of medium grade with deposition of the finer sand grade, silt and clay, located at different elevations without any order and possessing different dimensions and depths. The top surface generally consists of soils of different textures, heavy, medium and light.

Pure sand exists only in the active or some parts of the abandoned beds of rivers.

The thickness of soil crust is small. It varies from 5 to 20 ft. within the alluvium plains. Areas under the foot hill possess deposits of pedimont soil produced from disintegration of rocks. The soil crust of pedimont deposits is usually thicker and has predominence of medium or heavy soils particularly at some distance from the hills.

Old irrigation system

West Pakistan receives insufficient and unequally distributed precipitation. Artificial irrigation is essential for crop production. About 100 years back the population of the area was low, its requirement of food and fibre was small so that thin strips of land 5 to 10 miles wide along the two banks of the major rivers were sufficient to produce the agricultural requirements. Every year the summer floods raised the rivers to a high stage of flow. The water spread along the rivers, saturated the soils and with falling stage of the river, the excess water was drained out leaving sufficient moisture in the soil to grow winter crops. Irrigation requirements, if any, during the growth were satisfied by lifting underground water by the local system of Persian wheels. Summer crops were grown on the basis of monsoon rains. The crop production was sufficient for the small population. In certain areas particularly in Sind, inundation canals were dug to divert water during high stages of the river flow onto the land. This agricultural land thus received annual flushing. Doses of fresh fertile silt and washing of land by fresh water was an annual drainage feature of the land, which remained in production for ever without showing any sign of deterioration. This land constituted about 6.0 m.acres (2.4 m.ha.).

Present irrigation system

The present irrigation system was started to take shape about 100 years back when regular structure started to be built on the rivers to control the rivers and raise their level during low stage to perpetually feed the irrigation channels.

Extensive flat virgin land was in existence. It only needed water to bring it into production. The first irrigation system was undertaken in 1834. The success of this measure opened out a way to utilize practically all the perennial flow of the rivers. At present there are 17 low dams called the barrages, with a capacity to divert 350,000 cusecs (9905 c.m./sec.) of water.

Problems of irrigation agriculture

Irrigation of the virgin land caused reorientation of the salt balance in the soil and other soil structural changes. Addition of water to the formation from irrigation channels, agricultural operations, and changes in the natural drainage of the country resulted in water-logged conditions. The problem of salinity and deterioration of land made its serious appearance after 1920. By this time fall in yield at many places had started. Many fields were showing signs of salt accumulation but the menace of salinity had not yet taken a serious turn. Waterlogging was considered the main cause of all the ills and early measures were all directed to cure it.

Counter-measures for water-logging

In 1882 observation points were fixed to record the changes in the ground water twice a year. It was found that construction of canals, roads and rails had caused obstruction to the natural run off of the land which was considered to be a cause adding to the ground water. A system of surface land drains was taken in hand to quickly drain the rainfall accumulation.

Lining of channels to stop percolation from the sandy beds was attempted but the programme could not progress due to high cost of this operation and quick construction of new canals.

Wherever it was possible, the high elevation of irrigation canals was lowered to give relief to high level of ground water.

Even surface seepage drains were also attempted, but as the measures were short of the intensity of the problem, water table continued to rise in all areas where originally before the operation of irrigation it was very deep, upto a range of 60 to 100 ft. below surface. The rate of rise varied 1 to 2 ft. per year and when the water level reached close to the surface all the water originally adding to the aquifer started to be disposed off by evaporation or evapo-transpiration aggravating and quickenning the soil deterioration.

Among the mal-practices which helped in the deterioration of land were:

1. The insufficiency of irrigation water to bring the irrigation intensity to a high order. Generally in the old canal systems the irrigation intensity was fixed at 25% in summer and 50% during winter.

2. High water duty so that insufficient water was spread on the land. Usually the duty was fixed at 3 cusecs (0.8 c.meters/sec.) per 1000 acres (400 hec.).

3. Absence of drainage was never considered an essential component of a successful irrigation practice. There were no seepage drains, tile drains or any other system of land drainage.

