COMPREHENSIVE STUDY OF GROUND WATER CONTAMINATION IN THE VICINITY OF KHETRI COPPER COMPLEX

THESIS

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of the requirements for the degree of
DOCTOR OF PHILOSOPHY

By

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under the supervison
of Dr. R.S. PARIHAR

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CERTIFICATE

This is to certify that the thesis entitled "COMPREHENSIVE STUDY OF GROUND WATER CONTAMINATION IN THE VICINITY OF KHETRI COPPER COMPLEX " and submitted by SANTOSH KUMAR SINGH ID.No. 89PHXF013 for award of Ph.D. Degree of the Institute , embodies original work done by him under my supervision.

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CHAPTER : 1

GENERAL INTRODUCTION

1.1 ENVIRONMENTAL POLLUTION

Rapid industrialisation and urbanisation has brought out both benefits and miseries to humanity. Environment and development are two sides of the same coin. The need for development through socio-economic activities;specially with the growing population and a desire for higher standards of living with industrial production is obvious. Practically all socio-economic activities, for example industry, agriculture, transport, construction, road, housing etc. The complexities parameters have necessitated a multidisciplinary approach to environment protection. After independence industrial activity has increased manifold in India. In the recent years, a number of industries and thermal plants are being established to meet our increasing demand of various commodities day by day. More and more metallurgical units are being installed to make India self sufficient for its metal requirements. Consequently environmental contamination is on the increase. Although the pollution problems has not reached a critical level in India, yet it must be controlled in its beginning, lest it should become acute enough to enforce curative measure. Consequently, Government of India has laid down the guide

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GENERAL INTRODUCTION

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Chemical contamination through out the environment is characteristics of our advanced technological society. Industrial production often generates by products that are of little economic value but that, as residual waste material, may have severe environmental consequences. One of the primary pathway for migration of these contaminants is the water cycle. Ground water contamination has been recognised in the recent years as a very serious national problem.

The systematic pollution of our environment is one of the biggest hazards that humanity faces today. People are becoming increasingly aware of the threat for the pollution and the Governments are enacting legislation aimed at protecting environment. One of the factors that affect the degradation of the environment is the population growth with the development of thousands of chemical compounds to restore and enhance the soil fertility, and to protect many of the domestic species, man was able to expand his food production capacity significantly (Ehrlich and Holdern ,1971). A study conducted by SCEP (Study of Critical Environment Problems,1970) group points out that the demand for minerals, energy and space are exponentially increasing at a rate of 5 to 6 percent per year and this will increase the environment impact sixfold.

Now a days, in this industrialised world a huge amount of energy is required which is tapped by the mining of coal, hydroelectric power, extracting oil and natural gas and nuclear power etc. The impact on the environment has been massive with far reaching consequences. Water pollution, noise pollution and land pollution are caused due to generation and use of energy. A number of health hazards and environment imbalance occurs because of this section (Oden,1968 ; Ramana,1980 ; Singh,1990).

1.2 POLLUTION FROM INDUSTRIES

Industrial waste is one of the causes of pollution. It is roughly comparable in its nation-wide pollution effect, with municipal sewage are characterised by their differences and their similarities. Each individual plant is an individual problem. There are of course common parameters by which pollution can be evaluated. Most industrial wastes must be discharged from the plant premises, only rarely is it possible to let them with out discharge. When the waste is discharged it causes environmental pollution. Broadly environmental pollution may be water, air,land or noise pollution.

Development of mining, metallurgical and chemical industries is vital for the progress of the country as they supply essential commodities for human consumption. At the same time these industries are the largest sources of environmental pollution and a serious damage is done to vegetation and water resources due to mining. Water pollution problem arises due to the discharge of mine water and discharge from boilers, steam engines, compressors and different processes into stream or on land. Water from tailing is an important source of water pollution.

Mining and metallurgical industries also contribute air pollution. Dust is generated at all stages of mining during crushing and transport of the metal. Dust is also raised by wind from refuse dumps. The combustion processes during the metallurgical processes pollute the air by adding hydrocarbons, oxides of sulphur, oxides of nitrate, carbon dioxide, carbon monoxide and particulate matters of some heavy metals to it.

Land damage is done due to mining. Damages done to the interior and exterior of the earth. Cleaning of vegetation generally precedes the mining of ore from the area. Subsequently many structures are built, solid wastes are discharged on the land and when the ore is exhausted many dilapidated structures are left over due to all these denundation of vegetation occurs.

1.3 GROUND WATER POLLUTION

Water both for survival and in utilizing its resources has been a major factor in economic development. It is well known that it is only paucity of water which has alerted civilization since ancient times. Even the dislodging of areas of civilization has occured due to shift in water availability. Gradually, technology brought global culture to the cross road and as the population started increasing due to many fold factors of economic development and invention, human started tapping the water sources, both river and underground for survival. It is the modernization of culture which increased the water utilization.This utilization become so intense and that the consciousness of water , its conservation and new exploration become most crucial and disparing in other regions (Roy,1991).

Water in India is polluted to different intensities due to gaps in the methods and norms of purification in organised system. Even industrial waste and pollutants from rivers cause pollution to the sources of the water used for drinking. Precise data on the amount, nature and intensity of pollutants are not available, except in a few location and fixed points (Singh,1991).

Earlier investigations confirmed that Indian ground water is being contaminated by percolation of industrial waste and overflow. Ground water pollution is indirectly related to sewage disposal, agricultural activities, urban runoff and industrial waste disposal. There are many areas in India, where the risks of pollution may be intensified and habitants may face various types of water borne deseases such as cholera, typhoid , guineaworm etc. The incidence of such deseases, level of fatality and there by the death rate are at variance because of lack of authentic data maintained at hospitals and practising doctors. A large number of districts are affected with a strong prevalance in the state of Uttar Pradesh, Bihar, West Bengal, Orissa, Tamil Nadu, Andhra Pradesh. Ignorance of sanitation and clean drinking water are other characteristics of these areas. For India, it is said that the human population have become immune to water contaminants and when the degree of water contaminants increases in drinking water sources, epidemics take their toll during monsoon and transitory seasons. It is of concern that due to use of agricultural pollutants i.e. use of nitrogen, phosphate and potassium fertilizers for growing crops the concentration of nitrates in ground water has increased several hundred mg/l in parts of Punjab, Uttar Pradesh, Maharashtra, Andhra Pradesh and other states (Tyagi,1987).

Similarly fluoride concentration in arid and semi arid regions, iron contents in humid north east India,seepage of effluent in textile dyes in arid regions of Rajasthan and

Gujarat, discharge of untreated tannery and textile wastes in Andhra Pradesh, high concentration of chromium in gangetic Yamuna zone , etc. are alarming and the risks of hazards to habitants are ever increasing (Rajvanshi and Bhargava,1989 ; Roy,1991).

1.4 INTRODUCTION TO KHETRI COPPER COMPLEX

Khetri Copper Complex is the major constituents of Hindustan Copper Limited, a Government of India enterprise established in November 1967. Khetri Copper Complex is situated 190 km. west of Delhi, and 180 km. north of Jaipur, in Jhunjhunu district of Rajasthan state, at the altitude of 310 m. above the mean sea level. Khetri is situated in a cup shaped valley surrounded by hills.

1.4.1 Location

The copper and fertilizer complex at Khetri Nagar is 11 km. north east of Khetri (Latitude 29°6'2" N and longitude 75°50'22" E) 190 km. west of Delhi and 180 km. north of Jaipur, the capital of state. It is situated at the northen end of the large, 76km. long, copper belt (Khetri copper belt) extending from Singhana to Rughunathgarh, to mine and process the copper ore.

1.4.2 Historical background

The copper deposits were mined in ancient times working dating from Mauryan period, over 2000 years ago. The mines were active along the same time of Mughal emperor, a report of 1590 referring to them (Aanai - 1 - Akbari ,written by Abul Fazal,a courtier of emperor Akbar) more recently they were worked by local people who paid royalty on production to princely state of Khetri. Two mines were functioning in towns of Singhana and Khetri until closed by British in 1869. Regular mining ceased in 1872 , although sporadic activities continued until 1910. From 1944 to 1955 loaned to Jaipur mining corporation Ltd. but not worked.

The geological survey of Indian Bureau of Mines began in 1957. The project was handed over to National Mineral Development Corporation, in 1961 for further investigations. Initial feasibility studies were completed in 1963, a new source of copper was needed in India, as for almost two decades the national output had remained static about 10,000 t/ year , from Indian Copper Complex Corporation mines in Bihar. There was a pressing need to increase indigenous production to narrow the gap between India's own output and the steadily increasing demand.

The decision to proceed with the development of Khetri complex was taken by 1962. Shafts sinking and mine development began in 1964, and the first production of ore took place in 1970. The project was transferred to newly created Hindustan Copper Complex by Nov. 1967. The finance for the surface installation was not available immediately and construction of concentrator and smeltor did not begin until 1970. The concentrator came on stream in 1973, followed by the smeltor start up the following year. A fertilizer plant based on the sulphuric acid by product from the smeltor, plus phosphate rock from Rajasthan began production in 1975. There are four mines in the Khetri complex. The two major Khetri and Kolihan underground, the Chandmari open pit mine and the 100 t/d , Dariba under ground mine with a matching concentrator in the Alwar district of Rajasthan state, some 220 km. away from Khetri. The ultimate capacities of first three are designed to be 5,000; 3,000 and 1,000 t/d respectively.

1.4.3 Climate and rainfall

The area experiences semi arid climate and receives over 90% of the rainfall during the south west monsoon which lasts from the June to September. The annual rainfall pattern has been analysed statistically from the records of the rainfall (1957 - 1991) from the nearby station at Khetri (or at Pilani, the nearest observatory).

The details of the rainfall including the departure and cumulative departure from the mean annual rainfall are given in table 1.4.1. The summarised results are as follows:

1. Number of years of data analysed: 34 years from 1957 to 1991
2. Mean annual rainfall of 34 years: 527.00 mm.
3. Highest rainfall in the year of record : 1964 ; 848.90 mm.
4. Lowest rainfall in the year of record : 1989 ; 234.50 mm

1.4.4 Temperature

The climate of the area shows wide variation in the temperature from 2°C minimum to 45°C maximum temperature. The monthly temperature variation for Pilani, the nearest observatory are shown in fig.1.1 . The wind blows in the north - west direction except during August and September, when they blow in the south westerly direction.

1.4.5 Winds

Winds are generally light to moderate. In the summer ,winds blow from directions between north west and south west . During the south west monsoon winds blow west to south west direction. in post monsoon and winter months , winds are variable in all directions. The mean wind speed ranges from 6.2 to 18.5 km/hr . The wind speeds are high during May to July .

1.5 AIMS AND OBJECTIVES OF THE PRESENT STUDY

The present study deals with the study of ground water quality and its pollution around Khetri Copper Complex (KCC), Khetri Nagar, Jhunjhunu district, Rajasthan, due to the discharge of effluent from the large copper and fertilizer industrial complex with an emphasis on the following aspects:

1. Study of the quality of ground water in Jhunjhunu district, Rajasthan.
2. Study of aquifer properties in the Khetri area.
3. Study of the effect of effluent discharge on quality of ground water.
4. To give a mathematical model for contaminant transport in the aquifer for Khetri Copper Complex .

Table 1.4.1
Annual rainfall data and departure between 1957 -91 at Khetri

Year	Rainfall (cm) x	Departure ((x/x*)-1)	Cumulative departure
1957	56.06	-0.002	-0.002
1958	49.84	-0.112	-0.114
1959	37.94	-0.324	-0.438
1960	52.68	-0.062	-0.500
1961	49.68	-0.115	-0.615
1962	63.56	+0.132	-0.483
1963	46.16	-0.178	-0.661
1964	84.89	+0.512	-0.149
1965	35.36	-0.370	-0.519
1966	35.84	-0.362	-0.881
1967	75.61	+0.347	-0.534
1968	49.90	-0.111	-0.645
1969	48.02	-0.145	-0.790
1970	59.86	+0.066	-0.724
1971	64.91	+0.156	-0.568
1972	38.46	-0.315	-0.883
1973	57.52	+0.024	-0.859
1974	52.12	-0.072	-0.931
1975	74.72	+0.331	-0.600
1976	82.01	+0.461	-0.139
1977	75.49	+0.344	+0.205
1978	80.29	+0.430	+0.635
1979	29.73	-0.471	+0.164
1980	47.00	-0.163	+0.001
1981	368.0	-0.283	+0.344
1982	566.0	+0.102	+0.446
1983	707.2	+0.377	+0.823
1984	452.0	-0.119	+0.704
1985	596.0	+0.160	+0.864
1986	306.0	-0.404	+0.460
1987	277.0	-0.460	+0.000
1988	591.6	+0.123	+0.123
1989	234.5	-0.555	-0.432
1990	490.3	-0.0696	-0.5016
1991	539.3	+0.0233	-0.4783

Fig 1.1 VARIATION OF TEMP. IN JHUNJHUNU DISTRICT

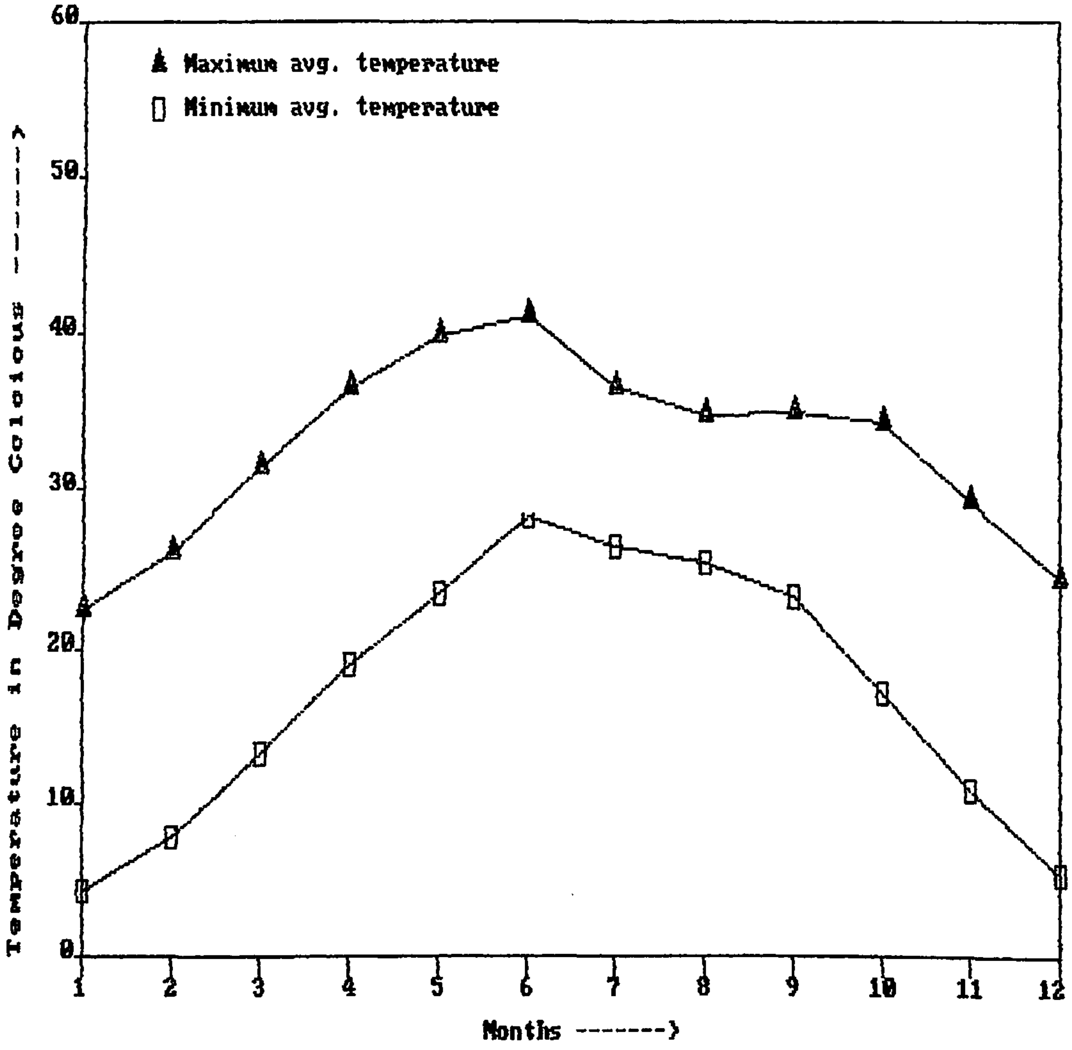

FIG. 1.2 MAP OF JHUNJHUNU DISTRICT.

CHAPTER : 2

GEOLOGY AND THE WATER BEARING PROPERTIES OF SUBSOIL IN THE KHETRI AREA

2.1 INTRODUCTION

The rocks in the Khetri area belong to the Delhi super - group of precamberian age, which is subdivided into the Alwar and Ajabgarh groups. The older Alwar rocks are derived from predominantly arenaceous sediments, while the younger Ajabgarh rocks were originally of a more agrillaceous nature the transition between the two being gradatonal. All these formations are metamorphozed to quartzites, schists and phyllites. Some intrusive dolerite dykes are present, and veins of quartz and carbonates are common.

The general strike of the formation is NNE - SSW with steep to gentle dips towards the WNW .The economic mineralisation which gives rise to the ore bodies is mainly localised in the upper parts of the amphibole- chlorite quartzites and garnet - amphibole -chlorite quartzite. The mineralisation occurs in, the form of veins, veinlets, stringers and disseminations (rarely massive), oriented in general parallel to the folination plane.

2.2 TOPOGRAPHY

The topographic feature of the area consists of a cluster of hill masses between Khetri and Chirani, and three well defined hill ranges from

(1) Shampura to Singhana,

(2) Khetri to.Singhana and

(3) Manuta to Isakpura and beyond.

The hills rarely rise to heights of more than 200 m. above the plains except near Khetri, where the peak of Bhopalgarh rises to a height of 710.79 m. above the mean sea level. The hills generally have a steep slope of 30° - 40° or more. The remaing area is gently undulating and forms the valley floor of the Singhana river and its principal tributory, the Kharkhar nala.

The present topographic features of the area can be attributed to differential errosion of the diverse lithological units of the intensely folded rocks of the Delhi system and their intrusives. The majority of the ridges are crystalline rocks, but some are also made up of blown sand, such as those occuring near Khetri and Kurana.

2.2.1 Drainage

The principal river in the Khetri area is the Singhana river , flows from near the hill fort of Bhopalgarh south of Khetri. It flows for a short distance northwards upto Khetri where after it maintains a general north easterly course. Above Singhana it is joined by several tributaries. The most important of which is the Kharkhar nala. Among the minor tributaries are those following past Kurana, Manuta and Gotro. In the upper reaches the Kharkhar nala drains the sand-dune covered area west of Shampura, but elsewhere it flows through a series of hill ranges on either side of Shampura. The bed of the river is mostly made up of a thin mantle of boulder gravel resting on phyllites of the Delhi system. Except for a stretch of a few km. near Khetri, the Singhana river bed comprises mostly of coarse sand and occasional gravel. The beds of the minor streams near Gotro, Manuta and Kurana are made up predominantly of unassorted gravel and cobbles.

All the streams in the area are ephemeral in character and rise in freshest at times of intense precipitation. The flood water, however is soon dissipated within a distance of about 30 km. from Khetri, part of the stream beds near Kharkhar and Khetri receive effluents seepage from dune sands and retain pools of water almost throughout the year. The Singhana river drains the waste water of Khetri Copper Complex.

2.3 SURFACE GEOLOGY

The Khetri area is underlain by recent to subrecent alluvium and blown sand overlying the Ajabgarh rocks of the Delhi system comprising quartzites, schists, phyllites, calc-granulites etc. The post Delhi intrusives are represnted by epidiosites, granites and pegamatites. The stratigraphic succession in the Khetri area is given in next page (Basu and Chaurasiya,1976).

