SOIL CONDITIONS AS AFFECTED BY TANNERY WASTE WATERS

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Summary

1. Eight samples of tannery effluents, twenty-three samples of soil drawn from eight profile pits (six located in the belt of land affected by the tannery effluent and two located in the adjoining fertile belt of land), four samples of sub-soil water from the profile pits in the affected belt, three samples of water from the wells in the area and a sample of water from the lake in the neighbourhood were examined and the results are given.

2. Analysis of the tannery effluents has shown that they invariably contain high amounts of salts, particularly sodium chloride, and also toxic elements such as chromium and arsenic. They possess the characteristics of tannery wastes in general.

3. Studies on the soil samples from the affected belt have shown that they contain high amounts of water-soluble salts, especially sodium chloride; that they also contain the toxic constituents, *viz.*, chromium and arsenic; that their mechanical texture has been adversely affected especially with regard to porespace and water-holding capacity; that sodium clay has formed and in consequence lime has been leached out; that the soil has become alkaline and the degree of alkalisation is over 50%.

The soils from the fertile belt lying on either side of the affected belt have shown the normal characteristics of a healthy soil.

4. The results of analyses of sub-soil waters lend further evidence that the reactions mentioned above have taken place in the soil.

5. Analysis of the irrigation water from the lake has not revealed any unusual feature, its composition being that of good irrigation water. So its use for crop irrigation cannot produce any adverse effect on soil conditions. The deterioration of the soil noticed could only be due to some factor other than the use of the irrigation water.

6. The results of the analytical studies and related evidence clearly show that the waste waters from the tannery have been responsible for the deterioration of the soil in the affected belt of land and for the failure of crops therein year after year.

During recent years, the leather industry in India has been rapidly growing, and the disposal of tannery effluents has been a problem of considerable importance mainly from the point of view of sanitation and public health. Tanneries are generally located in the neighbourhood of streams or rivers since an adequate supply of clean, soft water is essential for the various tanning operations. If the tannery wastes are not properly treated and disposed of, pollution of the waterways and other insanitary conditions would result. Thus, in Germany, Furkert reported the spreading of anthrax among cattle grazing on the meadows close to the Kruckau stream which happened to be the receptacle of the tannery wastes (cited by Harihara Iyer. Bulletin No. C.A.F./214, 1947 issued by the Chief Adviser, Factories, Ministry of Labour, New Delhi).

The waste waters from tanneries consist of soak water containing soluble mineral salts and suspended matter, including bits of flesh and large quantities of hair and dirt; spent lime liquor (containing caustic lime, a concentration of 18 p.p.m. of which is deadly to fish) and sodium sulphide solutions; dilute ammonium chloride and brine from vating operations; fat-liquoring emulsions and spent tan liquors. In the mixed wastes the spent lime and tanning materials mutually precipitate one another and reduce, the organic matter to be purified. The mixed waste is generally alkaline the pH value ranging from 7·5 to 9. The B.O.D. ranges from 50 to 60 parts per 100,000. The waste is brownish red in colour due to its high organic matter content, highly odorous, and polluting in character because of the dissolved impurities.

At the chrome tanneries, the wastes also contain small amounts of chromium, the presence of which as chromate has a deleterious effect on the purification by biological processes. Jenkins and Hewitt (*J. and Proc. Inst. Sew. Purifi.*, 1942, p. 222) have recorded that the presence in sewage of chromium in the form of chromate in concentrations higher than 0·2 part per 100,000 adversely affects nitrification and that, when present as trivalent chromium, even 1 part per 100,000 has no inhibiting effect on nitrification.

At tanneries, where bark tanning processes are employed, the waste liquid is more coloured and generally contains a higher amount of suspended solids. With chrome processes the waste is less concentrated, but its treatment may be more difficult.

At most of the tanneries, the vats are emptied only on one or two days a week so that the character and composition of the waste material differ from day to day. The difficulty caused by this trade effluent is further aggravated when it is suddenly discharged in larger quantities into public sewers, In most places, therefore, the manufacturers are required by the Local Public Health Authority to spread the volume of discharge uniformly over the day.