4. No systematic scientific crop rotation was adopted. It was left to the agriculturists to adopt any system they considered fit.

Summary

1. The practice of soil survey was started for the first time in West Pakistan in 1941 and till 1946 about 6.0 m.ac. were surveyed.

2. In 1953, classification of the soils of the Punjab into five textural series was started. All the 20.0 m. irrigated acres of the Punjab have been classified according to these five textural series.

3. Twelve million acres of the Sind are, however, being classified into six textural series.

4. Texturally the soil of the Indus plains can be classified into the following groups:

Texture of soils	Northern Indus Plains (The Punjab)	Central Indus Plains (Sukkur) percentage	Delta area of Indus Plains G. M. Barragge
Very light	59	17	15
Medium..............	35	48	27
Heavy	6	35	40

5. So far the published information available on the salinity status of the soils of Indus Plains is according to the percentage of soluble salts. This information is as under:

Percentage area with salts percentage

Zone	Area studied m. ac.	Non saline <0.2%	0.2–0.5%	0.5–1.0%	>1.0%
Punjab	4.6	56	23	14	7
Middle Sind*	1.2	58	15	20	7
Delta Area	2.5	18	16	36	30

* Middle Sind constitutes 7.0 m. ac. of which only Khairpur and Larkana districts were considered.

6. The existence of salts is due to
a) Old remanent of sea salinity when alluviums were depositing in the sea water.
b) From disintergration of rocks salts deposited with the alluvium.
c) Salts added by irrigation water.
d) Salts brought up by evaporation from sub-soil by high ground water.
e) Conversion of Ca and Mg salts into Na^+ complex to cause high order of alkalinity.

7. Considerable reorientation in the salinity distribution and concentration has taken place by washing of saline salts from surface by good quality water of the rivers.

The present status of ground water salinity and its depth in various zones of the Indus plains is as under:

Zone	Region	Total area	Area with salts less than 1000 ppm.	Average depth of good quality water ft.	Area with salts more than 1000 ppm.	Depth where saline water appears ft.
		Areas are in millions of acres and depths in ft.				
Punjab	Rechna Doab.	4.7	4.00	400–600	0.7	100–500
,,	Chaj	2.0	1.58	300–600	0.41	50–100
,,	Thal	5.3	3.84	200–400	1.48	100–200
,,	Lower Thal	1.3	1.12	500–700	0.16	200–300
,,	Bari	4.4	2.64		1.76	50–100
	Total	17.7	13.16	300–600	4.52	50–100
Delta Area	G. M. Barrage	2.8	0.28	40– 80	2.52	25– 50
Middle Sind	Sukkur Barrage	7.0	2.50	100–400	4.50	25–100
	Total	9.8	2.78	50–400	7.0	25–100

8. Depth of ground water in 60% area of 10 m.ac. of Rechna and Chaj Doab is within 10 ft. In the Sind in about 7.0 m.ac. it is at 15–26 ft. depth. Only about 2 m.ac. the Punjab within top 25 ft. is less than 1000 ppm. and in Sind in 7 m.ac. is much more than 1000 ppm. Evaporation continuously causes the salts of ground water to accumulate at the surface. This process is very serious in the Punjab but not so serious in the middle Sind for several reasons.

9. The water of Indus river system contains 100 to 250 ppm. of salts which Ca and Mg constitute about 67%, the rest are the sodium salts. The other radicals being Cl^- SO_4^{2-} and CO_3^{2-} or HCO_3^-. During the last 60–80 years these small doses of salts have continued to accumulate in the soil surface having no drainage.

10. Soils hazardous to alkalinity are now being classified on the basis of sodium absorption ratio (SAR) and the water on the basis of residual sodium carbonate (RSC) and exchangeable sodium percentage (ESP). For safe condition limits have been fixed for SAR, RSC and ESP at less than 10, 1.25 and 10 respectively.

Before 1953, degree of alkalinity, dispersion coefficient and salts index were developed as a criteria to determine the limits of hazardous soil and water.