Nearly half of the Khetri area is covered by the consolidated and folded rocks of the Delhi system and their intrusives. The remaining area is made up of unconsolidated recent alluvium and dune-sands.

2.3.1 Delhi System

The rocks of the Alwar series occur east of Khetri and north east of Monuta. They are mainly composed of quartzites, which in the Khetri area, are thin bedded with micaceous laminae, black lime stone , etc. are fine grained, reddish yellow or grey. The rocks of the Ajabgarh series, comprising of quartzites, limestone, phyllites, micaceous schists and calc granulites occur west of Khetri in two

Era/Period		Series	Lithological description
	Quaternary (Recent to Sub recent)	Dune sand and Alluvium	Sand dunes,alluvium,clay, silt ,sand and kankar
		Unconfirmity	
PRE CAMBRIAN		Post Delhi Intrusive	Amphibolite/epidiorite/ pegametite/rhyolite/granites /folcite
	Delhi Super -Group	Ajabgarh formation	Quartzites,limestone,slates, micaceous schists, calc granulites
		Alwar formation	Quartzites,occasional lime - stone

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prominent ridges flanking the Kharkhar nala and exsisting north - west upto Singhana and beyond. the rocks of the western flanke of the Kharkhar valley are predominantly quartzites and limestone, while the eastern flank comprises dominantly of the quartzites and schists, the intervening portion being hewn out of the less resistant phyllite. The quartzchlorite schists in the eastern flank of Kharkhar nala are mineraliesd with copper, mainly chalcopyrite.

The rocks of the Delhi system are compressed into a series of folds and have a regional strike of NE -SW , dipping generally to north - west at angles of more than 45° . These are also characterised by numerous transverse faults.

The rocks of the Delhi system are consolidated, dense and compact, except probably where they have undergone disturbances. They are generally well jointed at the surface, but few of the joints persist to great depths and when they do, they may be few and far between as observed in the various shafts and addits of the Madan Mines. In view of the slopes considerable parts of the water received as precipitation is carried away as run- off.

2.3.2 Post - Delhi Intrusives

The rocks intruded in the Delhi System use, in order of succession, the epidiorites (amphibolites), granites and pegmatites. While the epidiorities are seldom schistose, the granites , are typically foliated. The epidiorites and to a certain extent the granites by virtue of their lesser resistance to weathering do not give rise to marked surface reliefs as do the quartzites of the Delhi system. Out crops of granites forming small hillocks are to be found in the vicinity of Gotro, and those forming of amphibolites east of Chota Bagh.

A thin section of a sample of granite taken from an out crop about 100m. west of Gotro was examined under the microscope. The rock is described as medium grained, composed of essentially of quartz, orthoclase, plagioclase and hornblende with sphene, epidote and magnetite as accessories. The felspar exhibits perthitic growth. The epidote occurs due to the sassuritization of the plagioclase present in the rock.

2.3.3 Recent Alluvium

Recent Alluvium is to be found extensively in the valley floor of the Singhana river and its tributaries. They comprise of stream laid deposits of clay, silts, gravel, pebbles and boulders, mostly surrounded to angular. These are unconsolidated and do not have any cementing matrix, except within the capillary fringe where the grains are cemented with calcium carbonate, giving rise to kankar. Generally, above the water table the materials are finer, frequently very silty. A part from this, the coarseness of the materials varies areally, being finer away from the foot - hills depending on the prevaling stream gradient. The coarser sediments comprises predominantly of quartz, quartzites, amphobolite, phyllites, limestone and kankar. The finer aggregates include in addition to the above, garnet, magnetites, mica and other ferromagnesian minerals.

The sand-gravel-boulder materials of the alluvium are very porous with large intergranular spaces and hence when saturated, yeild water readily to wells tapping them. However, the finer ones comprising silt and clay, although very porous, yeild water less readily in view of the fineness of the pore spaces.

2.3.4 Blown Sand

The blown sand rests on the alluvium, or on the older consolidated rocks. The sand is fine to medium grained, occasionaly micaceous, and occurs extensively east of Shampura, west of Khetri, and to a lesser extent near Chirani, south west of Dhana and west of Singhana. They are mostly of the fixed type and support scanty vegetation.

Mechanical analysis of one sample of the dune sand collected from a point about 3 km. east of Shampura showed the distribution in grain size as given in table 2.3.1 . The blown sand, being loose, unconsolidated, and highly porous, readily absorbs rain water; but in view of the fineness of the pores the absorbed water yields very slowly. Many of the streams originating from the hills disappear in the dune country near Shampura because all the water is absorbed in the dune sands.

Table 2.3.1
Mechanical analysis of a dune sand sample

Cummulative volume percent retained Seive Size in millimeters			
0.249	0.124	0.074	0.04
0.21	44.10	97.75	100

2.4 SUBSURFACE GEOLOGY

The basement on which the alluvium and the blown sand were deposited comprise of the rocks of the Delhi system and the Post Delhi intrusives. The thickness of the unconsolidated sediments is governed by the subsurface topography of the older rocks as well as by the surface relief, because of the more or less constant trend of the rocks of the Delhi system, the subsurface ridges extended along the strike direction of the exposed rocks which stand out due to their superior toughness and resistance to weathering in comparison to the rocks which got eroded and were subsequently concealed by depletion of alluvium and blown sand.

2.4.1 Thickness of Recent Alluvium

The thickness of the alluvium varies considerably in the valley floor of the Singhana river up to its confluence with the Kharkhar nala, the thickness of alluvium is greater than 15 m.The same is true for the area between Kurana and Manuta, east of Singhana river. The thicker section of the alluvium are to be found along the present channel of the Singhana river. In the Kharkhar valley, east and north east of Shampura the thickness of unconsolidated materials at places is more than 20m. the maximum recorded being 25.6 m. The materials excavated from the dug wells have a great resemblance to the accumulations of dune sands in the vicinity. Coarser grains except kankar nodules are conspicuous by their absence. North of Kharkhar the alluvium consists of boulder gravel thinly mantling the underlying phyllites, which form the bed rock. South of Singhana the alluvium increases to about 20 m. between Banas and Kharkhar, the alluvium is thiner, rarely exceeding 10 m.

2.4.2 Bed Rock

In the Khetri area a study of excavated dumps around dry well and exploratory drilling suggest that in the vicinity of Gotro and further downstream, the bed rock comprises of granite occuring below a thin mantle of alluvium and blown sand. Granite was also encountered in some bore holes, below a depth of 19.5 m. Elsewhere in the Singhana valley the bed rock comprises mostly of quartzites except in the vicinity of Barabagh where amphibolites were encountered in some of the wells.In the Kharkhar valley, east of Shampura and south and south -west of Singhana, the bed rock occurs at a depth of more than 20 m. In the remaining area the bed rock is encountered at shallow depth. The bed rock here comprises essentially of phyllites.

A geological section is prepared taking the lithological data of drilled bore holes at Chaonra viz. of

KCP tubewells : C-4, C-3 and C-8 , which has been shown in fig. 2.1 . The section indicates that the gravel beds are thick towards Chaonra and Manipura and silt and clay contents increases towards the tubewell numbers C-3 and C-8 (i.e. near Gadla). Even there is a rise in the bed rock towards the later. The thickness of alluvium is 51.83 m. near C-4 in the south and reduces to 44 m. near C-3 and to 29 m. near C-8 located in the northen of the area. Lithologs of these boreholes (C-3, C-4 and C-8) are given in tables 2.4.1, 2.4.2 and 2.4.3 respectively .

Table 2.4.1
Litholog of bore hole C-3

Bore Hole no. : C-3
Location : Chaonra
R.L.M. Ground Level : 381.173 m.

Lithology	Depth Range (m.)	Thickness (m.)
Surface Sand	0 -1.52	1.52
Fine Sand	1.52 -7.62	6.10
Sand, Gravel and Kankar	7.62 -13.72	6.10
Clay, Kankar	13.72 - 22.87	9.15
Kankar, Pebble and Gravel	22.87 -27.44	4.57
Boulders	27.44 -35.06	7.62
Sandy clay and Kankar	35.06 -38.11	3.05
Boulders	38.11 -44.21	6.10
Rock	44.21 -49.39	5.18

Table 2.4.2
Litholog of bore hole C-4

Bore hole No : C-4
Location : Chaonra
R.L.M. Ground Level : 382.704

Lithology	Depth range (m.)	Thickness (m.)
Fine Sand	0 -3.05	3.05
Medium Sand	3.05 -10.67	7.62
Sand with Kankar	10.67 -14.63	3.96
Red Clay with Kankar	14.63 - 28.96	14.33
Sandy Clay with Kankar	28.96 -33.54	4.58
Small Gravel	33.54 -45.12	11.78
Boulder Stone	45.12 -51.83	6.71
Quartzite	51.83 -54.88	3.05

Table 2.4.3
Litholog of bore hole C-8

Bore hole No. : C-8
Location : Chaonra
R.L.M. Ground Level : 381.985 m.

Lithology	Depth Range (m.)	Thickness (m.)
Surface sand	0 - 3.05	3.05
Sandy Clay with Kankar	3.05 -10.67	7.62
Clay with Murum	10.67 -24.39	13.72
Coarse Sand	24.39 -28.96	4.57
Soft Rock	28.96 -31.40	2.44
Compact Rock	31.40 -32.83	1.53

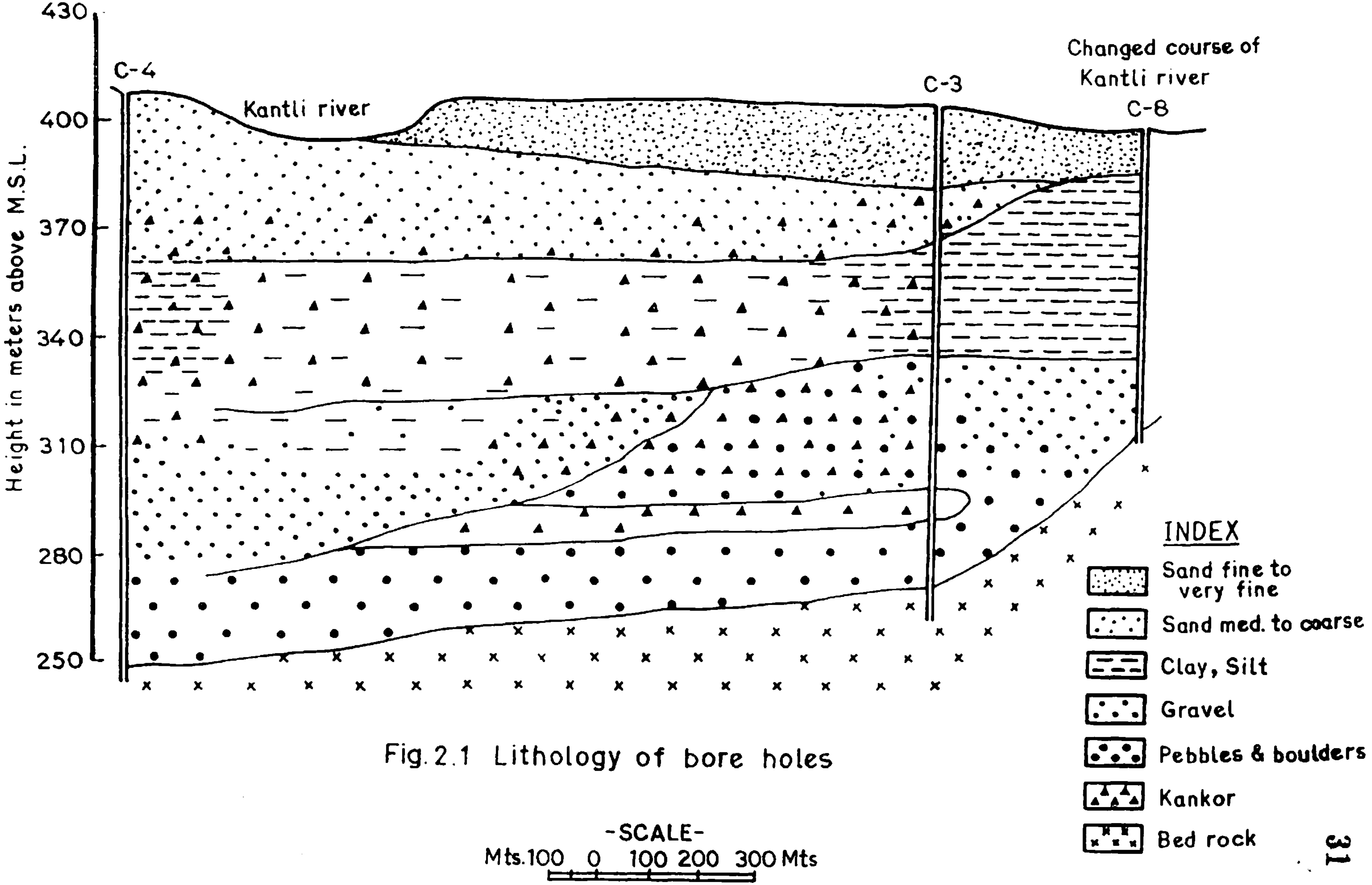


Fig. 2.1 Lithology of bore holes

2.5 COPPER MINES

There are four mines in the Khetri Complex the two major Khetri and Kolihan underground mines, the Chandmari open pit and the 100 t/d Dariba underground mine, with a matching concentrator, in the Alwar district of Rajasthan state some 220 km. away from Khetri. The ultimate capacities of the first three are designed to be 5,000; 3,000 and 1,000 t/d respectively.

In Khetri mine there are two distinct lodes namely the Madhan (or foot wall) lode and the Kudhan (or hanging wall) lode . The Madhan lode is fairly persistent, containing number of ore lenses. The Kudhan lode , on the other hand is narrower poorer in copper, and the lenses are less persistent. It is well formed in the central of the mine. At a Kolihan mine three distinct lode system have been identified:

Lode I (South lode)
Lode II (North lode)
Lode III (East or foot wall lode)

Of these lode I and III are persistent, but lode II is not persistent in depth.The felspathic quartz rocks which form the footwall are highly jointed but are neverthless, quite competent. The hanging wall consists of phyllites. At the Kolihan mine there is shear zone in the phyllites which poses some stability problems during stoping. There are number of transverse faults and shear planes, plus a number of longitudinal shear within the area of both under ground mines.

Chalcopyrite is the principal copper mineral in the ore. The mineralogical composition of the Khetri and Kolihan ore types, for which the concentrator was designed, are roughly as follows:

Mineral	Khetri (%)	Kolihan (%)
Chalcopyrite	3	11.7
Pyrite	1	0.1
Pyrrhotite	7	15.7
Magnetite	8	1.0
Silica	79	71.5
Others	2	-

The Kharkhar river flows in the valley immediately in the hanging of the mineralised rocks in the Khetri mine area. There is some make of water into the mine through tranverse faults having access to the river bed . To ensure stability the ore lenses near the hanging wall have not been worked in the upper levels of mine. At the Kolihan mine although the water table is only a little away below ground surface, no serious water problems have been encountered.

The initial exploration of the deposits was carried out from surface by diamond core drilling, and there is a continuous on going programme of core drilling from under ground to prove reserves: 1800 holes totalling 1,40,000 m. have yielded 6,280 intersections with ore.

2.5.1 Khetri and Kolihan Mines

The strike length of the deposits worked by the Khetri is about 3.6 km.,the workings being divided into North, Central and South blocks. The Kolihan workings are located on three lodes and extended over a total length of 600 m. The distance between the shafts system of the two mines is about 7.6 km. All levels in both mines are denoted by their heights relative to mean sea level.

The uppermost level of Khetri mine 421 m. is served by adits and has been worked by trackless equipments. The next level 350 km. is a tracked level served by inclines from surface. All workings below 350 m. belong to the "shafts mine ", access to which is through two vertical shafts sunk from surface to the 0.0 m. horizon .

Mine levels are at 60 m. intervals, on the 300 m., 240 m., 180 m., 120 m., 60 m., and 0.0 m., horizons. The Kolihan mine, similaraly, has an adit section (the 424 m. levels), a decline section, in which a 1 in 9 decline , 5.5

m. x 3.5 m. in cross section,serves the 364 m. and 306 m. levels, and the shafts section, for which access is via a shaft sunk from the 424 m. level.In this section ,development has been carried out on the 306 m. , 246 m. and 146 m. horizons .

2.6 SOIL CHARACTERISTICS

2.6.1 Type of soil

Soils are predominantly light textured, weak structured and well drained. The soil of the district Jhunjhunu is broadly classified as sand dunes and desertic soil in the northern part , alluvium in the southern part , red desertic soil in the south western part and lithosols & regosols of hills in the south eastern part near the hilly area. The soil found in the Khetri is sandy and sandy loam and is comparatively more fertile. The sandy loam soil, locally known as Dumat, is suited to irrigation and heavy cropping. All types of crops are grown in such soil.

At places, where the Kantli river has meandering course the river bed is composed of mostly medium to coarse sand with gravel and even boulders at depth. When ever the river maintains the linear course, the river bed is covered by silt to fine grained sand. The bed of river Dohan also comprises medium to coarse sand with gravels at depth.

Soil investigation of Jhunjhunu district has been carried out by author with a team of BITS Civil Engineering Staff (1989 -1992). Considerable number of soil testing (field and laboratary) for safe bearing capacity, soil profile, moisture content, dry density, void ratio and relative density of soil samples have been conducted, the sieve analysis results show that in those region the soil is mostly sandy silt and percentage of clay is negligible in most of cases. Colour of the soil is dark brown or camel brown colour. Existence of cohesive soil was found in isolated cases at deeper depths. However, the value of cohesion at foundation level in all cases were negligible. Average void ratio and relative density of the soil was found to be as follows:

void ratio (e) = 0.755
Relative density = 53.14 %
Dry density = 1.45 gm./cc

A chemical investigation of the soil on area of tailing dam at Khetri copper complex has also been carried out. The result of the investigation are given in table 2.6.1 .

Table 2.6.1
Chemical analysis of soil sample from Khetri copper complex

S.No.	Name of the test		Result
1.	Loss on ignition	%	4.11
2.	Silicon	%	46.91
3.	Iron Oxide ($Fe2O3$)	%	15.60
4.	Aluminate ($Al2 O3$)	%	5.93
5.	Lime (CaO)	%	18.40
6.	Magnisium Oxide (MgO)	%	3.10
7.	Copper (Cu)	%	0.02
8.	Sulphuric Anhydride	%	5.14

2.6.2 Water Bearing Properties of Sub Soil

2.6.2.1 Aquifer

Aquifers are the permeable formations having structure which permit appreciable quantity of water to move through them under ordinary field conditions. Thus these are the geologic formations in which ground water occurs. Unconsolidated sands and gravels are a typical example. synonyms frequently employed include ground water reservoir and water bearing formation.

2.6.2.2 Aquicludes

Aquicludes are the impermeable formation which contain water but are not capable of trasmitting or supplying a significant quantity. Clay, shale etc. are the typical example.

2.6.2.3 Aquifuge

Aquifuge is an impermeable formation which neither contains water nor transmits any water. Basalts, granites etc. are the typical examples.

2.6.2.4 Aquitard

A geologic formation of a rather impervious nature which transmits water at a slow rate compared to an aquifer but insufficient to individual wells. clay lenses interbedded with sand.

2.6.2.5 Transmissibility Coefficient

The coefficient of transmissibility (T) is the discharge through unit width of aquifer for the fully saturated depth , under a unit hydraulic gradient and is usually expressed as lpd/m. or sq.m /sec . It is the product of field permeability (K) and saturated thicknesss of the aquifer (b), it has dimension (L^2/T)

$$T = K \times b \qquad \ldots.(2.6.1)$$

The value of the coefficient of transmissibility determined by Geological Survey of India (GSI), ranges between 226 and 707 cu.m/d/m in the Jodhpura area and between 1212 to 3887 cu.m/d/m in the Chaonra area.