Apart from the liquid wastes, about 2 tons of slaked lime contaminated with hair and dirt are obtained in the dehairing of 1,000 hides. No cheap method is available for the treatment of this waste.

A considerable amount of work has been done on the treatment of the liquid wastes from tanneries, *e.g.*, by sedimentation after admixture with and without domestic sewage, and by chemical precipitation employing colloidal alumina (or potter's clay) after slight acidification to precipitate calcium sulphate and proteins. So far no method of treatment seems to have come into general use for the separate treatment of tannery wastes to yield an effluent of the quality usually required for a liquid to be discharged into a surface water (Southgate. "*Treatment and Disposal of Industrial Waste Waters*", Department of Scientific and Industrial Research, London, His Majesty's Stationery Office, 1948, p. 217).

In regard to the disposal of tannery wastes on land, the available information is meagre. Duchon and Macek (*Sbornik Ceskoslov Akad Zemedelske*, 1936, **11**, 27–34; *Amer. Chem. Abstracts*, 1936, **30**, 4609) carried out experiments with fertilisers prepared from waste sulphite liquors containing calcium and nitrogen and found that nitrogen in the fertiliser was available to the extent of 80%. From a tannery in Czechoslovakia producing 1,000 to 1,400 cubic metres of wastes daily, the waste waters from steeping (containing about 2 kg. of bleaching powder per cubic metre for the disinfection of foreign hides suspected of anthrax) and from tanning passed to special drum screens and then to improved sedimentation tanks from which the sludge was pumped to drying beds. The effluent passed on to 15 settling ponds in parallel and was then pumped to irrigation areas. The irrigation was merely intermittent ground filtration and no agricultural use was made of the effluent (Harihara Iyer, *loc. cit.*).

Recently, the present authors carried out an investigation into the effect of the waste waters from a moderate-sized tannery near Madras on the composition of soil in a stretch of paddy fields and the conditions for plant growth. The investigation is described in this paper.

MATERIALS

The enquiry arose from a study of the following circumstances. A piece of agricultural land adjoining the area where the waste waters from the tannery were impounded was steadily becoming infertile, although the soil was some years before fairly porous (being sandy loam) and fertile and had been heavily manured and irrigated with water from a lake in the locality. At the same time, in the contiguous belt of land the soil maintained its porosity, friable texture, and its natural colour (light red), and continued to be quite healthy and highly productive. The soil in the affected region showed marked variations in colour and in texture. Dark incrustations, impregnated with dissolved organic matter coming off in flakes, and whitish patches of salt accumulation were seen on the soil surface. Salt bushes, nut grasses and " korai ", characteristic of saline vegetation, throve in the area. But, paddy seeds when sown poorly germinated and most of the seedlings developed " yellowing " and dried up; and in the case of the few rice plants that came up, the grain formation and the quality of the grains were very unsatisfactory. The soil when dried up became very hard and difficult to work.

The affected and unproductive belt of the farm land covering a distance of three-fourth of a mile (about 92 acres, some of them having completely lost their productive capacity and others partially) was located down a falling contour closely lying below the basins scooped out of earth, into which the tannery effluents were, over a period of about 20 years, run and allowed to accumulate and stagnate. Such basins or ponds of tannery effluent lay over an area of about two and a half acres of land situated on a higher level and were separated from the cultivable land by a bund and the main irrigation channel from the irrigation tank in the vicinity. There was no provision for treating the trade effluent or for periodically leading it away from the farming area. Continued stagnation of the waste material caused putrefactive changes giving rise to hydrogen sulphide and other foul-smelling gases; and occasional overflow of the material (the overflow took place more frequently during the rainy season; the tract under consideration used to have heavy rainfall during the north-east monsoon) led to the formation of heavy incrustations of the organic matter and salts around the basins.