11. In this paper some basic general information about West Pakistan is also included.

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Обзор по засолению орошаемых почв Западного Пакистана

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Резюме

В настоящее время из 62 млн. акров (25 млн. га.), находящихся под сельскохозяйственным использованием, земель Индусской Низменности приблизительно 32 млн. акров (13 млн. га.) орошается водами реки Инда и ее притоков с использованием 87 000 млн. м³ воды.

В 1941 году впервые были начаты почвенные съемки этой территории, и в продолжении пяти лет было изучено примерно 6 млн. акров (2,5 млн. га.) земель, главным образом полевыми методами, дополненными некоторыми лабораторными анализами, как то: анализом механического состава почв, примерного содержания воднорастворимых солей и определением величины pH.

Некоторые коррективы в методике изучения почв были внесены в 1953 году, когда почвы Северной Низменности в районах Пуньяб и Бахавалпура подразделили на пять серий. При почвенных исследованиях в целях дренирования низко расположенной Индусской Низменности, проведенных в 1960 г., в районе Синда, почвы были разделены на семь главных групп по механическому составу.

Эти данные характеризуют 2,7 млн. га. почвы, из которых 1,3 млн. га. относятся к северному району, а остальная часть — к южному району низменности. Заключения в отношении засоленности этих почв были сделаны, главным образом, на основании присутствия в них воднорастворимых солей и по величине pH. Таким образом, по степени засоленности почвы были разделены на 4 или пять групп. Такие данные имеются для 2,8 млн. га. земель Индусской Низменности. Только в последнее время стали изучать отдельно засоленность и содоносность этих почв на основе содержания обменных катионов, главным образом катионов натрия, и содержания соды в них.

В настоящей работе почвы классифицируются, в первую очередь, по механическому составу и степени засоленности.

Процессы засоления и накопления соды в орошаемых почвах, происходящие под влиянием ирригационной воды, содержания воднорастворимых солей в почвенных горизонтах, засоленности грунтовых вод, накопления солей и превращение нормальных почв в содовые, объясняются на основе изучения содержания обменных катионов в почве. В работе приводятся данные химического анализа речной воды, анализа грунтовых вод, а также предельные данные минерализации грунтовых вод, для избежания опасности вторичного засоления.

В приложениях даются краткие сведения о землях и реках Западного Пакистана, и о развитии там орошаемого земледелия.

A) Почвенные исследования

а) *Механический состав почв*

Первые почвенные съемки в этой стране были проведены в 1941 г., когда был построен новый канал Тхал (С расходом 170 м³/сек.), второй по величине на этой территории, для орошения целинных земель Тхала. Эти исследования дали сведения по топографии, механическому составу и засолению верхних почвенных горизонтов. За этими работами последовали другие почвенные съемки, и таким образом, к 1946 году было изучено около 2,43 млн. га. земель. В 1953 г. впервые почвы района Пуньяб были разделены на пять групп по их механическому составу. Эти группы следующие: очень легкие почвы (Karg), легкие почвы (Fazida), средние почвы (Chruharkana), средне-тяжелые (Buchiana) и тяжелые почвы (Nothar). Номенклатура классификации соответствовала пяти, хорошо известным частям района Пуньяб. По этой классификации 1,2 млн. га. орошаемых земель Доаба, Тхал, Чей и Рехна по механическому составу распределялись следующим образом: 21% составляют очень легкие почвы, 36% — легкие, 34% — средние, 5,6% средне-тяжелые и тяжелые почвы.

4,86 млн. га. орошаемых земель нижней части Индусской Низменности носят название «синд». Эти почвы разделены на шесть групп по механическому составу следующим образом: легкие, легкие-тяжелые, средние-легкие, средние, средние-тяжелые, тяжелые-легкие и тяжелые. На основе этой классификации 0,5 млн. га. земель среднего Синда (Кхаирпур, Ларкана, Шикарпур) распределяются следующим образом: 15% — легкие, 50% — средние и 35% — тяжелые почвы. В районе Дельты, по той же классификации, территорию 1,1 млн. га. составляют 15% легких почв, 27% — средних почв и 40% — тяжелых.