2.6.2.6 Coefficient of Permeability (K)

Permeability (K) is the ability of a formation to transmit water through its pores when subjected to a difference in head. It can be defined as the flow per unit cross - section area of the formation when subjected to a unit hydraulic head per unit length of flow i.e. per unit hydraulic gradient. It has the dimension of velocity i.e. (L/T).

The permeability depends upon the grain size distribution , porosity , shape and arrangement of pores ,properties of fluid and entrapped air or gas and can be expressed as

$$K = C D^2 \frac{Yw}{u} \frac{e^3}{(1+e)} \qquad \ldots.(2.6.2)$$

where ,

C = a constant
D = effective size of the formation material
e = void ratio
Yw = unit weight of the water at the flow temperature
u = viscosity of water at flow temperature

The intrinsic or specific permeability (k) of a water bearing medium is given by

$$k = CD^2 \qquad \ldots.(2.6.3)$$

where, the constant C summarises the geometrical properties ,hence the coefficient of permeability is written as

$$K = kYw/u \qquad \ldots.(2.6.4)$$

The permability at different temperatures varies

Table 2.6.2
Coefficient of Permeability of different Soils

Soil type	Coefficient of Permeability (k) (cm/sec.)
Clean Gravel	1.00 and greater
Clean Sand	1.00 -0.01
Sand (mix.)	0.01 -0.005
Fine Sand	0.005 -0.001
Silty Sand	0.002 - 0.0001
Silt	0.0005 - 0.00001
Clay	0.000001 and smaller

inversely as the respective kinetic viscosities. The coefficient of permeability of different types of soils has been given in table 2.6.2 . Laboratory permeability test of the soil stratum near Khetri copper complex has been done in Civil Engineering laboratory ,BITS Pilani (1991). The average coefficient of permeability in the area was found to be 7.442×10^{-3} m./sec.

2.6.2.7 Porosity

Porosity is defined as the ratio of the volume of void space to the bulk volume of the porous medium and can be expressed as

$$n = Vv / V \qquad \ldots.(2.6.5)$$

where,

n = Porosity,
Vv = Volume of voids,
V = Total volume.

Porosity may be also expressed as

$$n = \frac{Pm - Pd}{Pm}$$

where,

Pm = density of mineral particle,
Pd = Bulk density.

Porosity of different types of soils are given in table 2.6.3.

2.6.2.8 Storage Coefficent

Storage coefficient of an aquifer is the volume of water discharged from a unit prism i.e. a vertical column of aquifer standing on a unit area (1 sq.m) as water level (Piezometric level in confined aquifer -artesian condition) falls by a depth (1 m.). For unconfined aquifer (water table condition) the storage coefficient is the same as specific yield. The storage coefficient for confined aquifers ranges from 0.00005 to 0.005 and for water table aquifers 0.05 to 0.30.

Under artesian conditions when the piezometric surface is lowered by pumping, water is released from storage by the compression of the water bearing material (aquifer) and by expansion of the water itself. Thus the coefficient of storage is a function of the elasticity of water and the aquifer skeleton and is given by (Jacob, 1950) as

$$S = Yw \times b(alpha + n \times B) \quad ....(2.6.7)$$

where,

S = Coefficient of storage

n = Porosity of aquifer

Yw = Unit weight of water

b = Saturated thickness of aquifer

B = 1/Kw, Reciprocal of bulk modulus of elasticity of water

alpha = 1/ Es , Reciprocal of the bulk modulus of elasticity of aquifer skeleton

2.6.2.9 Specific Yeild

The capacity of a formation to contain water is measured by porosity.However, a high porosity does not indicate that an aquifer will yield a volume of water to a well. The only water which can be obtained from the aquifer is that which will flow by gravity.

The volume of water, expressed as a percentage of the total volume of the saturated aquifer that can be drained by gravity is called the specific yeild (Sy) and the volume of the water retained by molecular and surface tension forces, against the force of gravity , expressed as a percentage of the total volume of the saturated aquifer, is called specific retention (Sr) and corresponds to yield capacity.

Porosity = Specific yeild + Specific Retention

or

$$n = Sy + Sr \qquad ....(2.6.8)$$

Specific yield is the water removed from unit volume of aquifer by pumping or drainage and is expressed as percentage volume of aquifer. Specific yeild depends upon grain size, shape and distribution of pores and compaction of the formation. Characteristics of some common formation materials are given in the table 2.6.3 .

Table 2.6.3
Charateristics of some common formation materials

Formation	Porosity (%)	Specific Yield (%)	Permeability lpd/d3
Clay	45 -55	1 -10	0.05 -100
Sand	35 -40	10 -30	$5x10^{3}$ -$15x10^{4}$
Gravel	30 -40	15 -30	$5x10^{4}$ - $7.5x10^{5}$
Sand and grvel	20 -35	15 -25	10^{3} -$2.5x10^{5}$
Sand stone	10 -20	5 -15	5 - $2.5x10^{5}$
Shale	1 -10	0.5 -5	10^{-5} - 0.1
Lime Stone	1 - 10	0.5 -5	-

2.7 STATISTICAL ANALYSIS OF RAINFALL DATA

Jhunjhunu district of Rajasthan is located in the north-eastern part of the state and lies between the north latitudes 27°38' and 28°31' and east longitudes 75°02' and 76°06'. It covers an area of 5928 square Km . It receives an average annual rainfall of 448.97 mm. The district has a dry climate with a hot summer, a cold winter and a short monsoon season. The cold season starts by about the middle of the November and continues till about the beginning of the March. The hot season follows there after and extends up to end of the June. The south west monsoon season is from July to mid September. The period from mid September to mid November constitutes the post monsoon season. It is specially a dry land area, where the crops mainly depend upon the rainfall. The conservation of soil moisture is very important for proper germination of seeds and plant development. This is particularly more important in rainfed agriculture, as that at Jhunjhunu district , where small deficiency in soil moisture leads to either significant decrease in yield or even complete crop failure.

Ashmore, (1944) had made a study of rainfall data of the Wrexham district in Pentrebychan. He concluded that the area received 30% of annual rainfall in six of the driest months, 40% of the annual rainfall in three of the wettest months and 50% of the annual rainfall in four of the wettest months.

Mishra , (1991) had made a study of rainfall contributed by six wettest months at Kharagpur from the 26 years record and developed relationships between different statistical parameters. The conclusion drawn were:

(i) On an average, the driest six months give about 7 %, the wettest two months 51 % and wettest five months 87 % of annual rainfall. The relationship between percentage of annual rainfall(P_k) and wettest months (m_j) was found to be

$$P_k = (1557\ mj - 404.78)^{1/2}$$

(ii) Relationship between C_v, the coefficient of variation and m_j, number of the wettest months was found to be

$$C_v = 10^{(1.45 - 0.132\ mj)}$$ and,

(iii) The relationship between C_v, coefficient of variation and P_k, the percentage of annual rainfall was found to be

$$C_v = 28.55 - 0.26\ P_k$$

The relationships between statistical parameters for rainfall of six of the driest months at Kharagpur were also developed.

The design of hydraulic structures depend upon the distribution of rainfall in time space and its total span during the whole period. When major annual rainfall is concentrated only in few months, large attention is required on its proper utilization, otherwise, the crop failure is certain in dry land agriculture.

2.7.1 Materials and Methods

The rainfall data for Jhunjhunu district, for 10 years, from 1982 to 1991, have been analysed. The daily rainfall data have been lumped to form time series (table 2.7.1). The three statistical parameters are :

1. $\overline{X}$, the mean of the data, given by

$$\overline{X} = \frac{1}{N} \Sigma X_i \qquad ,i = 1,2,.....N \qquad .... (2.7.1)$$

where , N is the total Number of observations, and X_i is the values of the variable for i = 1,2,3.....N.

2. S, the unbiased estimate of population standard deviation from sample, given by

$$S = (\frac{1}{N-1} \Sigma (X_i - \overline{X})^2)^{1/2} \qquad .... (2.7.2)$$

3. and C_v, the coefficient of variation, given by

$$C_v = \frac{S}{\overline{X}} \times 100 \qquad .... (2.7.3)$$

The following stepwise procedure was adopted for the analysis of data for six of the wettest months:

(i) Determining the wettest six months, in decreasing order of magnitude, in each year from the record of rainfall for the 10 years period,

(ii) Ascertaining the rainfall for each month, as in (i) above, as a percentage of the total rainfall for the corresponding years,

(iii)Grouping data from (ii) above into six groups for all 10 years, each group having 10 constitutents. The first group will have the rainfall for the first wettest month, the second group the rainfall for the first and the second wettest month and so on, such that the sixth group consists the percentage of annual rainfall contributed by all six wettest months,

(iv) Determining $\bar{X}$, S and C_v for each group.

(v) Examining if any relationship exists between P_k, the cumulative percentages of annual rainfall and the wettest months, as in (ii) above, defined as follows:

$$P_k = \sum_{j=1}^{k} \sum_{i=1}^{10} \frac{X_{ij}}{10}, \quad k = 1,2,3,....6 \qquad ....(2.7.4)$$

where , X_{ij} is the percentage monthly rainfall for the first j of the wettest month(s) of the ith year, m_j, is the number j(j = 1,2,3,....6) of the wettest months (m_j = 1,2,3,...6) and C_v, the coefficient of variation.

(vi) <u>Methods of Simple Averages</u>

This is the simplest and most accurate method of obtaining a seasonal index. The following steps are used for calculating the seasonal index.

(a) Arrange the unadjusted data by years and months (or quarters if quarterly data are given)

(b) Find the total of the rainfall of each months of different years considered

(c) Divide each total by the number of years for which data are given.

(d) Obtain an average of monthly averages by dividing the total of monthly averages by 12.

(e) Taking the average of monthly averages as 100, compute the percentages of various monthly averages as follows:

Seasonal index for January =

$$\frac{\text{Monthly average for January}}{\text{Average of monthly averages}} \times 100$$

If, instead of the average of each month, the total of each month are obtained, we will get the same result. Using above method the seasonal variation index is given in table 2.7.2 .

2.7.2 Discussion of the Result

Following the procedure explained earlier for the analysis of data, it was found that the wettest month of the year provides on an average, 33.39 % of annual rainfall, the wettest first two months of the wettest months 57.26 %, the first three months of the wettest months 74.13 %, first four months of the wettest months 85.58 %, first five months of the wettest months 91.20 % , and first six months of the wettest months 99.60 % of annual rainfall (fig. 2.2).

The relationship between, P_k, the cumulative percentage of annual rainfall, and m_j, the number $j (j = 1,2,3...6)$ of the wettest months, is found to be

$$\frac{1}{P_k} = 0.006 + \frac{0.024}{m_j}$$

or

$$P_k = \frac{m_j}{0.006\, m_j + 0.024} \qquad \text{....(2.7.5)}$$

This is the characteristic of the dry region. It is mainly due to high concentration of rainfall in few months only, while six of the driest months contribute, on an average, only 5.34 % of the annual rainfall.

The coefficient of variation decreases with an increase in the number of the wettest months. Thus, it is 1.98 % for six of wettest months, 2.48 % for five of wettest months, 3.07 % for four wettest months, 3.59 % for three of wettest months, 4.37 % for two of wettest months and 7.27 % for one of wettest months (fig. 2.3), yielding a relationship between C_v, the coefficient of variation, and m_j, number of wettest months as

$$C_v = 10^{(0.94-0.11m_j)} \qquad ....(2.7.6)$$

The coefficient of variation decreases as the cumulative percentage of annual rainfall during the wettest months increases. Thus, when the cumulative percentage of the average annual rainfall is 33.29, the coefficient of variation is 7.27 % and with 99.66 % of annual rainfall, the coefficient of variation is only 1.98 % (fig. 2.4) .

The relationship between C_v, coefficient of variation and P_k, the percentage of annual rainfall is given by

$$C_v = 10.33 - 0.9 P_k \qquad ....(2.7.7)$$

The results are in full agreement with Mishra (1991). Finally table 2.7.2, which shows the seasonal variation index, represents that there is more seasonal variation in wettest months of the year compared to driest months of the year.

TABLE 2.7.1
MONTHLY RAINFALL DATA(MM) AT PILANI FROM 1982 TO 1991

YEAR	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY
1982	4.2	11.1	9.7	19.2	88.4	56.9	48.3
1983	5.9	2.2	2.3	99.6	69.9	58.2	150
1984	0.0	5.0	0.0	2.5	0.3	50.8	84.5
1985	9.2	0.0	9.1	16.1	6.7	131.5	113.9
1986	2.4	28.6	19.3	2.9	50.6	35.3	130.8
1987	37.7	9.2	10.0	1.9	53.4	9.5	80.9
1988	0.6	3.4	37.8	2.2	10.4	148.4	120.8
1989	10.6	1.3	39.5	1.1	0.0	0.0	82.0
1990	22.6	79.4	0.7	9.2	11.8	46.8	148.1
1991	0.0	19.6	1.0	20.2	23.0	32.2	147.3

TABLE 2.7.1 (Continued)

YEAR	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
1982	189.4	5.1	20.4	29.1	5.2
1983	147.8	28.5	9.8	0.0	0.0
1984	74.4	91.3	0.8	0.0	0.0
1985	152.2	8.8	9.6	0.0	12.6
1986	99.9	6.4	2.4	0.0	0.0
1987	101.5	0.4	0.4	0.0	4.0
1988	159.6	108.0	0. 0	0.0	0.4
1989	39.4	57.6	0.2	1.0	1.8
1990	64.5	40.4	57.0	8.2	3.6
1991	296.0	30.2	0.0	2.3	4.6.

TABLE 2.7.2
ANALYSIS FOR SEASONAL VARIATIONS BY MONTHLY AVERAGE METHOD

	MONTHLY RAINFALL IN DIFFERENT YEARS												
MONTHS	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	Monthly Total for 10 years	Ten Yr. Average	Seasonal Variation index
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Jan.	4.2	5.9	0.0	9.2	2.4	37.7	0.6	10.6	22.6	0.0	89.0	8.9	25.60
Feb.	11.1	2.2	5.0	0.0	28.6	9.2	3.4	1.3	79.4	19.6	148.7	14.87	42.77
March	9.7	2.3	0.0	9.1	19.3	10.0	37.8	39.5	0.7	1.0	119.7	11.97	34.43
April	19.2	99.6	2.5	16.1	2.9	1.9	2.2	1.1	9.2	20.2	155.7	15.57	49.78
May	88.4	69.9	0.3	6.7	50.6	53.4	10.4	0.0	11.8	23.0	314.5	31.45	90.45
June	56.9	58.2	50.8	131.5	35.3	9.5	148.4	0.0	46.8	32.2	569.6	56.90	163.82
July	48.3	150	84.5	113.9	130.8	80.9	120.8	82.0	148.1	147.3	975.8	97.58	280.64
Aug	189.4	147.8	74.4	152.2	99.9	101.1	159.6	39.4	64.5	296.0	1324.3	132.43	380.87
Sept	5.1	28.5	91.3	8.8	6.4	0.4	108.0	57.6	40.4	30.2	346.50	34.43	99.65
Oct	20.4	9.8	0.8	9.6	2.4	0.4	0.0	0.2	57.0	0.0	100.6	10.06	28.93
Nov	29.1	0.0	0.0	0.0	0.0	0.0	1.0	8.2	8.2	2.3	38.2	3.82	10.99
Dec	5.2	0. 0	0.0	12.6	0.0	4.0	0.4	1.8	3.6	4.6	27.6	2.76	7.93
											4210.2	417.2	1210.56
											350.85	34.77	100.88

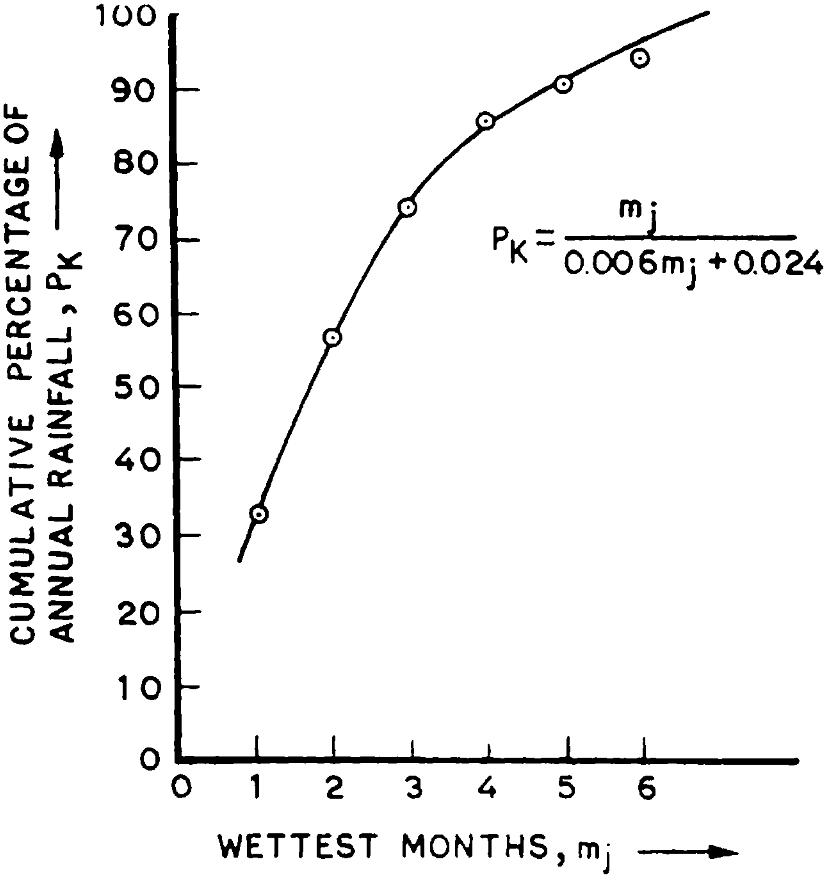


Fig.2.2 Relationship between P_K, the cumulative percentage of annual rainfall and m_j, the wettest months at Pilani.

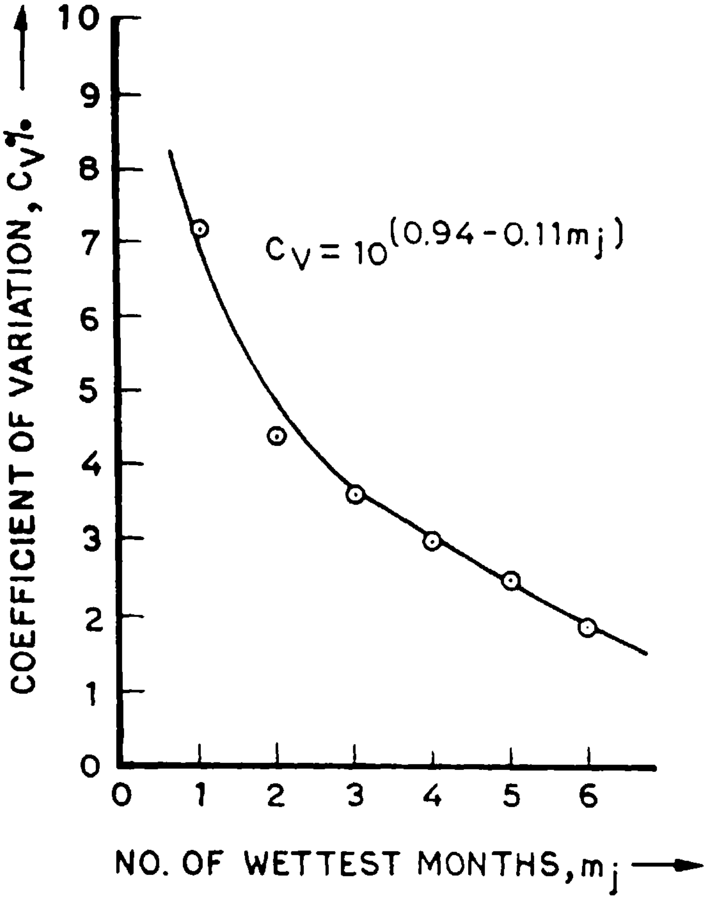


Fig.2.3 Relationship between C_V coefficient of Variation and m_j number of wettest months at Pilani.