The foregoing observations would suggest that the infertility of the soil and the failure of crops on the fields under consideration were due to seepage of the tannery waste effluent into the adjoining agricultural land and contamination of the irrigation water closely flowing through the channel from the lake, as also due to the overflow of the waste effluent especially during the rainy season. With a view to collecting definite information on these factors, a large number of representative samples of the tannery effluent, soils from the affected and the adjoining areas (profile pits were dug to a depth of 8 feet or less in case the water table or the parent rock was met with before that), sub-soil waters, waters from wells in the area and from the lake were taken and examined. The methods of analyses of these samples, the results obtained and the related evidence are given and discussed below.

METHODS OF ANALYSIS

The soil samples were analysed according to the methods recommended by Wright (" Soil Analysis ", second edition, 1939, Thomas Murby & Co.). The degree of alkalisation of the soils (the percentage of monovalent bases, sodium and potassium, on the total exchange capacity of soil—a measure of deterioration of soil) was determined by the method described by Puri (" Ammonium Carbonate Method ", *Soil Science*, 1935, **40**, 150). For the analyses of the effluents, waters, and water extracts of soils, the methods proposed by Theroux, Eldridge and Mallmann (" *Laboratory Manual for Chemical and Bacterial Analysis of Water and Sewage* ", second edition, 1936, McGraw-Hill Book Company, Inc.) were followed. Chromium was determined by the method given in " *The Chemists' Year Book* ", eighteenth edition, 1936, p. 1000, Sheratt and Hughes. Examination for arsenic was carried out by the " Marsh-Berzelius Test " (Lunge and Keane's " *Technical Methods of Chemical Analysis* ", second edition, 1924, Vol. I, p. 434, Gurney and Jackson).

RESULTS

The Tannery Waste Effluent.—The amount of total solids in the effluent was found to vary from 344·8 to 2,294·8 parts per 100,000, and the pH value of the material was found to range from 7·7 to 10·9 (Table I). The results of detailed analyses of three typical samples of the effluent are given in Table II.

TABLE I

Results of analyses of eight different samples of the tannery effluent (from different basins)

Sl. no. of the samples	Total solids (as parts per 100,000)	pH value
1	1,054·4	8·8
2	361·6	8·3
3	1,525·2	8·6
4	1,489·6	10·9
5	1,488·8	8·6
6	344·8	8·7
7	2,294·8	8·7
8	698·0	7·7

The results presented in Table II show that the tannery effluent contains considerable amounts of bicarbonates, carbonates, sulphates and

TABLE II

Results of detailed analyses of effluents showing the nature and amounts of different ingredients

(Results expressed as parts per 100,000)

	1*	3*	7*
Total solids ..	1,054·4	1,525·2	2,294·8
Loss on ignition ..	40·4	48·0	124·8
Mineral matter (by difference) ..	1,014·0	1,477·2	2,170·0
Silica (SiO_2) ..	10·6	5·6	17·2
Calcium bicarbonate [$Ca(HCO_3)_2$] ..	6·9	22·7	19·9
Magnesium bicarbonate [$Mg(HCO_3)_2$] ..	8·4	178·1	27·1
Sodium bicarbonate ($NaHCO_3$) ..	353·5	66·8	67·4
Sodium carbonate (Na_2CO_3) ..	74·0	46·9	111·9
Sodium sulphate (Na_2SO_4) ..	31·7	299·1	15·4
Sodium chloride (NaCl) ..	547·1	873·6	1,903·0
Chromium (Cr) ..	0·28	0·08	0·33
Arsenic (As) ..	Present	Present	Present

* These numbers relate to the serial numbers given in Table I.

chlorides of magnesium and sodium which are harmful to plant growth, and that these injurious salts amount to over 95% of the total solid content. The effluent contains beneficial salts, such as calcium bicarbonate, only in negligible amounts, *viz.*, ranging from 7 to 23 parts per 100,000.

Among the salts in the tannery effluent, sodium chloride forms the major constituent, being 60 to 80% of the total solids. It is well known that if a liquid with such a high sodium chloride content is allowed either to seep on land or run into irrigation water, it would bring about undesirable changes in the soil complex, giving rise to a soil mainly composed of soda clay.

The tannery effluents also contain chromium ranging from 0·1 to 0·3 part per 100,000 along with appreciable amounts of arsenic—the latter tested only qualitatively—and these elements are known to produce toxic effects on plant growth.