Вышеприведенные данные указывают на неоднородность по механическому составу почвенного покрова этих территорий. В северных районах Пуньяба преобладают почвы легкого механического состава, в центральных районах Синда почвы среднего механического состава, а ближе к Дельте, на юге, находится самые большие территории тяжелых почв.

Почвы Индусской Низменности образовались в нашей геологической эпохе. На значительных территориях поймы, на отложениях ила, почвообразование проходит и в настоящее время. На повышенных местах поймы, до сих пор имеющих связь с реками, в настоящее время не происходит отложения ила из рек, но некоторое количество свежего ила и глины отлагается при спуске ирригационных вод. На основе этого можно сказать, что Индусская Низменность поднимается на 1 фут за сто лет. Почвы низменности относятся к молодым, малоразвитым со слабой дифференциацией профиля.

б) *Засоленность почв*

При почвенных съемках этой территории, наряду с механическим анализом, проводились исследования химических свойств почвы. Общеизвестно, что почвы Индусской Низменности являются засоленными, щелочными и содержат соду, но до сих пор они классифицировались только по общему содержанию воднорастворимых солей. Указывалась лишь сумма воднорастворимых солей и величины pH. В более детальных химических анализах определялись ионы Ca^{2+}, Mg^{2+}, CO_3^{2-} и HCO_3^-, а также SO_4^{2-} и Cl^-. Ионы натрия и калия определялись по разности. В последние 8 лет проводились непосредственные (прямые) определения натрия и калия. Были попытки классифицировать щелочные почвы на основе степени их щелочности, коэффицинта дисперсности и величины pH, но они окончились неудачей. В настоящее время при классификации засоленных почв щелочность и содоносность оценивается по %-ому содержанию натрия (E. S. P.) и содержанию соды (R. S. C.). Карты, иллюстрирующие распределение щелочных почв, еще находятся в стадии подготовки.

в) *Процент засоленных земель в соответствии с различной степенью засоленности*

В настоящее время проводится детальная оценка почв с различным процентным содержанием водорастворимых солей. На основе этого, 1,8 млн. га. земель района Пуньяб и трех районов Доабс отнесены к незасоленным почвам с содержанием воднорастворимых солей меньше 0,2%. Эти почвы составляют 55,6% от всей территории. Почвы с содержанием солей от 0,2% до 0,5% составляют 23,1%, с 0,5 до 1,0% — 14%, и почвы, содержащие выше 1,0% солей, составляют только 7,5% территории.

Имеются подробные данные по засоленности для 1 млн. га. почв районы Дельты и для 1,8 млн. га. почв районов среднего Синда. В районах Дельты незасоленные почвы (содержание солей меньше 0,07%) и с содержанием солей до 0,2% составляют только 17%. Почвы с содержанием солей до 0,37% составляют примерно 15%, с содержанием солей до 0,73 и 1,4% составляют 35% и 30% всей территории. Почвы района Дельты сильно засолены. Незасоленных или слабозасоленных почв здесь мало.

Засоленные почвы территории среднего Синда (0,48 млн. га.) не слишком плохого качества. В этих районах незасоленные и засоленные почвы с содержанием солей до 0,2% составляют 30% и 28% от всей территории. Районы с засоленными почвами, содержащими солей 0,37%, 0,73% и 1,4% составляют соответственно 15%, 20% и 7% территории.

г) *Распределение засоленных почв на Индусской Низменности*

В настоящее время, на основе, статистически обработанных специально собранных данных, можно сказать, что из 14 млн. га. земель Индусской Низменности, 15% территории покрыта засоленными почвами, при этом половина этих почв имеет засоление старше пяти лет. Другая оценка почв была получена на основании исследований района по плану Коломбо. Было отмечено, что 2,0 млн. га. земель этого района относится к сильно засоленным, при этом 4,7 млн. га. слабо дренированы или временно затоплены водой.