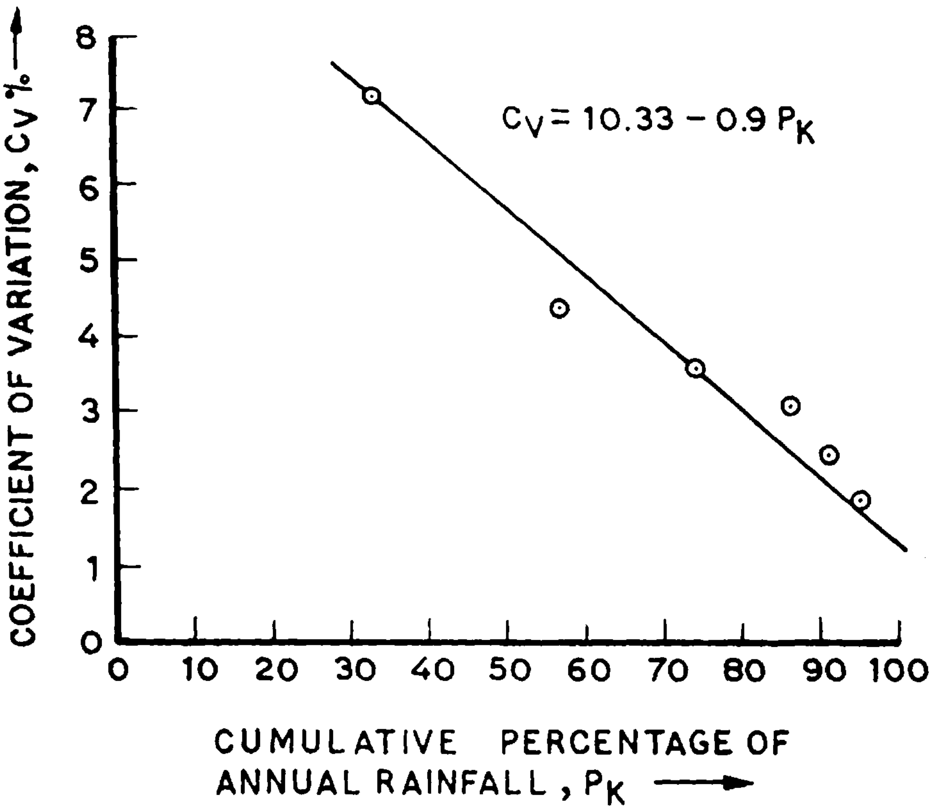


Fig.2.4 Relationship between C_V coefficient of variation and P_K the cumulative percentage of annual rainfall at Pilani for 10 years from 1982 to 1991.

2.8 GROUND WATER CONDITIONS IN KHETRI AREA

2.8.1 Source of Ground Water

The main source of ground water in the Khetri area is from precipitation which aggregates to about 53 cm. per annum. A part of the rainfall which falls on the region is returned to the atmosphere by direct evaporation, from the soil surface and the transpiration, a part flows directly to the stream and is carried away as runoff, and a part infiltrates into the soil and rocks till the zone of saturation is reached.

2.8.2 Occurance of Ground Water

In most of the Khetri area the ground water occurs under water table condition, except in parts of the alluvium where it possibly exists under very slight pressure conditions. The zone of saturation spreads through the rocks of the Delhi system, the Post-Delhi granites the expediorites, the recent alluvium and the dune sands. In the consolidated rocks the ground water circulation takes place mainly in the upper weathered mantle and the planes of structural weakness, such as joints, cleavages, faults, fissures etc. In the unconsolidated rocks movement of ground water takes place through the pore spaces between the grains.

Although in the entire area the ground water occurs in the unconsolidated rocks, in alluvium it occurs only in two places of significance.They are

(1) In the Kharkhar valley, in the area east of Shampura and extending northwards near about Kharkhar, and

(2) Parallel to the Singhana river in an elongated strip of area, about 0.8km. in width and about 8 km. in length commencing about 4 km. south ward of Manuta and extending up to Singhana, and probably beyond. Similar condition exsists also in small strips along the Kharkhar nala between Banwas and Singhana and in the vicinity of stream bed near Gaji Kalan.

2.8.3 Depth of Water Table

The depth to water table varies widely depending upon topography, drainage system, geology and depth of bed rock , etc. In order to study the behaviour of water table by way of periodical observation of water established by ground water wing of the Geological Survey of India (GSI) . The depth of water table ranges widely from near about 5 m. to over 50 m. below ground level. Water table is comparatively shallow in the southern and south eastern part, particularly in the vicinity of Kantli river, Singhana river and Budhi nala, where as it is deeper in the desertic plain which forms the major part of the Khetri area. The lowest value 6.05 m. has been observed at Khetri (Nov., 90) and highest 56.20m. at Baswant Kalan (Nov., 90). In general depth of water table varies between 10 to 50 m. below ground level.

2.8.4 Slope of the Water Table

The water table slopes broadly in the drainage direction. In the vicinity of Khetri and in the Kharkhar valley the water table has a slope of about 10 to 20 m./km. From about 3km. north of Khetri, the slope of the water table decreases to about 2 to 6 m./km. upto Singhana. In the rocks of the Delhi system and in the dune sands the slope of the water table is steeper, whereas in the weathered granites and in the highly permeable materials comprising the alluvium the slope is gentler.

2.8.5 Recharge of Ground Water

The ultimate source of recharge of ground water is precipitation. Part of the rainfall that falls on the land surface reaches the zone of saturation by downward percolation and a part by infiltration from ephemeral streams . The amount of water that reaches to the ground water depends on the nature of the rocks, slope of land surface, duration of flow of stream, intensity of rainfall and evaporation. In rocks of similar water bearing properties with ground water occuring in them under water table conditions, a measure of the ground water recharge is the height of the pheratic rise. In this area, most of the ground water recharge occurs during the monsoon period.

2.9 CONCLUSION

In this chapter geology and the water bearing properties of the soil in Khetri area have been discused. The rocks which are found in Khetri area belong to the Delhi super group of precambrian age. The principal river in the Khetri area is the Singhana river in which effluent from Khetri Copper Project (KCP), is discharged through the Kharkhar nala. Soils in the Khetri area are predominantly light textured, weak structured and well drained. The soils of the Jhunjhunu district are mainly classified as sand dunes and desertic soil,alluvium and lithosol soils. Soil found in Khetri area is sandy and sandy loam.

Statistical analysis of rainfall data of Jhunjhunu district has been done to study the rainfall pattern at Jhunjhunu district. Rainfall pattern at Jhunjhunu expresses the concentration of total annual rainfall in four months from June to September only , while remaining eight months represents dry period. Thus a high level of management is required to utilize the soil moisture. It will therefore, be very important to design runoff storage tanks in such areas, such that the water can be properly utilized in the deficit period without causing significant reduction in crop yields.

CHAPTER : 3

QUALITY OF GROUND WATER IN JHUNJHUNU DISTRICT, RAJASTHAN

3.1 INTRODUCTION

Ground water forms a major source of drinking water supply for urban and rural people of India. It is now generally recognised that the quality of ground water is just as important as its quantity. Since quality of public health depends to a great extent on the quality of drinking water. It is imperative that in depth information about the quality of drinnking water should be systematically collected and monitored. The chemical composition of ground water is related to the soluble products of rock weathering , decomposition and changes with respect to time and space. Geochemical studies provide a complete knowledge of the water resources of a hydrological regime and a better undenstanding of possible changes in quality as development progresses.

Biswas and Saha, (1982) has reviewed the available data on salinity, fluoride contents and also a few heavy metals in ground waters. The ground water in parts of the country (particularly in the arid, semi arid areas) contains relatively high dosage of toxic metals and/or fluorides, yet these are being consumed by people without any treatment. Though practically no scientific data exsists on the bacterial contamination of the ground water there are reasons to believe that such contamination is taking place, especially in and around the big cities.

Pandey and Hasan, (1983) has conducted a survey to study trace metals level in ground water. Arsenic , Cadmium, Copper, Lead, Maganese, Mercury and Zinc were determined in well water. Results revealed that mercury was almost absent in the well water and cadmium was present in traces in some water samples. Other trace metals except maganese were present far below their permissible limits. Hardness was found to be inversely related to the concentrations of cadmium and lead. As limit of 0.05 mg/l for maganese is fixed due to aesthetic reasons, rather than health point of view. The ground water surveyed, appears not to constitute any significant pollution.

Berbi, et al., (1991) had studied the quality of ground water of Sangrur block, Sangrur district, Punjab. Ground water samples from 305 working tubewells in 65 villages were analysed for their chemical composition and to assess for their suitability for irrigation purposes. Based on electrical conductivity (EC) and residual sodium carbonate (RSC) the samples were grouped into different categories for preparing water quality map of the district.

Thergaonkar and Kulkarni, (1971) studied the relationship between alkalinity and fluoride, chloride and sulphate by analysing 45 random samples of ground water. They found large and positive correlation coefficients (r = 0.86) between the above mentioned parameters. Other early studies to discover correlations among water quality parameters include those done by Handa, (1975); Bhargava, et al., (1978); Gupta, (1981); Brar, et al., (1984); Tiwari, et al., (1986); and Ali & Tiwari, (1989). Bhargava, et al.,(1978) confirmed the ratio of total alkalinity and total hardness was greater than 1.0 in most of the cases, if the fluoride concentration was greater than 1.0 mg/l. These results were supported later by Gupta ,(1981), when he analysed the ground water of Udaipur district. Brar, et al., (1984) carried similar experiments to study the quality parameters of ground water of Bhawanigarh block of Sangrur district (Punjab) . Tiwari, et al., (1986) studied the correlations among the physico chemical factors of ground water of 50 wells located in and around Meerut city in Uttar Pradesh. Tiwari, et al., (1986) and his associates have obtained a linear relationship between chemical oxygen demand (COD) and biochemical oxygen demand (BOD) for river Ganga at Kanpur. Tiwari and Ali ,(1989) found out the regression and cluster analysis of water quality parameters of ground water at Nuzvid town (Krishna dt.) of Andhra Pradesh.

In the present work , study of quality of ground water of Jhunjhunu district (of which Khetri is a part) for its suitability for drinking and irrigation purposes has been carried out.These investigations have also been extended to make a systematic study of correlations among 14 water quality parameters by considering 35 locations of Jhunjhunu district of Rajasthan. The sample sites have been shown in the fig 3.1 .

3.2 WATER QUALITY CRITERIA

In water resource evaluation the quality of ground water is of nearly equal importance to quantity.The chemical, physical and bacterial characteristics of ground water determine its usefulness for municipal, commericial, industrial, agricultural and domestic water supplies. The study of ground water quality involves a description of the occurance of the various consituents and the relation of these constituents in ground water .In addition, ground water quality data give importants clues to the geologic history of rocks and indication of ground water recharge, discharge, movement and strorage. Transfer of water quality informations among individuals and groups require the use of standardised techniques and terminology to assure accurate understanding by all concerned. Without a common "Language", effective communication in planning and implementing quality control programmes will not be possible.

Therefore it is necessary to establish comprehensive and complex system of measurements and to standardise them as much as possible, consistent with maintaining both desirable accuracy and a reasonable work effort. The approach is based on using quantitative and reproducible parameters that are as discriptive and ambigious as possible. It increases the accuracy and ease of measuring water quality parameters and conveying that informations to others.

3.2.1 Systems for Measuring Water Quality

Water quality is dynamic , subject to major changes with or without human intervention. Also, many different parameters are used to describe and specify quality characteristics. Therefore, decisions on which parameters should be measured, how to collect samples, when to collect samples, how to preserve them, untill they can be analysed, and how to select appropriate analytical methods involve an extra ordinary matrix of variables. Analytical measurements of a water quality may be divided into following five groups.

1. Analysis based on measuring concentration of specific constituents of water, in which they are reported directly and quantitatively.

2. Analysis based on direct and quantitative measurements of quality characteristics. The parameters may be expressed on predetermined arbitrary scales, which actually may not related to concentrations of any specific constituents.

3. Measurement of specific constituents or quality characteristics that are different from those of principal interest but are associated with them.

4. Measurement of the effects of constitutents as contrasted with their concentrations in water.

5. Description or specification of water characteristics in qualitative terms.

Analytical techniques used in water supply and waste water disposal are based largely on standardised procedures, the most common one being published in standard methods for the examination of water and waste water (water pollution control fedration, 1980). It is usually important that those who produce and use data on water quality characteristics understands the advantages and limitations of "Standard Methods" and be prepared to adopt other techniques when necessary to insure accurate results. A helpful book for understanding and interpreting standard analytical procedures, and the results obtained using them, is the one by Sawyer and Mc Carty, (1978). Another important reference is published by the U.S. Environmental Protection Agency,

(1979) that one presents recommended or connection with waste water discharge permits or for other purposes of concern to that agency. Other organisations concerned with water quality also publish collections of different standard methods for use by their personnel or others having similar interests and needs.

3.3 STANDARDS FOR WATER

Standards are the means by which regulatory agencies define their requirements for water courses and for each individual . The development of standards include careful attention to programme objectives and quality criteria for the designated use, but they also consider several additional facets of the matter, including economic aspects, public need and desires, political reaction and practical attainability. A factor that should be recognised as important in setting standards is what Phelps, (1949) referred to as the "principle of expediency", that is the level at which a standard is set often depends heavily on what is attainable in the real world, technically and at a cost viewed as reasonable.The water quality should satisfy the requirements or standards set for the specific use, namely domestic, live stock, agricultural and industrial purposes.

3.3.1 Drinking Water Standards

Degree of purity required for drinking purpose is highest in relation to other uses of water. Water for this purpose should be free from suspended impurities, dissolved harmful salts, and disease producing bacteria. Water should not be very hard but some hardness is tolerable. The drinking water standards laid down by U.S. Public Health Services ,World Health Organisation (WHO) and Government of India, Ministry of works and housing are given in table 3.3.1, table 3.3.2 and table 3.3.3, respectively.

In Jhunjhunu district the cases of fluorisis and methemoglobenemia are not reproted. But the problems of coloured teeth and molten teeth were reported from some places, hence considering the local factors as done by the Public Health Engineering Department, Jhunjhunu, the standards for fluorides, nitrate and total disolved solids (TDS) are raised safely as shown in table 3.3.4 .

3.3.2 Irrigation Water Standards

Generally, the standards for irrigation water are laid down in terms of the following:

(i) Total Salt Contents in ppm,

(ii) Sulphate Contents in ppm,

(iii) Chloride Content in ppm,

(iv) Percentage of Sodium, which equals $\frac{100\ Na}{Ca + Mg + K + Na}$

(v) Boron Content in ppm and

(vi) Electrical Conductivity in micro - mhos ($EC \times 10^{-6}$)

On the basis of the limits of above constituents, water is divided in three classes which are given in table 3.3.5. The criteria for classification of irrigation water as recommended by the U.S. Salinity Laboratary of Department of Agriculture, are based on electrical conductivity (or total soluble solids) and S.A.R. value, limits of which have been indicated in table 3.3.6 and table 3.3.7,respectively (Sharma,1988) . S.A.R. value reported in the table 3.3.7 is expressed as follows:

$$S.A.R. = \frac{Na^{+}}{\sqrt{(Ca^{++} + Mg^{++})/2}}$$

where, the concentrations of the constituents are expressed in miligram per litre.

3.3.3 Industrial Water Standards

For industrial purpose the water should be chemically pure. Various manufacturing unit require absolute pure water because even slight amount of impurity may considerably influence the final product. The nature of water required by different industries may be so varying that normally industries install their own water supply plants, suiting to their standards. Recommended quality standards for various industries as compiled from numerous sources are given in table 3.3.8 (Raghunath,1987).

Table 3.3.1
U.S. Public health Services drinking water standards,1971

S.No.	Characteristics	Acceptable	Cause for rejection
1.	Turbidity (on J.T.U. scale)	2.5	10
2.	Temperature	10xC to 15.6x	
3.	Taste	unobjectionable	Unobjectionable
4.	Odour	unobjectionable	unobjectionable
5.	Colour (on platinum cobalt scale)	5.0	25.0
6.	pH value	7.0-8.5	6.5-9.2
7.	Total dissolved solids	500	1500
8.	Total hardness (as CaCO3) in mg\l)	200	600
9.	Chlorides (mg\l)	200	1000
10.	Sulphates (mg\l)	200	400
11.	Flourides (mg\l)	1.0	1.5
12.	Nitrate (mg\l)	45	45
13.	Calcium (mg\l)	75	200
14.	Magnesium (mg\l)	30	150
15.	Iron (mg\l)	0.1	1.0
16.	Manganese (mg\l)	0.05	0.5
17.	Copper (mg\l)	0.05	1.5
18.	Zinc (mg\l)	5.0	15.0
19.	Phenoric compounds (mg\l)	0.001	0.002
20.	Anionic detergents (mg\l)	0.2	1.0
21.	Mineral oil (mg\l)	Nil	Nil
22.	Cadmium (mg\l)	0.01	0.01
23.	Chromium (mg\l)	0.05	0.05
24.	Cyanide (mg\l)	0.05	0.05
25.	Lead (mg\l)	0.1	0.1
26.	Selenium	0.01	0.01
27.	Mercury	0.001	0.001
28.	gross alpha activity	3 pci/l	3 pci/l
30.	Gross beta activity	30 pci/l	30 pci/l

Table 3.3.2

World Health organisation water standards - International Standards (1963)

Characteristic	[8]Limit of general acceptability mg/l	Allowable limit (mg/l)
Total solids	500	1500
Colour(xH)	5	50
Tubidity	5	25
Chloride	200	600
Iron	0.3	1
Manganese	0.1	0.5
Copper	1.0	1.5
Zinc	5	15
Calcium	75	200
Magnesium	50	150
Magnesium and sodium sulphare	500	1000
Nitrate (as No3)	45	-
Phenols	0.001	0.002
Synthetic detergents(ABS)	0.5	1.0
Carbon - chloroform extract	0.2	0.5
pH	7-8	min. 0.5 max. 9.2

Table 3.3.3

Government of India, Ministry of works and housing drinking water standards (1975)

S.No.	Characteristics	Acceptable	Cause of rejection
1.	Turbindity (J.T.U.scale)	2.5	10.0
2.	Color (Hazen Unit)	5.0	25.0
3.	Taste and odour	Nothing disagreeable	
4.	pH	7.0 -8.5	8.5-9.2
5.	Total disolved solids mg/l	500	1500
6.	Total hardness mg/l	200	600
7.	Chloride as CL mg/l	200	1000
8.	Sulphate as SO4 mg/l	200	400
9.	Flouride as F mg/l	1.0	1.5
10.	Nitrate as NO_3 mg/l	45	45
11.	Calcium as Ca mg/l	75	200
12.	Magnesium as Mg mg/l	30	150
13.	Iron as Fe mg/l	0.1	1.0
14.	Manganese as Mn mg/l	0.05	0.5
15.	Copper as Cu mg/l	0.05	1.5
16.	Zinc as Zn mg/l	5	15
17.	Phenolic compounds mg/l as phenol	0.001	0.002
18.	Mineral oil mg/l	0.01	0.30
19.	Arsenic as As mg/l	0.05	0.05
20.	Cadmium as cd mg/l	0.01	0.01
21.	Chromium as Cr mg/l	0.05	0.05
22.	Cyanides as CN mg/l	0.05	0.05
23.	Lead as Pb mg/l	0.01	0.1
24.	Selenium as Se mg/l	0.01	0.01
25.	Mercury as Hg mg/l	0.001	0.001

Table 3.3.4
Standards for drinking water given by P.H.E.D. Jhunjhunu (1981)

S.No.	Characteristics	Acceptable Limits
1.	Turblndity (J.T.U.scale)	10.0
2.	Color (Hazen Unit)	28.0
3.	Taste and odour	-
4.	pH	8.5-9.2
5.	Total disolved solids mg/l)	3000
6.	Total hardness mg/l	600
7.	Chloride as Cl mg/l	1000
8.	Sulphate as SO4 mg/l	400
9.	Fluoride as F mg/l	3.0
10.	Nitrate as NO_3 mg/l	100
11.	Calcium as Ca mg/l	200
12.	Magnesium as Mg mg/l	150
13.	Iron as Fe mg/l	1.0
14.	Manganese as Mn mg/l	0.5
15.	Copper as Cu mg/l	1.5
16.	Zinc as Zn mg/l	15.0
17.	Phenolic compounds mg/l as phenol	NT
18.	Mineral oil mg/l	NT
19.	Arsenic as Rs mg/l	NT
20.	Cadmium as cd mg/l	NT
21.	Chromium as Cr mg/l	NT
22.	Cyanides as CN mg/l	NT
23.	Lead as Pb mg/l	0.01
24.	Selerium as Se mg/l	0.01
25.	Mercury as Hg mg/l	0.01

Table 3.3.5
Standards for irrigation water

Class of water	Total salts in ppm	sulphates in ppm	Chlorides in ppm	Sodium percentage	Boron in ppm
First	0 - 700	0-192	0-142	0-60	0-0.5
Second	700-2000	192-480	142-355	60-75	0.5-2
Third	over 2000	over 480	over 355	over 75	over 2

Table 3.3.5 (Continued)

Class of water	Electrical conductivity	Suitability for irrigation
First	0-750	Exellent to good for irrigation
Second	750-2250	Good to injurious. Suitable only for permeable soils and moderate leaching. Harmful to more sensitive crops
Third	over 2250	Unfit for irrigation

Table 3.3.6

Water quality criteria for irrgation purposes

S.No.	Water calss	Electrical conductivity (Micro mhos
1.	Excellent	Less than 250
2.	Good	250 - 750
3.	Permissible	750 - 2000
4.	Doubtful	2000-3000
5.	Unsvitabe	more than 3000

Table 3.3.7

Water quality criteria for irrigation purposes

S.No.	Water class	S.A.R. Value
1.	Excellent	Less than 10
2.	Good	10-18
3.	Fair	18-26
4.	Poor	more than 26.