Sub-soil water in the affected belt of land.—In Table III are presented the figures for the total solids (mainly composed of soluble salts) and pH values of the sub-soil water samples collected from four profile pits in the affected belt.

The above results show that the sub-soil water in the affected belt of land contains a very high amount of total solids, ranging from 675 to 960 parts per 100,000. Under normal conditions even with the rise of the water table, the sub-soil water should correspond in composition to that of the

TABLE III

Results of analysis of sub-soil water from profiles in the affected belt

Samples of sub-soil water from four different regions in the affected belt of land	Total solids (parts per 100,000)	pH value
1	752·8	7·9
2	958·4	8·1
3	674·4	7·8
4	914·8	8·0

irrigation water applied to the soil or contain only slightly larger amount of salts which might have been brought down by the washing of the soil strata. The composition of the sub-soil water is apparently due to seepage of the tannery waste effluent through the permeable strata disposed between the effluent basins and the cultivated fields.

The nature of the salts present in one of the sub-soil water samples examined is given in Table IV.

TABLE IV

Results of detailed analysis of sub-soil water from one of the profiles in the affected belt of land

	Parts per 100,000
Total solids	958·4
Loss on ignition	36·8
Mineral matter (by difference)	921·6
Silica (SiO_2)	16·0
Calcium bicarbonate [$Ca(HCO_3)_2$]	111·5
Calcium sulphate ($CaSO_4$)	15·3
Magnesium sulphate ($MgSO_4$)	82·0
Sodium sulphate (Na_2SO_4)	130·0
Sodium chloride ($NaCl$)	537·5

The results indicate that over 50% of the salts is composed of sodium chloride lending support to the view that it could not have been derived from any source other than the tannery effluent, as its range is more or less of the same order as noticed in the effluents. 90% of the total solids is made up of salts of magnesium and sodium, the remaining 10% being calcium bicarbonate amounting to 111·5 parts per 100,000. This high amount of calcium bicarbonate is significant as it throws light on the trend of changes taking place in the soil complex. It is only reasonable to expect that the high concentration of sodium chloride in the sub-soil water led to the gradual displacement of the calcium from the soil complex by the sodium resulting in the formation of the soda clay, the displaced calcium being found in solution in the sub-soil water. Normally in a cultivated soil irrigated with good irrigation water, the sub-soil water should never contain such a high amount of calcium bicarbonate as is met with here; if calcium bicarbonate is present at all in the sub-soil water, it can only be in negligible amounts. From these data as well as from the observation on the degree of alkalisation of the soil (Table X), it is evident that deterioration of the soil was progressively taking place, through contamination of the sub-soil water with the effluent containing harmful salts already mentioned. The sub-soil water samples, like the samples of tannery effluent, are alkaline in reaction.

Waters from wells in the area and from the lake in the neighbourhood.—The amounts of total solids in the water samples from the wells and lake and their pH values are given in Table V.

TABLE V

Results of analyses of the well water and lake water samples

Water samples	Total solids (parts per 100,000)	pH value
1. Well water (from the fertile belt of land) ..	97·2	8·7
2. Well water (from the fertile belt of land) ..	74·8	8·5
3. Well water (from the affected belt of land ..	351·6	8·2
4. Lake water ..	123·2	7·9

All the samples show fairly low total solid contents with the exception of the well water drawn from the field in the affected belt, which has a total solid content of 352 parts per 100,000. The lake water has a total solid content of 123 parts per 100,000 which is due to the falling off of the water level in the lake (caused by the constant use of the water for irrigation and by the concentration during summer). When the lake is full, these salts are present only in traces. The results of detailed analysis of the lake water (Table VI) indicate the presence of over 20% calcium salts and 80% magnesium and sodium salts. This gives a rather erroneous picture of its normal composition due to the reasons already given. The lake water may normally be taken to represent water of the highest standard of purity that could be met with in the area. The well water samples drawn from the fertile belts contain total solids from 75 to 97 parts per 100,000 indicating the absence of contamination through seepage and their suitability for irrigation purposes.