Б. Причины, вызывающие засоление почв

В этой работе разбираются пять факторов, вызывающих засоление почв:

1. Поверхность Индусской Низменности в давние геологические времена была занята морем. Впадина заполнялась аллювиальными наносами, приносимыми реками. С тех времен произошло сильное выщелачивание солей, но все таки встречаются линзы остаточного морского засоления. Эти линзы, в виде нескольких небольших пятен, находятся в верхней и средней части Индусской Низменности. В районе Дельты, где до сих пор нет интенсивного орошения, незначительное количество осадков, не происходит на-

водкового затопления почв — там почвы содержат большое количество водорастворимых солей. В некоторых случаях засоленность грунтовой воды такая же, как морской.

2. Некоторое количество водорастворимых солей накапливается вместе с аллювиальными наносами. Происхождение их, надо пологать, связано с выветриванием горных пород. Воды, переносящие соли, откладывают их в образованном пласте. С течением времени происходят значительные изменения в залегании солей, в их концентрации и количестве. Соли, смываясь в основном с пойменных территорий, откладываются на низко расположенных участках с глубоким уровнем залегания грунтовых вод и с высокой крутизной уклона подпочвы. Центральный район Доабса представлял собой зону, где грунтовые воды находились глубоко от поверхности, так смытые соли, естественно, откладывались над ними.

3. Воды рек также можно считать источником накопления солей в почве. Из речных вод почва получает ежегодно примерно 43 тонны солей. В настоящее время для орошения 10 млн. га. земель используется приблизительно 87 000 млн. м^3 воды, таким образом на один акр почвы приходится 1 тонна солей, приносимых водой. Вода реки Инда и ее притоков приносит с собой приблизительно от 100 до 200 мг./л. солей, из которых на соли кальция и магния приходится около 70%, на соли натрия и калия — 30%. Из анионов в этих водах содержатся карбонаты, хлориды и сульфаты. На основе этих данных, можно сказать, что в этих водах при концентрации водорастворимых солей, равной 200 мг./л., катионы натрия и калия составляют только 1/3 часть. Другие 2/3 части солей оказывают благоприятный эффект на почвы.

Необходимо отметить, что в Западном Пакистане, вообще, не проектируется дренажня сеть, и вода всегда покрывает обширные территории. Орошаемая Дельта расположена довольно высоко и редко требует дополнительного дренажа. Результатом этой системы орошения было то, что все соли оросительных вод остались на территории орошения, без каких либо надежд на их выщелачивание. Отложения солей на некоторых территориях в течение последних 60—80 лет в результате орошения может быть одним из источников высокого содержания солей в почве.

4. В результате орошения наблюдается поднятие уровня грунтовых вод, так в районах Рахна и Чей Доабс грунтовые воды на 10% территории находятся на глубине 0,5 м., а в других частях района (50%) в пределах 3-х метров. В районе Доабс на площади в 4 млн. га. нет такого места, где грунтовые воды были бы глубже 9,15 м.

На территории, площадью в 1,2 млн. га., являющейся частью районов Рахна, Чей и Тхал Доабс, имеется приблизительно 0,08 и 0,4 млн. га., где уровень грунтовых вод залегает на глубине между 0,92 и 1,83 м. В этих районах наблюдается капиллярное поднятие грунтовых вод до поверхности почвы, таким образом, соли этих вод непосредственно соприкасаются с верхними почвенными горизонтами. При содержании в грунтовых водах 1000 мг./л. солей, за один год на одном акре почвы накопляется около 50—60 кг. солей. Это также является одним из источников накопления солей в почве.

Положение в северных районах, имея в виду засоление почв поливными водами, не так опасно и верхние грунтовые воды вполне пригодны для орошения. Залегающие глубоко соленосные воды (солей более чем 1000 мг./л.) можно встретить на территории площадью в 1,8 млн. га., а воды, содержащие меньше 1000 мг./л. солей, на территории в 5 млн. га. Положение в Дельте в районах Синда является более серьезным. В районах дельты грунтовые воды с содержанием солей 20—24 тыс. мг./л. залегают на глубине 4,6—6,1 м. от поверхности.