Table 3.3.8
Quality of water for industrial uses - allowable limits in ppm.

Industry or use	Colour (Standard Cobalt scale)	Iron as Fe	Mang nese as Mn	Total solids	Hardnes as CaCO3	Alkalinity as CaCO3	Hydro gen Sulphide	pH	Other requirements
Air conditioning		0.5	0.5				1.0		Cool, non-corrosive
Baking	10	0.2	0.2				0.2		Moderately hard (calcium sulphate) water desirable
Boiler Feed									
Pressure 0-10 kg/cm^2	80			3000-500	80		5	8.0	
Pressure10-17 kg/cm^2	40			2500-500	40	Low	3	8.4	Low dissolved oxygen and silica, non-corrosive
Pressure17-27 kg/cm^2	5			1500-100	10		0	9.0	
Pressure >27 kg/cm^2	2			50	2		0	9.6	
Brewing & distilling		0.1	0.1	500-1000		75-150	0.2	6-7	NaCl 275
Canning		0.2	0.2		25-75 for peas & other legumes		1.0		Pure water(potable)
Carbonated beverages	10	0.2	0.2	850	250	50-100	0.2		Pure water(potable)
Confectionery		0.2	0.2	100			0.2	7.0	Requirements differ for different candies
Cooling		0.5	0.5		50		5		Cooling, non-corrosive
Cotton bandages		0.2	0.2						
Food(general)		0.2	0.2						Pure water(potable)
Ice	5	0.2	0.2	1300					SiO$_2$ 10 (potable water)
Laundering		0.2	0.2		50				
Plastics (clear)	2	0.02	0.02	200					
Paper and Pulp									
Ground Wood	20	1.0	0.5		180				No grit or corrosiveness
Kraft pulp	15	0.2	0.1	300	100				
Soda & sulphite pulp	10	0.1	0.05	200	100				
High-grade light papers	5	0.1	0.05	200	50				No slime formation
Rayon (viscose)									
Pulp production	5	0.05	0.03	100	8	50			OH 8, Al$_2$O$_3$ 8, SiO$_2$ 25, Cu 5
Starch manufacture		0.0	0.0		55			7.8-8.3	
Tanning	10-100	0.2	0.2		50-135	135			OH 8
Textiles	20	0.25	0.25	200					Constant composition; Al$_2$O$_3$ 0.5

3.4 MATERIALS AND METHODS OF ANALYSIS

Ground water samples were collected from different parts of the Jhunjhunu district from tubewells and open wells in 500 ml plastic bottles for analysis. The density of samples taken from Khetri Copper Complex is more as there were the doubts of contamination of ground water from Khetri Copper Project effluent discharge. For various physical and chemical parameters, the sample were analysed. The various parameters of water were analysed as per given in Standard Methods, (1980) . The physical and chemical parameters which were analysed are pH, specific conductance, carbonates, bi-carbonates, chlorides, sulphates, nitrates, phosphates, hardness, calcium, magnesium, sodium, potassium, fluoride, iron, silica and total dissolved solids. All these parameters were analysed in public health engineering laboratory to verify the data given by various agencies like Central Ground Water Board, Jaipur, Rajasthan Pollution Control Board, Jaipur and Public Health Engineering Department Jhunjhunu.

3.5 ANALYSIS OF DATA FOR WATER QUALITY

The characteristics of ground water samples collected from different parts of Jhunjhunu district have been shown in table 3.5.1 (see fig 3.1).

3.5.1 Analysis of Data for Drinking Purposes

To analyse the data for drinking purpose, the limits of various constituents of ground water found in the samples is to be compared with the standards for the potable water given by various organisations. Here, we find that except nitrate (NO_3), Fluoride (F) and total dissolved solids (TDS) all other characteristics of water in all the 35 samples are within the permissible limits. Excessive nitrate i.e. more than 100 ppm was found in 15 samples out of 35 samples (i.e. in Badgaon, Basai, Bhagwant Kalan, Bissau, Bohana, Galdhana Khurd, Malsisar, Mauro, Mandesi Mundrella, Manuta, Posana, Pilani, Sahar and Sonasar). Thus we can say that the risk of methemoglobinemia due to excessive nitrate present in the ground water (which is the ground water pollution) is present in about 42% area of the district. The presence of excessive fluoride that is more than 3.0 ppm , was found in 7 samples namely Alsisar, Bodha, Birmi, Pachari, Dighal, Malsisar and Mundawar. This represents about 20% of the total area of the district. Normally the fluroide problem exists in the northern part of the district as five samples out of seven falls in this area as shown in fig. 3.1.

TDS more than 3000 ppm was found in 3 samples, most of them falls in the N-NW part of the district. The excessive TDS problem was found at Malsisar and Mandasi. Hence we can conclude that in general except the small belt of north-north west part of the district, the ground water is suitable for drinking purpose.

3.5.2 Analysis of Data for Irrigation Purposes

In order to check the suitability of ground water for agriculture purposes the chemical data were plotted on the sodium (alkali) hazard versus salinity hazard diagram given by the U.S. salinity laboratory staff on the basis of rating of irrigation water with references to this diagram (see fig 3.2) , the quality of water falling in various groups are given below :

Salinity groups	Quality for irrigation purposes
C_1S_1, C_2S_1	Good
C_1S_2, C_2S_2, C_3S_1, C_3S_2	Moderate
All other groups	Bad.

The plots on this diagram fig 3.2 are mostly in the field of S_1C_2, S_1C_3, S_4C_3, S_2C_3 and S_4C_4. Four samples falls in C_2S_1 field showing that the water at places namely at Golyana, Gurha - Gaurji, Mandrella and Posana is good for agricultural purposes.

Total eleven samples fall in moderate groups i.e. five samples in C_3S_2 field (sample Nos. 4,6, 10,33 and 35) and six samples in the field C_3S_1 (i.e. sample Nos. 2,13,15,18,24 and 30). Hence total fifteen samples (four for good and eleven for moderate range) giving about 42% area of the total show that the ground water at these places is suitable for irrigation purposes. Other samples representing 58% of the total fall in the bad range showing unsuitability of the ground water for irrigation purposes.

The location of the samples suitable for irrigation purposes falls around the Kantli river passing through the central part of the district. Hence we can conclude that except the areas along the kantli river, in general ground water is not suitable for the irrigation purposes. The 42% areas lying along the length of the kantli river in both west and east sides is suitable for the irrigation purposes.

3.5.3 Geo Chemical Analysis

Further results of chemical quality analysis of these water have been plotted in trilinear diagram (see fig 3.3) as recommended by Piper, (1944). In this diagram only the relative proportions of principal cations and anions in terms of percentage of e.p.m (equivalent per millions) have been plotted. The diamond shaped field in this diagram has been divided horizontally into two equal triangles. The water samples plot which fall in the lower half, are termed as primary saline secondary alkaline water and those falling in the upper half are classified as primary alkaline and secondary saline water. In the fig.3.3, 23 points fall in lower range, hence about 65% water samples show that the water is primary saline secondary alkaline ground water.

Nitrogen is a very minor constituent of rock ,but major constituent of atmosphere .Nitrogen and oxygen of the atmosphere combine by electrical discharges during lightening and dissolve in rain water.Average nitrate content in the rain water is 0.2 ppm . However part of nitrate may be fixed by plants before the rainwater infiltrates below the root zone. Nitrate that utilized by plants is partly returned to the soil when plants die, although some of the nitrate is lost to surface run off(Hem ,1985).

The greatest contribution of nitrate to ground water is from decaying organic matter, sewage and waste and nitrate fertilizers .As such , rather high concentrations of nitrate are found only in localised areas. Ground water when not polluted contains less than 5 ppm of nitrates, but polluted water contains upto 100 ppm or more . Nitrate derived from organic sources may indicate pollution of water and possible presence of pathogenic bacteria. In quantities over 45 ppm, nitrates is harmful for infants .

The important fluorine bearing minerals are fluorites (calcium fluoride), apetite(complex fluorine bearing silicates) certain amphiboles and mica. The concentration of fluorides is limited due to the ' low solubility of most of the fluorites. The solubility of fluorites in pure water ,at 25°c ,is only due to the extent of 8.5 ppm of fluoride. magnesium fluoride is more soluble than calcium fluoride .sodium fluoride is the most. Ground water with dissolved solids less than 1000 ppm contains less than 1 ppm of fluoride but in some areas the concentration reaches above 5 ppm. Concentration above 50 ppm is exceptional. The highest concentration reported was 66 ppm in a water sample from Union of South Africa (Hem, 1985).Some of the ground water that contains rather large amounts of fluoride contents have a high pH, but not all the fluoride bearing water has a high pH. it has been observed that water high in calcium are low in fluorides (Hem,1985). Ground water containing fluoride concentrations exceeding 1ppm is found in a large variety of geologic terrains. The element fluorine is used higher life forms in the structure of bones and teeth. Excessive fluorine is known to cause fluorisis, disease manifesting in skeletal deformities and molten teeth.

The bulk of the total dissolved solids includes bicarbonates , sulphates and chlorides of calcium magnesium, sodium and silica.Potassium chloride and nitrates form a minor part of the dissolved solids in ground water .The total dissolved solids in precipitated water is less than 10 ppm. In regions of high rainfall and insoluble rock, the concentration of dissolved solids may be as low as 10 ppm.The total dissolved solids content may vary from 10ppm in areas of high rainfall to over 1,00,000 ppm in some desert brines. a saturated sodium chloride may contain more than 300,000 ppm . several processes may cause this increase in dissolved solid contents of ground water. These includes movements through rock containing soluble mineral matter, concentration by evaporating and contamination due to influx of sea water and industrial and municipal disposal.

Table 3.5.1
Characteristics of ground water in Junjhunu District

S.No.	Location	pH	Sp Cond.in micromhos/cm at 25xC	Value expressed in ppm/epm			
				CO3	HCO3	Cl	SO4
1	2	3	4	5	6	7	8
1.	Alsisar	8.4	6250	192 6.4	1635 26.8	893 25.2	316 6.58
2.	Bapai	8.1	1380	Nil	476 7.8	149 4.2	08 2.04
3.	Badgaon	8.6	1940	48 1.6	220 3.6	340 9.6	110 2.3
4.	Bagar	8.5	960	36 1.2	207 3.4	128 3.6	22 0.48
5.	Basai	8.5	2370	24 0.8	207 3.4	482 13.6	100 2.08
6.	Bhagwanth	8.0	1475	Nil	354 5.8	163 4.6	Tr –
7.	Bhirr	8.9	2580	120 4.0	512 8.4	454 12.8	240 5.0
8.	Bodha	9.0	3640	168 5.6	854 14.0	630 18.0	285 5.93
9.	Birmi	8.5	2250	96 3.2	573 9.4	312 8.0	160 3.33
10.	Bissau	8.0	2120	Nil	537 8.8	227 6.4	64 1.33
11.	Bohana	8.0	1990	96 3.2	378 6.2	277 7.8	48 1.0
12.	Dighal	8.9	1700	120 4.0	598 9.8	128 3.6	9.0 0.18
13.	Galdhana	8.1	1040	Nil	220 3.6	85 2.4	30 0.62
14.	Golyana (Udaipurwati)	8.0	520	Nil	220 4.4	85 1.0	30 0.2
15.	Gothra	8.0	1290	Nil	85 1.4	135 3.8	320 6.66

16.	Gurha Gaurji	8.4	570	48	171	35	Tr
				1.6	2.8	1.0	-
17.	Jaisinghpura	8.1	2250	Nil	732	425	48
					12.0	12.0	1.0
18.	Khetri	7.7	1410	Nil	378	7177	260
					6.2	5.0	5.4
19.	Malsisar	8.2	4500	Nil	781	723	440
					12.8	20.4	9.16
20.	Macro	7.8	2740	Nil	134	808	110
					2.2	22.8	2.29
21.	Mandawar	8.35	1610	120	720	35	17
				4.0	1.18	1.0	0.35
22.	Mandasi	8.8	2790	120	268	397	96
				4.0	4.4	11.2	2.0
23.	Mandella	8.1	610	Nil	171	57	Tr
					2.8	1.6	-
24.	Manuta	8.2	890	Nil	305	78	32
					5.0	2.2	0.66
25.	Mukandgarh	8.65	2890	84	854	469	45
				2.80	14.0	13.20	0.90
26.	Muradpur	8.6	2020	72	329	418	150
				2.4	5.4	11.8	3.1
27.	Pachari	8.4	5550	48	378	1751	82
				1.6	6.2	45.4	1.7
28.	Posana	8.5	730	24	159	57	23
				0.8	2.6	1.6	0.48
29.	Pilani	8.9	1670	72	305	248	14
				2.4	5.0	7.0	0.29
30.	Pipli	8.0	1890	Nil	366	263	345
					6.0	7.40	7.19
31.	Sahar	8.8	2220	72	293	440	160
				2.4	4.8	12.4	3.33
32.	Singhana	7.9	2340	Nil	390	383	590
					6.4	10.8	12.7
33.	Sithal	8.35	1250	24	293	213	63
				0.8	4.8	6.0	1.31
34.	Sonasar (Baisira Ki Dhani)	9.0	1790	108	403	213	48
				3.6	6.6	6.0	1.0
35.	Suhana	8.35	1030	36	378	78	12
				1.2	6.2	0.25	2.2

Table 3.5.1 (Contd.)
Characteristics of ground water in Junjhunu District

S.No.	Location	NO3	PO4	Total-hardness as CaCO3	Ca	Mg	Na
		Value expressed in ppm/epm					
1	2	9	10	11	12	13	14
1.	Alsisar	648.0	7.6	320	24	63	1587
		10.45	0.24	6.4	1.2	5.2	69.0
2.	Bapai	73	2.04	520	144	39	108
		1.17	-	10.4	7.2	3.2	4.7
3.	Badgaon	236	0.14	330	24	66	328
		3.8	-	6.6	1.2	5.4	14.2
4.	Bagar	21	0.14	90	16	12	166
		0.33	-	1.8	0.8	1.0	7.2
5.	Basai	260	0.22	450	40	85	345
		4.19	-	9.0	2.0	7.0	0.16
6.	Bhagwanth	300	0.26	340	76	36	170
		4.83	-	6.8	3.8	3.0	7.4
7.	Bhirr	10	7.8	200	24	34	621
		0.645	0.24	4.0	1.2	2.8	27.0
8.	Bodha	25.0	0.20	160	12	32	943
		8.4	-	3.2	0.6	2.6	41.0
9.	Birmi	35	1.7	320	24	63	374
		0.56	-	64	1.2	5.2	16.2
10.	Bissau	424	0.2	480	32	97	316
		6.83	-	9.6	1.6	8.0	13.7
11.	Bohana	200	0.2	160	12	32	421
		3.22	-	3.2	0.6	2.6	18.3
12.	Dighal	100	0.2	70	8.0	12	414
		1.6	-	1.4	0.4	1.0	18
13.	Galdhana	220	0.16	300	48	44	72
		3.54	-	6.0	2.4	3.6	3.15
14.	Golyana	35	0.1	180	44	17	58
	(Udaipurwati)	0.56	-	3.6	2.2	1.4	2.5
15.	Gothra	75	0.2	440	112	39	97
		1.2	-	8.8	5.6	3.2	4.2
16.	Gurha	77.0	0.12	230	40	32	46
	Gaurji	1.2	-	4.6	2.0	2.6	2.0

17.	Jaisinghpura	30	0.3	180	24	29	506
		0.48	–	3.6	1.2	2.4	2.2
18.	Khetri	30	0.22	670	164	63	85
		0.58	–	13.4	8.2	5.2	3.7
19.	Malsisar	592	0.46	860	84	158	794
		9.54	–	17.2	4.2	13.0	34.5
20.	Macro	300	Tr	1280	308	124	45
		4.84	–	25.6	15.4	10.2	6.3
21.	Mandawar	96	0.58	50	8.0	7.3	414
		1.54	–	1.0	0.4	0.6	18.0
22.	Mandasi	744	0.28	660	16	151	472
		12.0	–	13.2	0.8	12.1	20.5
23.	Mandella	140	0.2	270	44	39	28
		2.25	–	5.4	2.2	2.2	3.2
24.	Manuta	18	0.88	240	40	34	110
		1.89	–	4.8	2.0	2.8	4.8
25.	Mukandgarh	90	–	210	24	37	644
		–	–	4.20	1.20	3.0	28.0
26.	Muradpur	22	0.6	330	24	56	380
		0.35	–	6.6	2.0	4.6	16.5
27.	Pachari	65	1.52	760	232	44	989
		1.04	–	15.2	11.6	3.6	43.0
28.	Posana	136	0.1	190	28	29	87
		2.19	–	3.8	1.4	2.4	3.8
29.	Pilani	103	0.24	10	12	17	331
		1.66	–	2.0	0.6	1.4	1.44
30.	Pipli	25	–	820	208	73	101
		0.4	–	16.4	10.4	6.0	4.4
31.	Sahar	200	0.2	210	12	44	506
		3.22	–	4.2	0.6	3.6	22.0
32.	Singhana	40	0.44	1020	168	146	223
		0.64	–	20.4	8.4	12.0	9.7
33.	Sithal	38	0.78	268	40	39	189
		0.6	–	5.2	2.0	3.2	0.1
34.	Sonasar (Baisira Ki Dhani)	118	0.2	80	12	12	404
		1.9	–	1.6	0.6	1.0	17.5
35.	Suh[illegible]	58	0.54	200	32	29	155
		0.92	–	4.0	1.6	2.4	6.75