TABLE VI

Results of detailed analysis of lake water showing the nature and amounts of different ingredients

	Parts per 100,000
Total solids ..	123·2
Loss on ignition ..	28·0
Mineral matter (by difference) ..	95·2
Silica (SiO_2) ..	2·0
Calcium bicarbonate [$Ca(HCO_3)_2$] ..	10·9
Calcium sulphate ($CaSO_4$) ..	7·2
Calcium chloride ($CaCl_2$) ..	5·3
Magnesium chloride ($MgCl_2$) ..	13·7
Sodium chloride ($NaCl$) ..	54·4

Water soluble salts in soils.—The amount of total water soluble salts in each of the soil samples drawn from different depths of the profiles is presented in Table VII.

Samples from profiles 1 and 2 which are situated farther away from the tannery effluent basins do not show appreciable amounts of salts. Amongst the other profiles, those (3 to 6) situated in the heart of the affected belt show high concentration of salts ranging from 26 to 130 parts per 100,000. The nearer the profile is to the tannery basins the higher the concentration of salts present. Thus in profile 4, the two one-foot layers of soil contain 130·2 and 63·4 parts of soluble salts per 100,000. The samples from the other profiles, namely, 3, 5 and 6, also contain more or less the same amounts of water soluble salts (of the order of 40 parts per 100,000). Profiles 7 and 8 which are situated in the fertile belt contain an uniform concentration of 6 to 8 parts of salts per 100,000 throughout all layers of the profiles. These data go to confirm the absence of salts or, if at all present, only in negligible amounts, thus indicating the high productivity of the soils. The presence of high concentrations of salts in profiles 3 to 6 taken in conjunction with the records of crop yields confirm their unproductivity.

Considering that the soils are sandy loams, with low water-holding capacities, as seen from their mechanical composition (Table IX), it is but natural to expect that the concentration of salts noticed in these profiles would definitely prove toxic to plant growth.

TABLE VII

Results of analyses of water extracts (1 to 5) *for water soluble salts in the various profile samples*

(Results expresed as parts per 100,000)

Serial number of samples	Profile number	Location of the profiles	Depth	Water soluble salts
1	1	Profiles 1 and 2 situated farther away from the tannery effluent basins	0″–12″	29·2
2	,,		12″–24″	14·0
3	,,		24″–42″	13·4
4	2		0″–6″	41·0
5	,,		6″–18″	13·0
6	,,		18″–30″	5·0
7	,,		30″–45″	9·2
8	3	Profiles 3 to 6 situared in the heart of the affected belt	0″–12″	44·4
9	,,		12″–24″	35·0
10	,,		24″–36″	46·4
11	4		0″–12″	130·2
12	,,		12″–24″	63·4
13	5		0″–12″	41·2
14	,,		12″–30″	25·4
15	6		0″–12″	70·2
16	,,		12″–24″	45·8
17	,,		24″–36″	41·0
18	7	Profiles 7 and 8 situated in the fertile belt	0″–12″	6·8
19	,,		12″–24″	5·8
20	,,		24″–36″	7·8
21	,,		36″–54″	7·4
22	8		0″–12″	8·8
23	,,		12″–30″	7·6

The nature and amounts of the water soluble salts in soil samples from profile No. 8 in the fertile belt and from profile No. 4 (the one showing the highest salt content amongst the profiles in the affected belt) are given in Table VIII.

In the case of the soil profile in the fertile belt the total solids themselves being low, the nature of the salts is of little consequence. In the soil (the top 12″) from the affected belt nearly 92% is composed of injurious salts of sodium of which 65% is sodium chloride. A similar feature is also exhibited by the second foot sample of this profile. The high concentration of injurious salts present in the profile in the affected belt as against negligible amounts in the profile in the fertile belt clearly shows that the former soil is unproductive.

Mechanical composition and physical characteristics of the soils.—The results of mechanical analyses of the soils from the fertile and affected areas and the percentages of their water-holding capacity and porespace are given in Table IX.