5. Накопление солей в почве может происходить в результате процесса обмена катионов. Почвы бассейна Инда являются щелочными и имеют pH = 7,4. Засоленные почвы содержат хлориды, сульфаты, а также карбонаты натрия и калия. Иногда эти соли выцветают на поверхности почвы, особенно в зимний период. Некоторые почвы превращаются в темноцветные, с бурым оттенком болота, непригодные для развития с. х. растений. Эти почвы имеют в поглощающем комплексе ионы кальция и магния, их водопроницаемость довольно высокая и при достаточном количестве воды, соли могут быть вымыты из почвы.

Если в почве имеются обменные катионы натрия, то, несмотря на то, что энергия поглощения этого иона меньше, чем у ионов кальция и магния, происходит ионный обмен в почве в пользу ионов натрия, если реакция среды почвы щелочная. Такие почвы сильно дисперсные, практически водонепроницаемы, в сухом состоянии при ударе издают металлический звук и территории распространения таких почв представляют собой пустыню с миражами. Обычно подобные почвы содержат мало солей. В Западном Пакистане значительные территории заняты почвами с высоким содержанием водонарастворимых солей, это или засоленные или содово-засоленные почвы.

В. Пределы обмена ионов натрия

Как было указано, при классификации засоленных почв часто встречаются трудности. Исходя только из величины pH трудно получить необходимые сведения. Степень щелочности так же не оказывает помощь в решении этого вопроса. По всей вероятности это же является причиной, почему в литературе засоленные щелочные почвы не выделялись. В настоящее время определение степени поглощения ионов натрия (SAR), которая является величиной концентрации катионов натрия по отношению к концентрации катионов кальция и магния, помогает в определении пределов (критериев) безопасного, средне опасного и опасного для засоления характера почв. В почве со значением (SAR) меньше 10 не имеется опасности для засоления, со значением от 10 до 20 — средняя опасность для засоления, больше чем 20 — имеется большая опасность засоления этих почв.

Г. Пределы для определения пригодности грунтовых вод для целей орошения

Качество оросительных вод влияет на ионный обмен солей в почвах. В 1936 г. Аскар Пури и Тейлор пытались использовать солевой индекс для определения качества оросительных вод. Солевой индекс вычислялся с катионами натрия, кальция и других по следующему уравнению:

$$\text{Солевой индекс} = (\text{сумма } Na^{+} - 24{,}5) - (\text{сумма } Ca^{2+} - Ca^{2+} \text{ из } CaCO_3) \cdot 4{,}85.$$

В настоящее время установлено, что определение содержания соды и % обменного натрия является лучшим критерием для классификации качества воды, по сравнению с уравнением. На этой основе поливные воды разделили на три класса: пригодные, переходные и непригодные для орошения, следующим образом:

Название	Знак	Опасность для засоления		
		малая	средняя	сильная
Сумма растворимых солей	TDS	1000 мг./л,	1000—2000 мг/л.	2000 мг./л.
Степень поглощения натрия	SAR	10	10—20	20
Содержание соды в почве	RSC	1,25	1,25—2,5	2,5
Обменный натрий в %	ESP	10	10—20	30

Д. Мелиорация содово-засоленных почв

На основании данных опытов за 24 года установлено, что в настоящее время засоленные почвы Индусской Низменности можно мелиорировать без особых трудностей. Вода, если она доступна, является средством, при помощи которого можно мелиорировать эти засоленные почвы.

При мелиорации щелочных засоленных почв встречаются некоторые трудности, так как они требуют для мелиорации, с одной стороны химических средств, как, например, гипса, с другой стороны, требуют зеленых удобрений — оба они являются нелегкодоступными мероприятиями в условиях Западного Пакистана. Щелочные почвы в некоторых местах успешно улучшались вышеназванными методами за 3—6 вегетационных периода. Мелиорация почв Чаканквали Форм и Монтгомери является хорошим примером этого.