Table 3.5.1 (Contd.)
Characteristics of ground water in Junjhunu District

S.No.	Location	Value expressed in ppm/epm				
		K	F	Fe	SiO(2)	T.D.S.
1	2	15	16	17	18	19
1.	Alsisar	30 0.775	7.2	Tr	15	2772
2.	Bapai	9.3 0.24	1.2	0.13	-	785
3.	Badgaon	3.9 0.1	0.3	Tr	22	2400
4.	Bagar	1.6 0.04	0.8	Tr	18	1817
5.	Basai	6.2 0.16	0.65	0.53	-	1294
6.	Bhagwanth	41 1.05	0.8	0.10	-	2124
7.	Bhirr	10 0.225	0.98	Tr	22	1848
8.	Bodha	1.6 0.04	8.0	0.1	-	16930
9.	Birmi	117 3.0	4.4	Tr	12	1571
10.	Bissau	4.7 0.12	1.16	Tr	13	2300
11.	Bohana	2.0 0.05	0.94	0.10	-	1820
12.	Dighal	Tr -	4.5	0.10	-	1340
13	Galdhana	41 1.05	0.2	0.1	20	554
14.	Golyana (Udaipurwati)	2.3 0.06	0.34	Tr	22	1700
15.	Gothra	2.0 0.05	0.68	0.8	59	1386
16.	Gurha Gaurji	1.6 0.04	0.44	Tr	27	416

17.	Jaisinghpura	3.5 0.09	1.36	Tr	13	2327
18.	Khetri	5.2 0.135	0.22	Tr	36	2201
19.	Malsisar	16 0.41	3.5	Tr	16	4250
20.	Macro	8.0 0.21	0.1	Tr	36	1080
21.	Mandawar	2.9 0.075	7.2	Tr	13	924
22.	Mandasi	5.8 0.15	1.38	Tr	13	7802
23.	Mandella	Tr –	0.28	0.10	–	1972
24.	Manuta	5.8 0.15	0.18	Tr	16	508
25.	Mukandgarh	6 0.15	1.60	–	–	1525
26.	Muradpur	5.2 0.135	1.44	0.38	34	878
27.	Pachari Kalan	78 2.0	3.8	0.10	–	878
28.	Posana	2.7 0.07	0.04	Tr	24	416
29.	Pilani	2.3 0.06	1.6	Tr	16	2772
30.	Pipli	7 0.17	0.16	–	–	1902
31.	Sahar	5.4 0.14	0.4	0.2	24	2171
32.	Singhana	6.2 0.16	0.9	0.28	36	2310
33.	Sithal	3.9	Tr	0.10	–	618
34.	Sonasar (Baisira Ki Dhani)	2.0 0.05	2.56	Tr	16	3373
35.	Suhana	1.6 0.04	0.3	0.2	–	2600

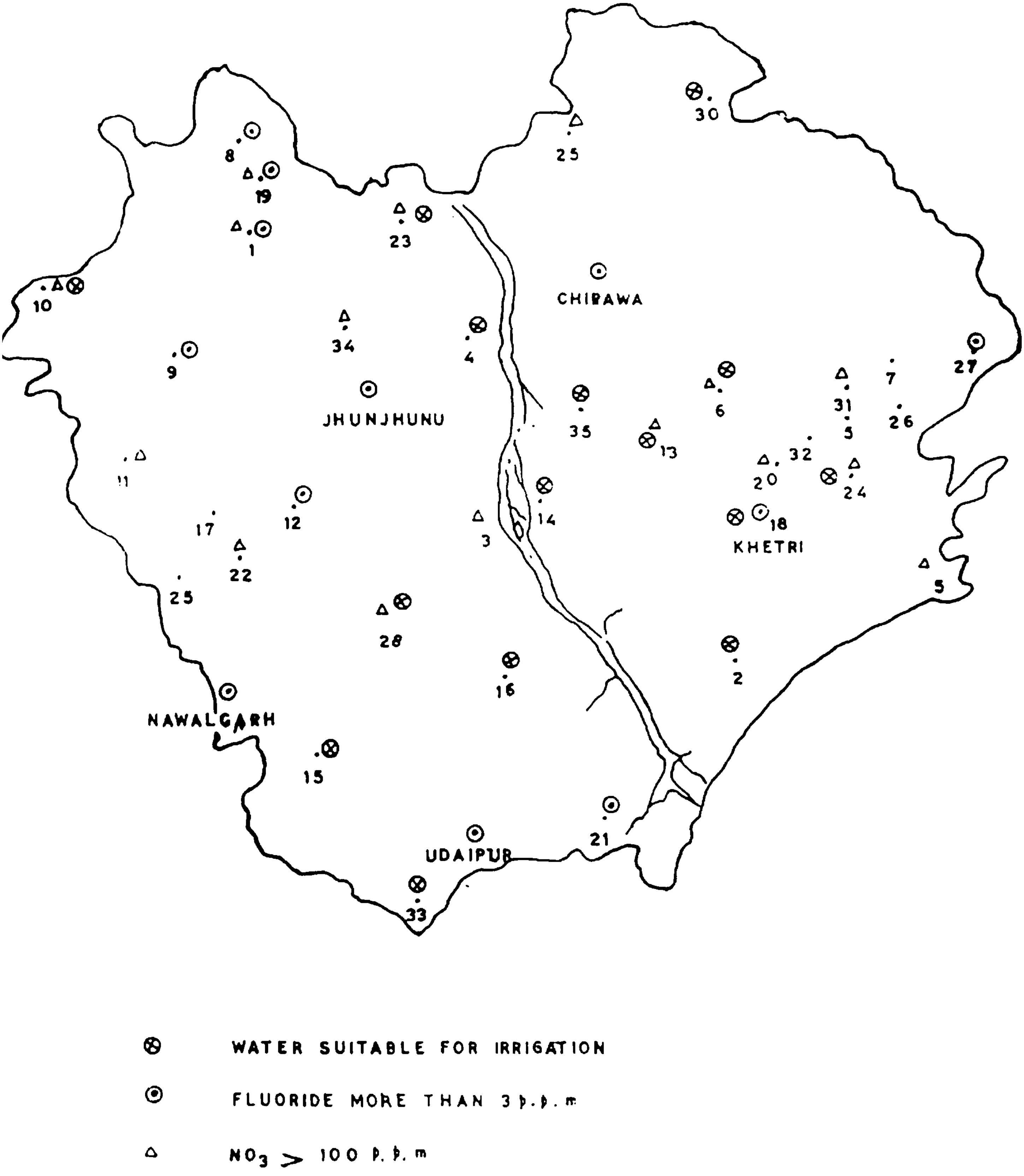


FIG.3.1 JHUNJHUNU MAP SHOWING SAMPLE SITES

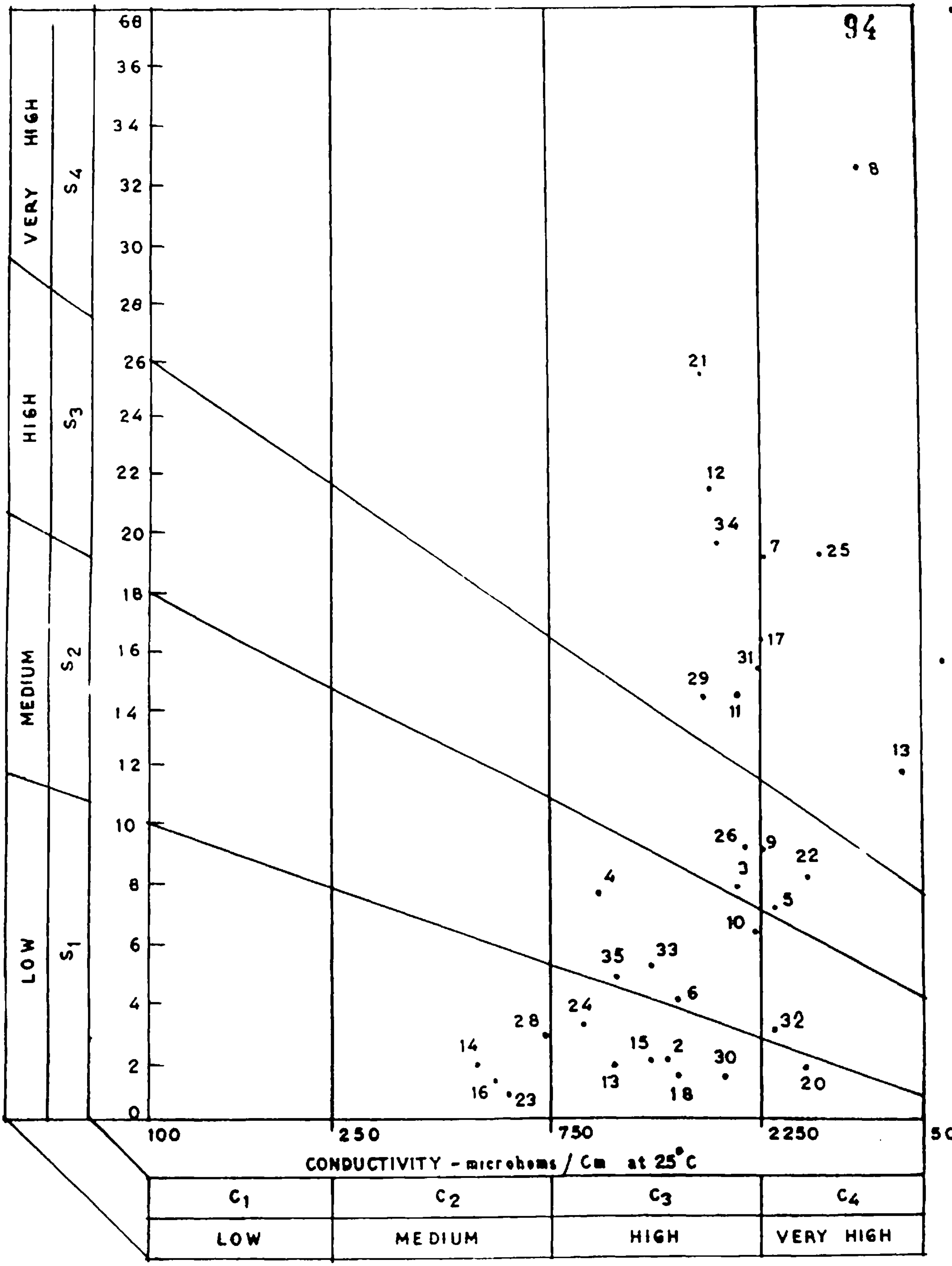


FIG. 3.2 U.S. SALINITY DIAGRAM FOR IRRIGATION WATER CRITERIA.

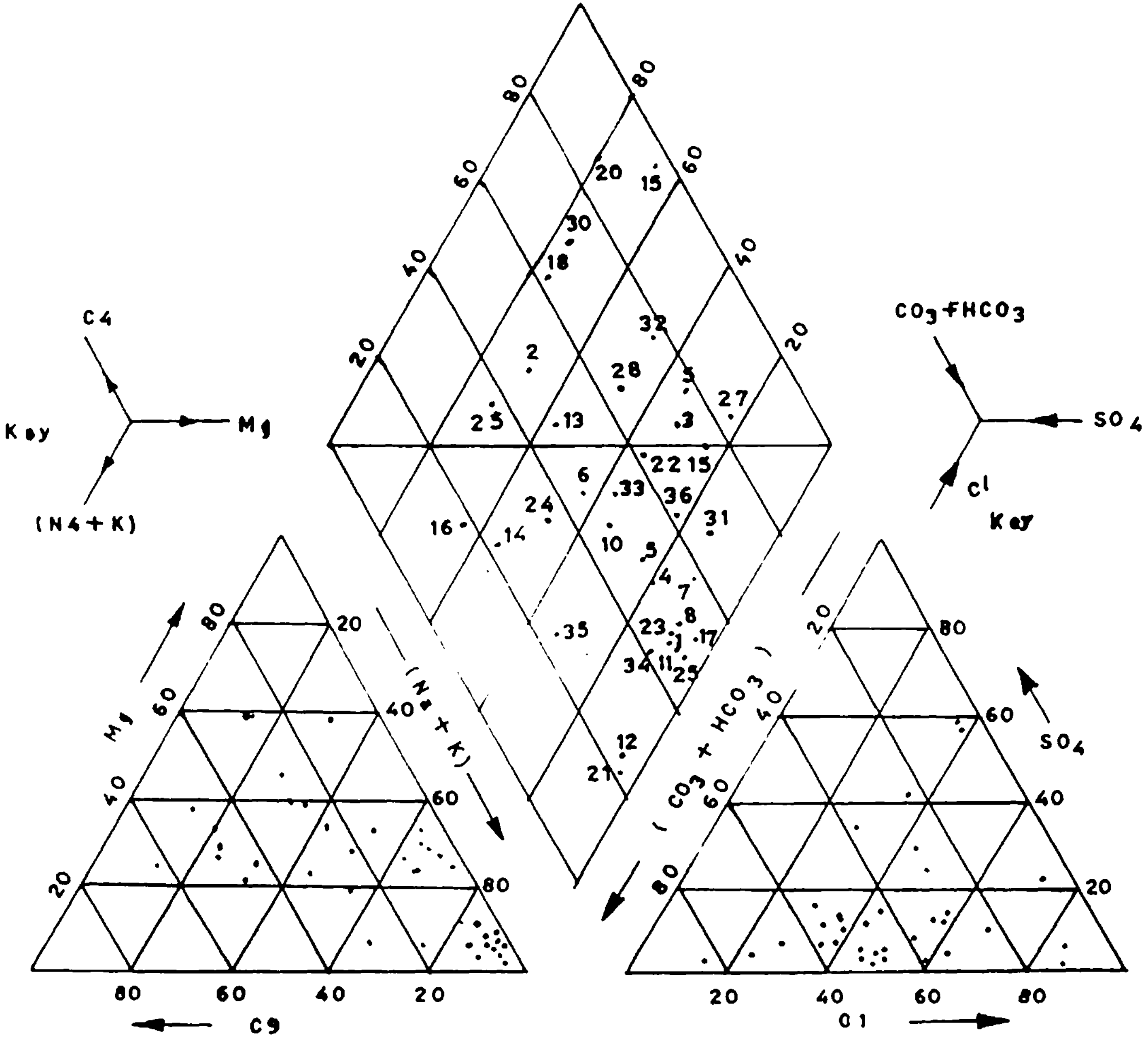


FIG.3.3 PLOTTING OF GROUND WATER ANALYSIS DATA FROM JHUNJHUNU DISTRICT (RAJ.)

3.6 CORRELATION AMONG DIFFERENT WATER QUALITY PARAMETERS

Quality of water supply is as important as its quantity. Ground water contains various impurities in one or more than one of colloidal, suspended and dissolved forms. To establish the quality criteria chemical, physical and biological constituents must be analysed which are quite large in number. In a developing country like India which contains 1.62 lacs problem villages out of 5.75 lacs villages, to check all these parameters is not possible. It not only needs a lot of effort but money also. To overcome this problem if we can find a correlation between the various parameters then the task would be much easier. Correlation analysis can be used in case of water quality to measure the closeness of the relationship between different constituents of water.

In the present study we extended these investigations to make a systematic study of correlations among 14 water quality parameters by considering 35 locations of Jhunjhunu district of Rajasthan. The sample sites have been shown in fig 3.1 .

3.6.1 Correlation Analysis

Correlation analysis helps us in determining the degree of relationship between two or more variables , but it does not tell us any thing about cause and effect relationship. The effect of correlation is to reduce the range of uncertainty. The prediction based on correlation analysis is likely to be more variable and near to reality. Correlation is classified in three ways mainly as

- Positive/Negative correlation
- Simple/partial/multiple correlation
- Linear/Nonlinear correlation

(i) Positive correlation: If two variables X & Y vary in same direction i.e. if as one variable is increasing the other on an average is also increasing or, if as one variable is decreasing the other, on an average is also decreasing, then the correlation is said to be positive.

(ii) Negative correlation: If the variables are varying in opposite direction, i.e. as one variable is increasing, the other is decreasing or vice versa, then the correlation is said to be negative.

(iii) Simple correlation: If the number of variables studied is only two it is a simple correlation.

(iv) Partial correlation: In a partial correlation the number of variables is more than two, but we consider only two variables to be influencing each other, the effect of other influencing variables being kept constant.

(v) <u>Multiple correlation:</u> In a multiple correlation three or more variables are studied together.

(vi) <u>Linear correlation</u> If the amount of change of one variable tends to bear constant ratio to the amount of change in the other variable then the correlation is said to be linear correlation.

(vii) <u>Non linear correlation:</u> If the amount of change of one variable does not bear any constant ratio to the amount of change in the other variable then the correlation is said to be non linear correlation.

3.6.2 Correlation Coefficients

To find the correlation coefficient between the various water quality parameters, the data of water quality of Jhunjhunu district , given in table 3.5.1 have been used. Let x and y be any two water quality parameters (like pH, specific conductivity etc.) and let (x_i, y_i) be n pairs of observed values of these variables (i = 1,2,....n , number of observations n = 35, in our case). Then the correlation coefficient r between the variables x and y is given by the relation:

$$r = \Sigma (u v) /[\Sigma (u)^2 \quad \Sigma (v)^2]^{1/2} \qquad ...(3.6.1)$$

where,

$$u = (x - \bar{x}) \quad ; \quad v = (y - \bar{y}) \qquad ...(3.6.2)$$

$$\bar{x} = \Sigma x/n \; ; \quad \bar{y} = \Sigma y/n \qquad ...(3.6.3)$$

and all the summations are to be taken from 1 to n (= 35 in our case).

3.6.3 PARAMETERS OF STRAIGHT LINE

If the correlation r between two variables x and y is fairly large, a linear relationship of the form

$$\frac{x}{y} = A + Bx \qquad ...(3.6.4)$$

may be obtained to correlate these two variables. (where A and B are the parameters of the straight line given by equation 3.6.4 . However according to Wonnacott and Wonnacott, (1981) the best estimates of the parameters of A and B are given by

$$A = \bar{y} - A\,\bar{x} \qquad ...(3.6.5)$$

$$B = \Sigma\; uy/u^2 \qquad ...(3.6.6)$$

where $\bar{x}$ and $\bar{y}$ are given by equations 3 and 4 and the summations are to be taken from 1 to n as earlier.

3.6.4 Discussion of the Result

The correlations obtained here ,include both positive and negative in the first category, multiple in the second category and non linear in the third category. The correlation coefficient 'r' among various parameters of ground water is shown in table 3.6.1 . Least square fitting of the relation $x/y = A + Bx$ among various parameters have also been given in table 3.6.2. Various calculations were carried out with the help of a FORTRAN programme given in appendix A2 . The above study of correlation analysis reveals that

1. In the first instance it is clear that neither perfect positive nor perfect negative correlation exists between any two parameters.

2. High positive correlations ($r \geq 0.6$)have been found between 9 pairs of parameters, these are Ca -Mg ; CO_3 -HCO_3 ; Ca -TH ;Mg -TH ;Sp.Cond. --F ; Sp.Cond. -HCO_3 ; Mg -NO_3 ;F -CO_3 ;F -HCO_3 , out of which the highest correlation coefficient was found ($r = 0.858$) between calcium and total hardness (fig 3.4).

3. High correlations are observed between carbonates and bicarbonates (fig 3.5) .

4. Calcium and magnesium showing high positive correlation with total hardness implies that these cations are responsible for the total hardness of water (fig 3.6) .

5. Specific conductivity showing high positive correlations with fluoride (F) and bicarbonate (HCO_3) implies that these anions are responsible for the specific conductivity of water (fig 3.7) .

6. High correlation between Mg and NO_3 implies the presence of the salts of $MgNO_3$ in the ground water of Jhunjhunu district.

7. Low correlations between Na - Mg, Mg-K and Na - K arise due to the fact that all these are alkali metals (their presence or absence occurs together).