TABLE VIII

Results of detailed analyses of water extracts (1 to 5) of the profile samples of soils from the fertile belt and from the affected belt

(Results expresed as parts per 100,000)

	Soil profile in the fertile area		Soil profile in the affected area	
	0″–12″	12″–30″	0″–12″	12″–24″
Total solids ..	8·8	7·6	130·2	63·4
Mineral matter ..	8·3	7·4	123·4	61·8
Silica (SiO_2) ..	1·6	0·6	2·1	2·9
Iron and aluminium oxides (Fe_2O_3 and Al_2O_3)	0·4	0·2	0·4	0·2
Calcium bicarbonate [$Ca(HCO_3)_2$] ..	1·2	2·0	2·8	2·0
Magnesium bicarbonate [$Mg(HCO_3)_2$]	0·8	0·8	0·6	0·1
Magnesium sulphate ($MgSO_4$) ..	1·1	0·3	..	..
Magnesium chloride ($MgCl_2$) ..	0·1	..	..	..
Sodium bicarbonate ($NaHCO_3$) ..	..	..	14·9	24·2
Sodium carbonate (Na_2CO_3) ..	..	..	1·4	2·3
Sodium sulphate (Na_2SO_4) ..	..	0·4	20·2	11·1
Sodium chloride (NaCl) ..	2·6	2·8	83·2	17·0
Chromium (Cr) ..	Nil	Nil	Traces	Traces
Arsenic (As) ..	Nil	Nil	Traces	Traces

TABLE IX

Mechanical composition and physical characteristics of the soils

	Soil profile in the fertile belt		Soil profile in the affected belt	
	0″–12″	12″–30″	0″–12″	12″–24″
Mechanical composition of soil (%) :				
Coarse sand ..	54·1	44·0	48·6	45·9
Fine sand ..	20·5	23·5	23·5	12·8
Coarse fraction ..	74·6	67·5	72·1	58·7
Silt, fine silt and clay	25·4	32·5	27·9	41·3
Physical characteristics :				
Maximum water-holding capacity (%)	37·7	47·1	24·1	..*
Porespace (%) ..	40·7	46·8	28·5	..*

* Resisted wetting in spite of being left in contact with water layer for over 27 days.

The soil in the fertile belt is composed of 68 to 75% of coarse fraction and 25 to 33% of fine fraction. This composition would place the soil in the category of sandy loam with its characteristic feature of water-holding capacity and other physical properties. The water-holding capacity of the top foot is 38% and of the bottom layer 47% substantiating the group characteristics. Such a composition would facilitate easy permeability and seepage. The composition of the soil in the affected belt shows a coarse fraction of 72% and fine fraction of 28% in the top layer and 59% and 41% respectively in the bottom layer. The top layer shows a water-holding capacity of only 24% and a porespace of 28% (having observed it to take over 4 days to absorb water), while the bottom layer was found to resist wetting in spite of its being left in contact with water layer for well over 27 days. The limited porespace noted above along with the presence of sodium clay would accentuate this property of resistance to wetting. These factors should naturally adversely affect its productivity. In this connection, it would be interesting to record the rapidity with which the samples from the fertile belt absorbed water, a similar column of sample taking under 30 minutes to get wet.

Degree of alkalisation.—The degree of alkalisation is an index of the extent of deterioration a soil has undergone as a result of the reaction brought about in the soil complex consequent on the interaction of soluble salts present in the soil. Thus, if sodium chloride is present, it interacts with the insoluble calcium and magnesium in the soil complex rendering them soluble. The salts of calcium and magnesium are brought into solution and removed from the soil; the sodium from the sodium chloride combines with the clay complex to form soda clay. The resulting sodium clay possesses properties detrimental to plant growth. The degree of alkalisation is expressed as a percentage of the exchangeable sodium and potassium to the total amount of exchangeable calcium, magnesium, sodium and potassium present in the soil. These data are of great value in assessing correctly the productivity of soils in general.