3.7 CONCLUSION

The above study shows that there is no major pollution hazards in the ground water of Jhunjhunu district. In the north-north west part of the district the problems of excessive TDS and fluoride were found. The area lying in the vicinity of river Kantli shows that the ground water is good for agricultural purpose. Excessive quantity of nitrate was also found at many places . In general the quality of ground water in most of the area of the district is suitable for drinking and irrigation purposes.

The present study of correlations among fourteen water quality parameters has revealed a number of interesting features of the hydrochemistry of ground water of Jhunjhunu district. This systematic study of correlation analysis will facilitate in rapid monitoring of water quality and control of ground water pollution.

TABLE 3.6.1

CORRELATION COEFFICIENT r AMONG VARIOUS PARAMETERS OF GROUND WATER

Paramter	pH	Sp-Cond	CO3	HCO3	Cl	SO4
pH	1.000	0.183	0.343	0.172	-0.282	-0.204
Sp-Cond	0.183	1.000	0.561	0.684	0.158	0.427
CO3	0.343	0.561	1.000	0.797	0.187	0.610
HCO3	0.172	0.684	0.797	1.000	0.067	0.247
Cl	-0.282	0.158	0.187	0.067	1.000	0.235
SO4	-0.204	0.427	0.610	0.247	0.235	1.000
NO3	-0.008	0.478	0.384	0.306	-0.053	0.126
PO4	0.176	0.508	0.502	0.594	0.027	0.259
TH-CaCO3	-0.530	0.352	-0.127	-0.116	0.303	0.547
Ca	-0.586	0.204	-0.283	-0.212	0.359	0.358
Mg	-0.284	0.390	0.155	0.075	0.122	0.541
Na	0.460	0.393	0.409	0.368	-0.016	0.029
K	-0.021	0.350	0.092	0.163	0.051	0.050
F	0.380	0.600	0.769	0.753	-0.022	0.154

TABLE 3.6.1 (Contd.)

CORRELATION COEFFICIENT r AMONG VARIOUS PARAMETERS OF GROUND WATER

Parameter	NO3	PO4	TH-CaCO3	Ca	Mg	Na
pH	-0.008	0.176	-0.530	-0.586	-0.284	0.460
Sp-Cond	0.478	0.508	0.352	0.204	0.390	0.393
CO3	0.384	0.502	-0.127	-0.283	0.155	0.409
HCO3	0.306	0.594	-0.116	-0.212	0.075	0.368
Cl	-0.053	0.027	0.303	0.359	0.122	-0.016
SO4	0.126	0.259	0.547	0.358	0.541	0.029
NO3	1.000	0.169	0.300	-0.067	0.608	0.150
PO4	0.169	1.000	-0.005	-0.011	-0.013	0.206
TH-CaCO3	0.300	-0.005	1.000	0.858	0.782	-0.164
Ca	-0.067	-0.011	0.858	1.000	0.388	-0.174
Mg	0.608	-0.013	0.782	0.388	1.000	-0.107
Na	0.150	0.206	-0.164	-0.174	-0.107	1.000
K	0.026	0.210	0.137	0.160	0.039	0.039
F	0.147	0.308	-0.189	-0.215	0.027	0.396

TABLE 3.6.1 (Contd.)

CORRELATION COEFFICIENT r AMONG VARIOUS PARAMETERS OF GROUND WATER

Parameter	K	F
pH	-0.021	0.380
Sp-Cond	0.350	0.600
CO3	0.092	0.769
HCO3	0.163	0.753
Cl	0.051	-0.022
SO4	0.050	0.154
NO3	0.026	0.147
PO4	0.210	0.308
TH-CaCO3	0.137	-0.189
Ca	0.160	-0.215
Mg	0.039	0.027
Na	0.039	0.396
K	1.000	0.299
F	0.299	1.000

TABLE 3.6.2

LEAST SQARE FITTING OF THE RELATION $x/y = A + Bx$ AMONG VARIOUS PARAMETERS

x	y	r*	B	A
pH	TH-CaCO3	-0.530	0.1400	-1.1071
pH	Ca	-0.586	0.5387	-4.1588
Sp-Cond	CO3	0.561	0.0082	15.5327
Sp-Cond	HCO3	0.684	0.0019	2.1416
Sp-Cond	PO4	0.508	1.3698	3679.9541
Sp-Cond	F	0.600	0.0178	3876.5427
CO3	HCO3	0.797	0.0014	0.0931
CO3	SO4	0.610	0.0252	0.1746
CO3	PO4	0.502	2.5103	77.1686
CO3	F	0.769	-2.8675	312.0543
HCO3	PO4	0.594	1.8744	632.1265
HCO3	F	0.753	-0.1803	842.7800
SO4	TH-CaCO3	0.547	0.0045	0.0983
SO4	Mg	0.541	0.0224	0.1935
NO3	Mg	0.608	0.0260	0.1516
TH-CaCO3	Ca	0.858	0.0343	0.8296
TH-CaCO3	Mg	0.782	0.0252	0.4898

*r : Correlation coefficient between x and y

TABLE 3.6.3
Predicted & Observed values of Calcium (Ca) as a function of Total hardness as $CaCO_3$: (r = 0.858)

Total hardness as $CaCO_3$ (in ppm)	Calcium (Ca) in ppm	
	Predicted	Observed
320	27.1	24
520	27.8	144
330	27.16	24
90	22.98	16
450	27.67	40
340	27.22	76
200	26	24
160	25.33	12
320	27.1	24
480	27.76	32
160	25.33	12
70	21.67	8
300	26.98	48
180	25.7	44
440	27.64	112
230	26.38	40
180	25.7	24
670	28.14	164
860	28.36	84
1280	28.61	308
50	19.6	8
660	28.12	16
270	26.76	44
240	26.49	40
210	26.14	24
330	27.16	24
760	28.26	232
190	25.86	28
10	8.53	12
820	28.32	208
210	26.14	12
1020	28.48	168
268	26.74	40
80	22.39	12
200	26.0	32

TABLE 3.6.4

Predicted & Observed values of Bicarbonates (HCO3) as a function of Total hardness as Carbonates (CO3) : (r = 0.797)

Carbonates (CO3) (in ppm)	Bicarbonates (HCO3) (in ppm) Predicted	Observed
192	530.5	1635
48	300	220
36	257	207
24	190	207
120	460	512
168	512	854
96	422	573
96	422	378
48	300	171
120	460	720
120	460	268
24	398	854
72	371	329
48	300	378
24	190	149
72	371	305
24	190	290
108	442	403
36	251	378

TABLE 3.6.6
Predicted & Observed values of Magnisium (Mg) as a function of Total hardness as Carbonates (CO3) : (r = 0.782)

Total hardness as CaCO3 (in ppm)	Magnisium (Mg) (in ppm)	
	Predicted	Observed
320	37.4	63
520	38.25	39
330	37.5	66
90	32.7	12
450	38	85
340	37.5	36
200	36.2	34
160	35.4	32
320	37.4	63
480	38.0	97
160	35.4	32
70	31.0	12
300	37.3	44
180	35.8	17
440	38.0	39
230	36.6	32
180	35.8	29
670	38.7	63
860	38.8	158
1280	39.1	124
50	28.5	73.3
660	38.5	151
270	37.0	39
240	36.7	34
210	36.3	37
330	37.5	56
760	38.7	44
190	36.0	29
10	13.4	17
820	38.8	73
210	36.3	44
1020	38.9	146
268	37.0	39
80	32.0	12
200	36.2	29

TABLE-3.6.7

Predicted & Observed values of Fluorides(F) as a function of Bicarbonates (HCO3): (r = 0.753)

Bicarbonates (HCO3) (in ppm)	Fluorides (F) (in mg/l) Predicted	Observed
1635	2.98	7.2
476	0.63	1.2
220	0.273	0.3
207	0.256	0.8
207	0.256	0.65
354	0.45	0.8
512	0.68	0.98
854	1.24	8.0
573	0.775	4.4
537	0.72	1.16
378	0.49	0.94
598	0.81	4.5
220	0.274	0.2
268	0.34	0.34
85	0.10	0.68
171	0.21	0.44
732	1.03	1.36
378	0.49	0.22
781	1.11	3.5
134	0.164	0.1
720	1.0	7.2
268	0.34	1.38
171	0.21	0.28
305	0.387	0.18
854	1.24	1.6
329	0.42	1.44
378	0.49	3.8
159	0.2	0.04
305	0.39	1.6
366	0.47	0.16
293	0.37	0.4
390	0.50	0.9
403	0.52	25.6
378	0.49	0.30

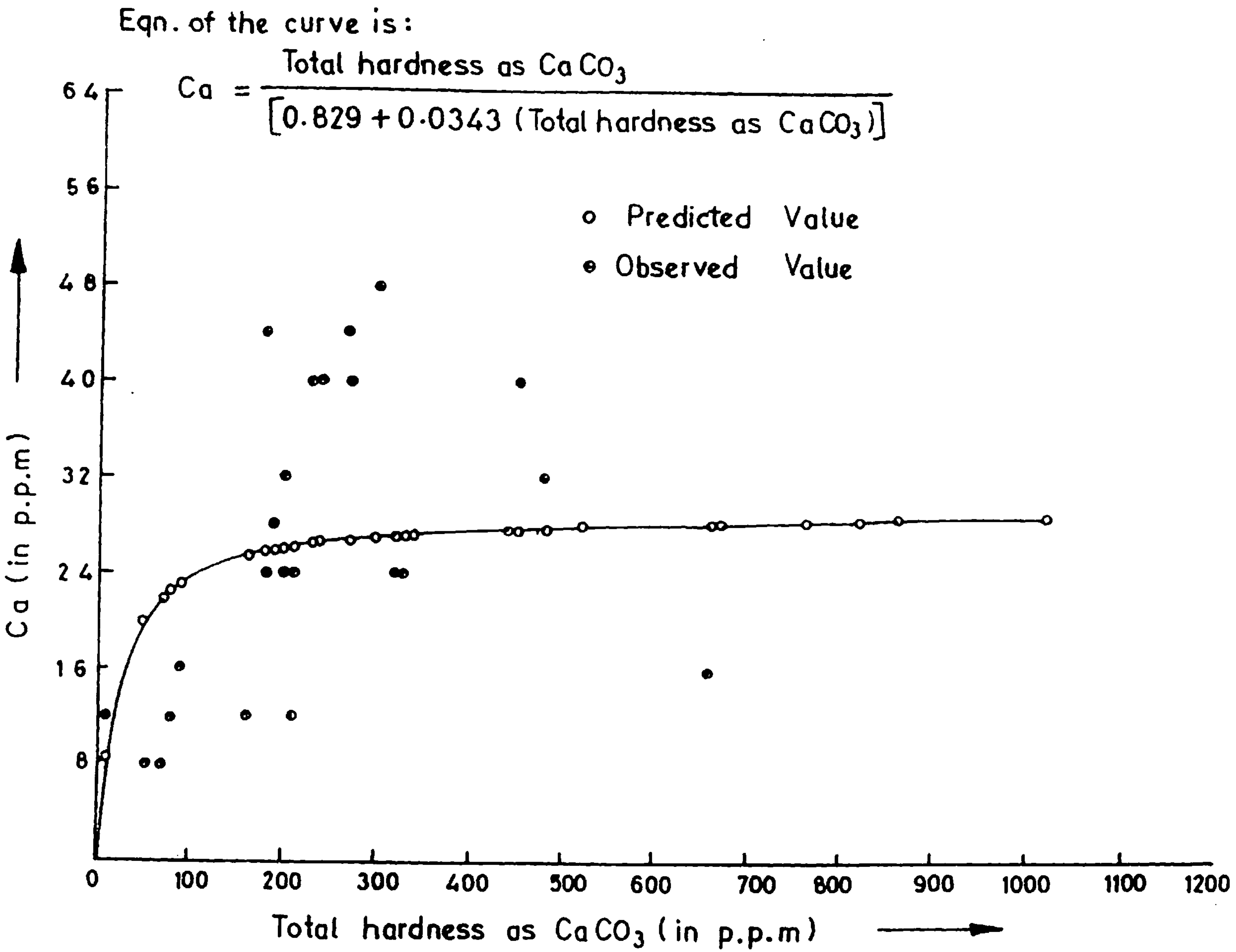
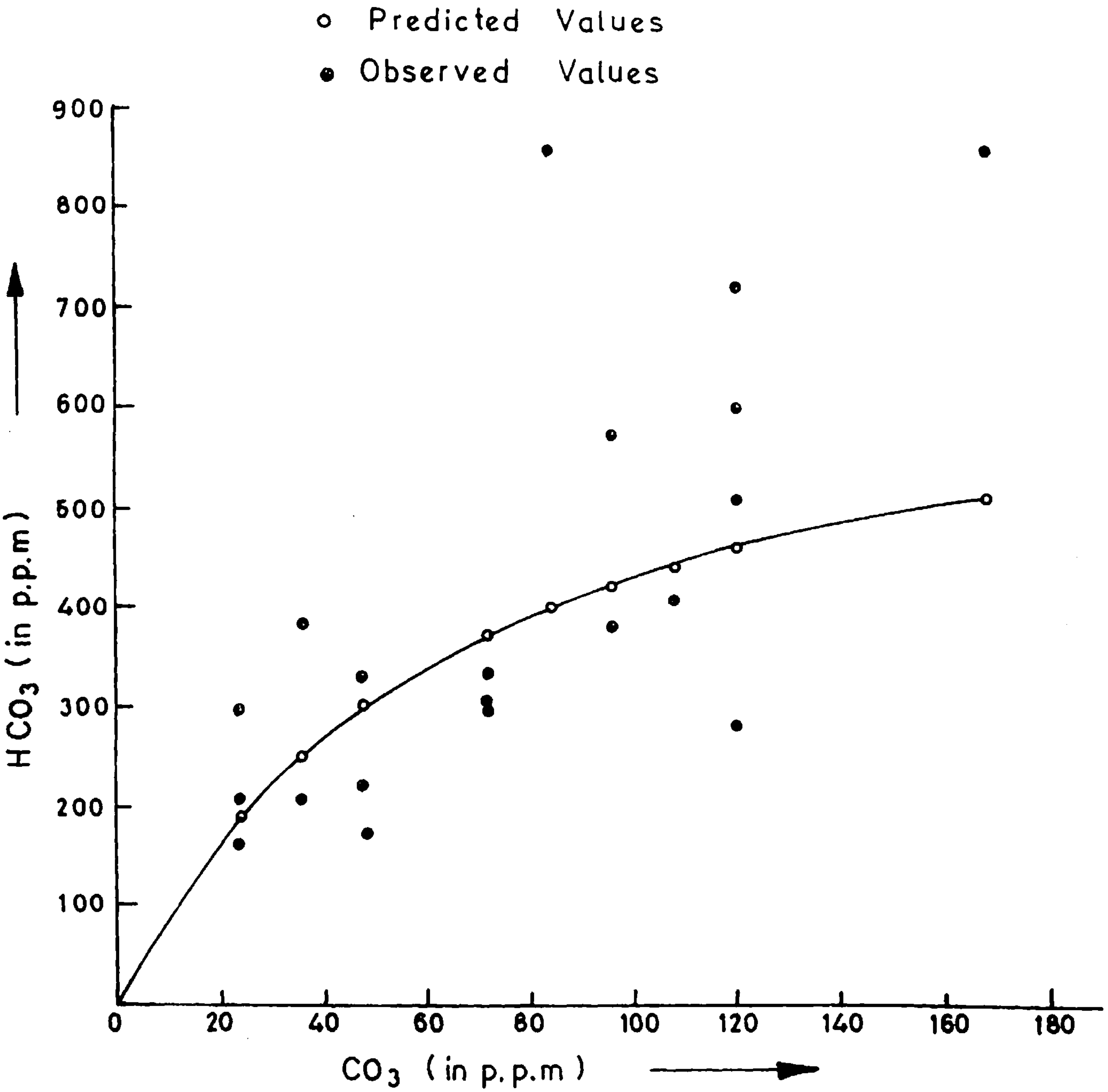