Taylor, Puri and Asghar (*Punjab Irrigation Research Institute Publication*, 1934, Vol. 4, Part 7) working on soils in the Punjab have shown that there is correlation between the degree of alkalisation and crop growth. With the rise in this factor, there is a corresponding fall in the yield. The diminished yield has been traced to changes in the physical condition of the soil, a higher degree of alkalisation being responsible for greater dispersion of the clay. As long as the degree of alkalisation is within 25% there is not much adverse effect on the crop yield; higher limits, say, from 30 to 40%, have been found to cause the maximum dispersion in the soil, and thus lead to low productivity. Hence the determination of this factor indirectly gives an insight into the exact soil conditions and the probable effects on crop production.

The data pertaining to the degree of alkalisation of the soils are given in Table X.

TABLE X

Exchangeable bases in milli-equivalents in the soil profiles in the fertile and affected areas

(Degree of alkalisation)

	Soil profile in the fertile belt		Soil profile in the affected belt	
	0″–12″	12″–30″	0″–12″	12″–30″
Exchangeable				
Sodium and potassium ..	0·7	0·4	9·5	11·7
Magnesium ..	3·2	6·0	3·9	5·0
Calcium ..	3·2	4·1	5·3	4·1
Total exchangeable bases ..	7·1	10·5	18·7	20·8
Degree of alkalisation:				
$\frac{\text{Ex. Na + K}}{\text{Total exchange capacity}} \times 100$ ..	9·9%	3·8%	50·8%	56·2%
Average ..	6·8%		53·5%	

The degree of alkalisation for the soil in the fertile belt ranges between 3·8 and 9·9% with an average of 6·8% for the profile; whereas the soil in the affected belt shows a range of 50·8 to 56·2% with an average of 53·5% for the profile. These figures viewed in the light of the foregoing observations would confirm that the soil under reference has undergone maximum deterioration.

Toxic elements.—The presence of chromium was noticed both in the effluents and in the soils from the affected belt. This would lend further support to the observations already made that considerable seepage or overflow of the contents of the tannery basins has taken place into the soils of the affected belt. The work of Jenkins and Hewitt (*loc. cit.*) has clearly demonstrated that the presence of chromate chromium in amounts higher than 0·2 part per 100,000 in effluents is detrimental to the microbial activity. It follows therefrom that the productivity of the soil would also be impaired if any liquid containing chromium in amounts higher than the above amount is allowed to come into contact with it. The results pertaining to chromium in the effluents would clearly show that irrigation with or seepage of the effluent is deleterious to crop growth.

The presence of arsenic was also noticed in the effluents and in the soil samples from the affected belt, while it was conspicuously absent from the soils from the fertile belt. The presence of arsenic might have also contributed to a considerable extent to the failure of crops on the fields in the affected belt.

DISCUSSION

The studies carried out on the samples of tannery waste effluent, soils and sub-soil water have thrown considerable light on the soil conditions as affected by the liquid wastes from the tannery basins closeby and their effect on plant growth.

Examination of the effluents has shown that they contain sodium salts, especially sodium chloride ranging from 60 to 80% (650 to 2,000 parts per 100,000) of their total solids. The concentration of the salts is very high and such liquid if allowed to soak through and contaminate the irrigation water or allowed to overflow directly into agricultural land, is bound to adversely affect the soil processes. The toxic limit of sodium chloride in irrigation water has been reported to be 100 parts per million (Puri, *Punjab Irrigation Research Institute Publication*, 1933, Vol. 4, Part 5).

The adverse effect of sodium chloride is due to the displacement of lime from the soil; the calcium is leached out as calcium bicarbonate resulting in the formation of sodium clay which is deleterious to the soil processes and crop growth. That this reaction has taken place is evident from the very high content of calcium bicarbonate in the sub-soil water (111 parts per 100,000) and the very low content of calcium bicarbonate in the water extract of the soils from the affected belt (2·8 parts per 100,000). The composition of the sub-soil water would further indicate the possibility of seepage as well as overflow of the effluent.

In addition to the high salt content of the effluents, they contain chromium and arsenic which are known to be toxic to plant growth. The presence of these elements in the soils of the affected belt would further support the view that the tannery effluent must have overflown into the adjacent fields. The proximate composition of the tannery waste effluent as given in Table II and the composition of the sub-soil water and of the water extract of the soil from the affected area as given in Tables IV and VIII respectively seem to bear comparison (Table XI).

The soil extracts from the affected belt show very high salt concentrations ranging from 40 to 140 parts per 100,000. As they are sandy loam they exhibit the characteristic property of the group, namely, permeability and low water-holding capacity ranging from 25 to 35%. Consequently

TABLE XI

Composition of the tannery waste effluent, of the sub-soil water and water extract of the soil from the adjoining affected area

(Results of chemical analysis expressed as parts per 100,000)

	The tannery waste effluent	Sub-soil water from the adjoining land	Water extract of the affected soil (1 to 5) from the adjoining land
pH value	8·7	8·1	..
Total solids	1,624·8	958·4	130·2
Loss on ignition	71·1	36·8	..
Mineral matter	1,553·7	921·6	123·4
Silica (SiO_2)	11·1	16·0	2·1
Calcium bicarbonate [$Ca(HCO_3)_2$]	16·5	111·5	2·8
Magnesium bicarbonate [$Mg(HCO_3)_2$]	71·2	..	0·6
Sodium bicarbonate ($NaHCO_3$)	162·6	..	14·9
Sodium carbonate (Na_2CO_3)	144·3	..	1·4
Sodium sulphate (Na_2SO_4)	115·4	130·0	20·2
Sodium chloride (NaCl)	1,107·9	537·5	83·2
Chromium (Cr)	0·23	..	Traces
Arsenic (As)	Present	..	Traces

the limit of salt tolerance in them would naturally be far lower than those for clayey soils. It is hence safe to assume a concentration of 10 parts of sodium chloride per 100,000 to be the salt tolerance limit for crops raised on them. Judged by this standard, most of the soils in the affected belt show a concentration much above this limit, explaining their infertility. Further, the high content of sodium chloride, *viz.*, 82 parts per 100,000 noticed in the profile in the affected belt would accentuate the adverse conditions for crop growth. In addition, the high amounts of exchangeable sodium and potassium, 9·5 and 11·7 milli-equivalents (Table X) present in this profile point to the occurrence of sodium clay already shown to be injurious to crops.

The water-holding capacity, porespace and other related physical properties of the soils from the affected belt are adversely affected largely due to the presence of sodium clay, in spite of their being sandy loam in structure. The poor porespace and the slow rate of wetting of the soils are unfavourable to the healthy growth of crops. These changes have been brought about by the combined influence of the high concentration of sodium chloride and the changed soil complex.

The foregoing observations on the soils and sub-soil water would clearly show that their high sodium salt content and also the toxic elements (chromium and arsenic) present in them must have been derived from an external source other than the irrigation water from the lake. The latter contains neither any of the toxic elements nor the sodium salts in appreciable amounts. The lake water was found to contain only 54 parts per 100,000 of sodium chloride; even this amount is due to the low water level at the time of the sampling. Normally, during the irrigation season, the tank is full and the water contains only traces of this salt. Moreover, the lake is fed by water from rainfall received in a catchment free from salt owing to its lateritic origin.

There is thus strong evidence to show that the presence of excessive amounts of sodium salt and the toxic elements in the soil is entirely due to seepage and overflow of the tannery effluent.

In considering the question of satisfactory sanitary disposal of the tannery effluent it may be emphasised that the material should be treated in order to prevent spreading of anthrax if the skins in the tannery are suspected of the infection; to remove the grease and other suspended matter by provision of scum boards and screens; to reduce the chromate in the wastes by sulphur dioxide, if necessary; and to dilute the material in proper proportion with less polluted water, *e.g.*, domestic sewage. The Bureau of Sanitary Engineering of the Wisconsin State Board of Health (1930) reported that tannery wastes can be successfully treated with sewage without impairing the digestibility and the drying property of the sludge, provided the volume of the waste does not exceed that of sewage. In one sewage works at Wisconsin, tannery waste waters are screened and added to the sewage before settling (Harihara Iyer, *loc. cit.*).

In conclusion, it is the pleasant duty of the authors to thank Dr. V. Subrahmanyan and Mr. C. V. Ramaswamy Iyer for their valuable advice and suggestions in the course of the investigation.