Fig.3.4 Correlation between calcium and Total hardness as $CaCO_3$



Eqn. of the curve is : $HCO_3 = CO_3 / [0.0931 + 0.0014 (CO_3)]$

Fig.3.5 Correlation between Carbonates and Bicarbonates

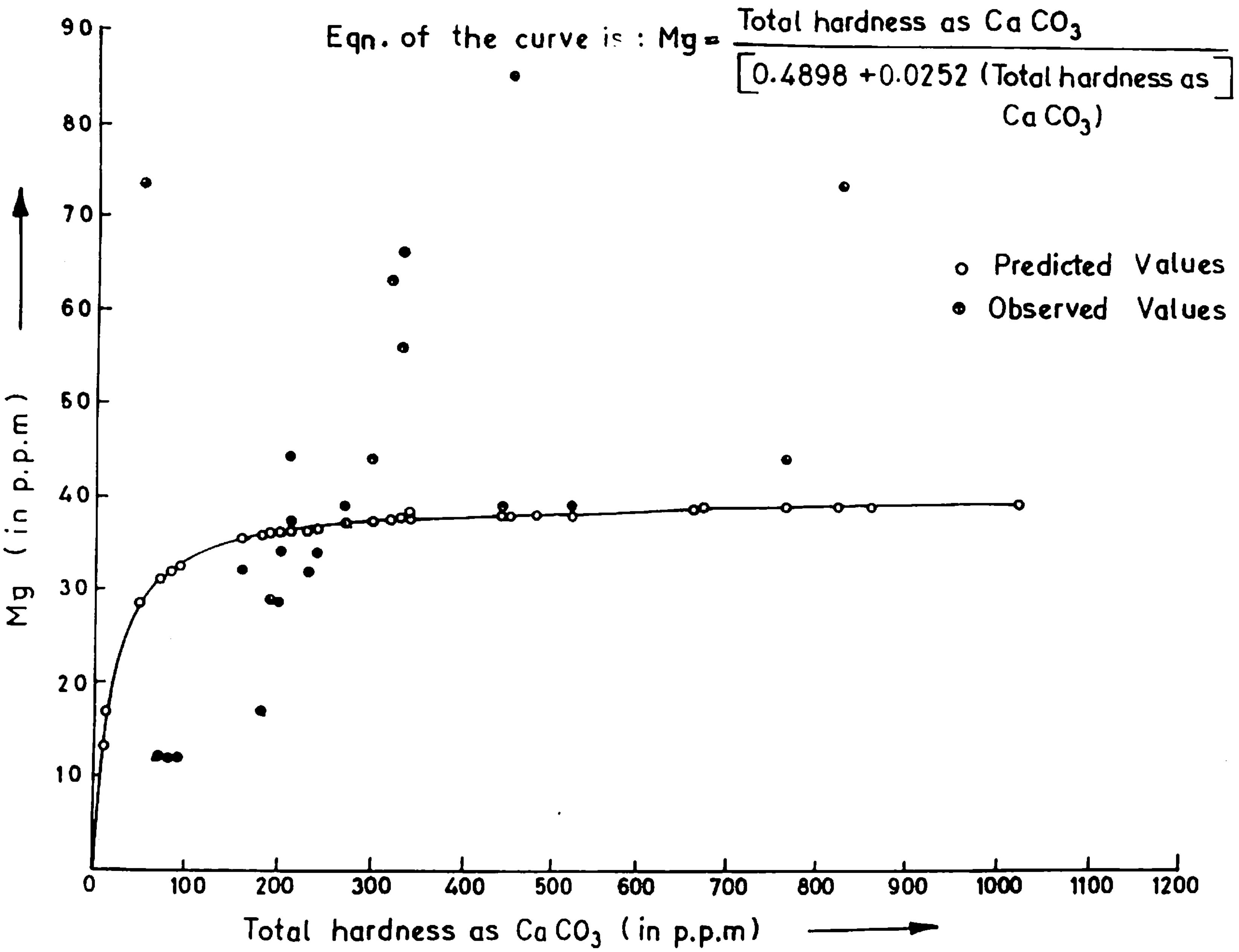


Fig.3.6 Correlation between magnesium and Total hardness as CaCO$_3$

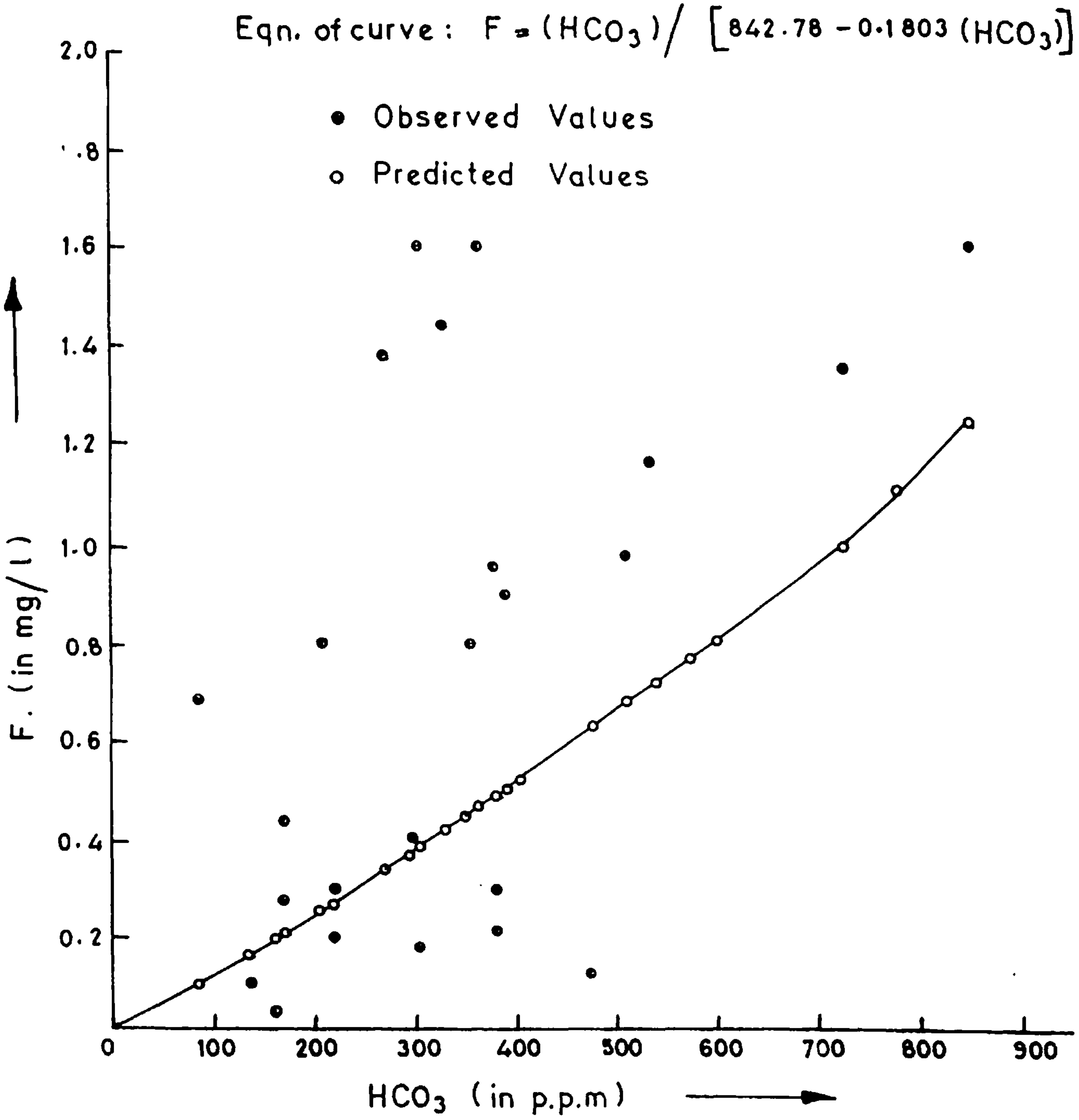


Fig. 3.7 Correlation between fluoride and Bicarbonates.

Chapter : 4

CHARACTERISTICS AND MODE OF DISPOSAL OF EFFLUENT FROM KHETRI COPPER COMPLEX.

4.1 INTRODUCTION

Urbanisation and industralisation of a country normally leads to the discharge of large volume of sewage and industrial wastes into natural water courses. Many industrially advanced countries have paid a heavy price for not safeguarding their rivers and ground water resources. Even after several decades of planning and control, those rivers have not regained their original characteristics. A similar situation is being witnessed all over India during the past few years, resulting in indiscriminate pollution of the natural water resources.

The volume of waste water discharged from a few major industries in India along with the important chemical characteristics and pollution loads are presented in table 4.1.1 (Raghunath,1987). This clearly shows that large volume of waste water containing a variety of objectionable and toxic organic and inorganic chemicals are being discharged. If we consider sugar industry alone, it is expected that sugar effluent discharge will be 150 million m^3. In other words the daily BOD discharged by the sugar industry is almost equivalent to the BOD present in the sewage daily generated by Greater Bombay and Madras put together.

Srivastava, (1990) has studied the disastrous aspect of sugar factory effluent with respect to its physio-chemical and biological characteristics. The BOD value was found low. The high nitrate, phosphate and chloride content may be responsible for low biochemical oxygen demand (BOD). The pH ranged from 6.4 - 8.2. The effluents also showed serious hygienic problems among the local people.

Srinivas, et al. ,(1984) had studied the tannery effluents in North Arcot district, Tamilnadu with respect to ground water pollution. The effluents discharged from the tanneries located in North Arcot district have caused serious deterioration in the quality of ground water. Consequently, the quality and quantity of agricultural production have gone down significantly. The electrical conductivity (EC) of the analysed samples was greater than 3 m mhos/cm, while the adjusted SAR is much greater than the permissible 16. The chloride content varies from 601.8 mg/l to 3115.2 mg/l , far in excess than the maximum allowable concentration of 355 mg/l.

Chakraborty and Arceivala , (1971) have studied waste water from fertiliser factories. Waste water from fertiliser factories contains not only ammonia, ammonium salts, phosphates, acids and alkalies, but also substances having high oxygen consuming properties and toxicity. They have also discussed a rational approach for their effective disposal. They concluded that the effluent from a fertiliser factory is a very complex one and contains various toxic and undesirable constituents. Its discharge to a drinking water course is therefore, to be preceded by proper treatment.

The existing waste water treatment units of super phosphate fertiliser factory together with the effluent quality presented and discussed in by Arora and Chattopadhyay ,(1974). Certain modifications have been proposed for improvements in the quality of final effluent. The possibility of utilisation of the waste containing hydrogen fluoride for the manufacture of fluosilic acid (an insecticide) or the further conversion to sodium or magnesium silico fluoride has been brought out.

Forsberg, (1984) discussed disposal of hazardous elemental waste. The permanent safe disposal of toxic elements such as arsenic, cadmium and lead in hazardous wastes present technical, political and economic difficulties. These hazardous elemental wastes are currently disposed of by shallow and burial. Since the wastes are not degradable, they remain toxic forever and may require perpetual maintenance. A safe disposal method has been suggested by the author for such type of wastes.

Table 4.1.1
CHARACTERISTICS OF WASTE WATER FROM A FEW INDUSTRIES IN INDIA

INDUSTRY	FLOW	pH	SS mg/l	BOD mg/l	COD mg/l	BOD/ COD	BODLOAD g/unit PRODUCT	POLLUTANTS & TOXIC CONSTITUTENTS
Dairy	71/1 of milk	8.0	690	816	1340	0.6	5.7	Oil and grease, ready putrescibility
Distillery	14.1/1 rectifiedspirit	4.0-4.5		40000	80000	0.5	560	High TDS CI.SO_4 colour and putrescibility
Cotton Textile	25.1/m Cloth	7.0-10.0	375	350	525	0.66	8.75	TDS:3,000 mg/l%Sodium 90and colour
Viscose Rayon	570 l/kg fiber	2.8 4.1	200		210			Zinc 6-18 mg/l polysulphides
Tanery	31.1 /kg hide	8.0	1800	1700	3500	0.18	5.1.4	Cr^+ :0.35-0.45 g/kg ie, 4600 mg/l, tannin colour sulphides
Pulp & Paper (Kraft proc.)	310 l/kg paper	6.5 8.2	375	165	610	0.26	50	1 lignin,colour,suspended solids
Cake Oven (HTC)	31./kg coke	8.6 11.2	82	1200	2900	0 .41	3.6	HN_3 ,phenonl,CN,CNS, tar & oil
Phenol formaldehyde	3.4 l/kg	4.0-7.0	-	23160	32160	0.73	80	Phenol: 7900 mg/l HCHO: 4360 mg/l
Oil Refinary	1.5 l/kg oil	6.8-7.2	200-400	100-300	-	-	0.3	Free oil: 2000-3000 mg/l emulsified oil 80-120, H_2S & RSH: 10-220, phenols 12-30 mg/l, ammonia and chromium if cooling water is also Free oil

4.2 DIFFERENT PROCESSES IN KCC

KCC is a major constituent part of Hindustan Copper Limited (HCL), comprising of mining, concentration, smelting, refining, acid and fertiliser, and other supporting establishments. The entire picture of operational activities, pollutants , its impact and existing control devices at KCC are shown in fig.4.1 .

4.2.1 Mining Activities

There are four mines in KCC, the two major Khetri and Kolihan underground mines, the Chandmari open pit and Dariba underground mine. The ultimate capacity of first three are designed to be 5000, 3000 and 1000 t/d respectively, of Dariba underground mine 100 t/d .

4.2.2 Concentrator

The 150 mm ore from the mines is crushed in secondary and refinary crushing to 20 mm size, ground in rod and ball mill and is sent to the floatation section. The final concentrate after thickness is filtered and sent to beding building. The tails after thickness are sent for tailing dropped. The water is reclaimed and reused in the plant. Slag from the smeltor plant which contains 3-4 %

copper is also processed in the concentrator plant .

4.2.3 Smeltor

The wet concentrate is fed to the drier in the smelter and the dried concentrate is fed to the reaction shift of the flash furnace. The slag and matte formed are periodically tapped separately. The matte containing about 50% copper is charged to convertors. The convertor slag returns a blister copper and is 99% pure. It is charged into the anode furnace and refined. The product is anode copper and is 99.5 % pure. The gases from the flash furnace and convertor after removal of the dust are sent to sulphuric acid plant.

4.2.4 Refinery

The refinery consists of an electrolytic plant for electro refining of anode copper and a wire bar casting for casting into wire bars .

(a) Electro refining

Anode copper from smelter is sent for electrolytic refining. The cathodes obtained after the process are 99.99 % pure and after proper washing are sent to wire bar casting plant.

(b) Wire bar casting

The cathodes are melted and casted at controlled temperature into wire bars.

4.2.5 Acid and Fertiliser Plant

(a) Sulphuric acid plant

The clean gases from the convertor containing sulphur dioxide gas varying from 5 % to 7.8 % are sent to sulphuric acid plant. The design capacity of the plant is 700 tonnes of sulphuric acid per day.

(b) Phosphoric acid plant

It is used for the production of phosphoric acid, to be used for simple super phosphate fertiliser production. The production capacity of the plant is 400 tonnes of phosphoric acid per day in the form of 4.5% P_2O_5 acid.

4.3 QUANTITY OF EFFLUENT FROM KCC

The daily consumption of industrial water is 3100 m^3. This is obtained from 18 tubewells sunk into aquifers in the Chaonra and Jodhpura formations at two sites, some 25 km and 42 km away, respectively. Potable water is obtained form

Table 4.3.1
Unit wise flow rates of effluents from Khetri Copper project

Plant	Operational unit	flow rate Cubic m./hr.
1. Mines		30-70
2. Concentrator		
	(i) Tailing Dam, Cooling Water lime flush water	50-60
	(ii) Auto crusher	30-80
	(iii) Concentrator	120-150
	(iv) Compression Cooling	25-30
3. Sulphuric Acid Plant	(i) Acid Plant	15-20
	(ii) Cooling tower sludge	3-15
4. Refinery	(i) Wire bar	
	(a) Cooling water	25-30
	(b) D.M. Plant	9-10
	(ii) Refinery	1-2
5. Fertiliser	(i) Granulation	25-30
	(ii) Mixing	15-20
6. C.I.S.F. main gate	Combined main channel	270-1000 AV. 350

14 tubewells sunk in to the bed of Kharkhara nala, the daily cosumption being 9900 m³. The water after consumption is obtained as waste water. The unit wise flow rates of effluents from Khetri Copper Complex are given in table 4.3.1 .

4.4 QUALITY OF EFFLUENT FROM KCC

For determination of quality of effluent from different processes, waste water samples were collected from various operational plants. The generated effluents from different operational plants are allowed to flow into the main channel which ends into the river Singhana through Kharakhara nala . The samples were analysed for various parameters. Parameters which have been are pH, colour, total dissolved solids, Ca hardness, Mg hardness, total hardness, chemical oxygen demand, sulphides, total residual chlorine, oils and grease, phosphates, silica, fluorides, copper, lead, nickel, zinc, arsenic, iron, sodium and potassium. The nature of effluent from different processes is being discussed below.

4.4.1 Mines and Concentrator

The result of analysis of water from Khetri Copper mines has been shown in table 4.4.1. The discharges from mining activities are not harmful, mostly the same is utilised in the concentrator plant. The concentrator plant generates tailing in slurry form which is pumped to tailing dam. The characteristics of tailing from effluent is shown in table 4.4.2 . Most of the discharges are recycled in the plant and there is a proposal for utilising the settled clear water from tailing pond also.

4.4.2 Smeltor and Refinery

Chances of any effluent from smeltor are rare. The result of analysis of effluent from refinery has been given in table 4.4.3. The effluents from refinery are subjected to pass through a lime pit and finally allowed to flow into the main channel.

4.4.3 Acid and Fertiliser Plant

The sulphuric acid plant effluent is recycled and some volume is again passed through a lime pit neutralisation unit. The analysis is shown in Table 4.4.4. The flow is allowed to find its way into main channel.

4.4.4 Main Channel

To study the characteristics of effluent in the main channel, the samples were collected from main gate of

Khetri copper project (Dec., 1990). The analysis of the samples have been given in table 4.4.5.

4.5 MODE OF DISPOSAL OF TAILING FROM KCC

Tailing constitute a major portion of environmental pollution in mining and metallurgical industries. Solid fraction of the tailing is an important source of solid waste , as the liquid fraction or tailing may contaminate ground water. The tailing can be disposed of in two ways (Sen and Mishra, 1974).

a. Direct disposal

b. Total containment.

The method of "Total Containment" i.e. by storing it in an enclosed space i.e. a natural basin or space surrounded by artificial enclosing dams to avoid its flow into natural water courses, is being practiced at Khetri Copper Complex. The thickened slime containing tailings is hydraulically transported to the tailing pond through a pipeline system. The tailing pond is situated at a distance of about 1 km from the main plant site, on Singhana - Khetri Road. It is a depression created by the basins of hillrocks. On the three sides of the tailing pond are the hillocks but it is open on Sighana Khetri Road side. Tailing are discharged from the top of the hillock.

Table 4.4.1
CHARACTERISTICS OF COPPER MINES EFFLUENT

Sl. No.	Parameters	Average value
1.	pH	7.86
2.	Colour (Hazen Unit)	5
3.	Total Suspended Solids,mg/l	12.5
4.	Sulphides as S, mg/l	0.14
5.	Total Residual Chlorine as Cl mg/l	0:02
6.	Flouride as F, mg/l	0.54
7.	Phosphates as P; mg/l	0.02
8.	Copper as Cu; mg/l	0.03
9.	Lead as Pb; mg/l	N.T.
10.	Nickel as Ni; mg/l	0.04
11.	Zinc as Zn; mg/l	0.10
12.	Arsenic as As; mg/l	Traces
13.	Iron as Fe; mg/l	N.T.
14.	Oil & Grease mg/l	N.T.
15.	Chemical Oxygen Demand. mg/l	4.0
16.	Dissolved Oxygen mg/l	6.56

N.T. = Not Traceable

Table 4.4.2

CHARACTERISTICS OF TAILING DAM EFFLUENT

8

Sl. No.	Parameters	Average value
1.	pH	8.00
2.	Colour (Hazen Unit)	5
3.	Total Suspended Solids,mg/l	27.9
4.	Sulphides as S, mg/l	0.14
5.	Total Residual Chlorine as Cl mg/l	0.035
6.	Flouride as F, mg/l	0.80
7.	Phosphates as P; mg/l	0.02
8.	Copper as Cu; mg/l	0.008
9.	Lead as Pb; mg/l	N.T.
10.	Nickel as Ni; mg/l	0.04
11.	Zinc as Zn; mg/l	0.10
12.	Arsenic as As; mg/l	Trace
13.	Iron as Fe; mg/l	N.T.
14.	Oil & Grease mg/l	N.T.
15.	Chemical Oxygen Demand. mg/l	12.8
16.	Dissolved Oxygen mg/l	6.9

N.T. = Not Traceable

Table 4.4.3
CHARACTERISTICS OF PROCESS FINAL EFFLUENT FROM REFINERY

Sl. No.	Parameters	Average value
1.	pH	9.91
2.	Colour (Hazen Unit)	5
3.	Total Suspended Solids,mg/l	1275
4.	Sulphides as S, mg/l	0.11
5.	Total Residual Chlorine as Cl mg/l	0.05
6.	Flouride as F, mg/l	1.13
7.	Phosphates as P; mg/l	0.20
8.	Copper as Cu; mg/l	N.T.
9.	Lead as Pb; mg/l	N.T.
10.	Nickel as Ni; mg/l	0.15
11.	Zinc as Zn; mg/l	0.38
12.	Arsenic as As; mg/l	Traces
13.	Iron as Fe; mg/l	4.06
14.	Oil & Grease mg/l	1.66
15.	Chemical Oxygen Demand. mg/l	2.92
16.	Dissolved Oxygen mg/l	4.40

N.T. = Not Traceable

Table 4.4.4
CHARACTERISTICS OF EFFLUENT FROM ACID AND FERTILISER PLANT

Sl. No.	Parameters	Average value
1.	pH	3.70
2.	Colour (Hazen Unit)	Milky White
3.	Total Suspended Solids,mg/l	463
4.	Sulphides as S, mg/l	0.13
5.	Total Residual Chlorine as Cl mg/l	0.04
6.	Flouride as F, mg/l	33
7.	Phosphates as P; mg/l	97
8.	Copper as Cu; mg/l	1.21
9.	Lead as Pb; mg/l	0.09
10.	Nickel as Ni; mg/l	0.14
11.	Zinc as Zn; mg/l	0.40
12.	Arsenic as As; mg/l	0.003
13.	Iron as Fe; mg/l	18.20
14.	Oil & Grease mg/l	0.06
15.	Chemical Oxygen Demand. mg/l	18.90
16.	Dissolved Oxygen mg/l	4.65

N.T. = Not traceable

Table 4.4.5
QUALITY OF EFFLUENT IN THE MAIN CHANNEL AT KHETRI COPPER PROJECT MAIN GATE

Characteristics	value*
pH	9.0
Color(Hazen unit)	Grey
Na	704.0
K	23.0
Ca	186.0
Mg	98.0
Cu	42.7
Pb	0.20
Zn	0.75
Ni	0.75
Co	0.70
Cd	0.08

* All values are in ppm except pH and color

4.6 CONCLUSION

In this chapter characteristics of the effluent discharged from different processes at Khetri Copper Complex have been discussed . The quality of the waste water is different for different processes , which makes it complex . The treatment to be given to the waste being received from different operatios will be different. The tailings obtained from concentrator is disposed in tailing pond, located between hillocks ,after treating it in settling tanks , and the waste water from other processes is disposed in the main channel from where it goes to Singhana river through Kharakhar nala.

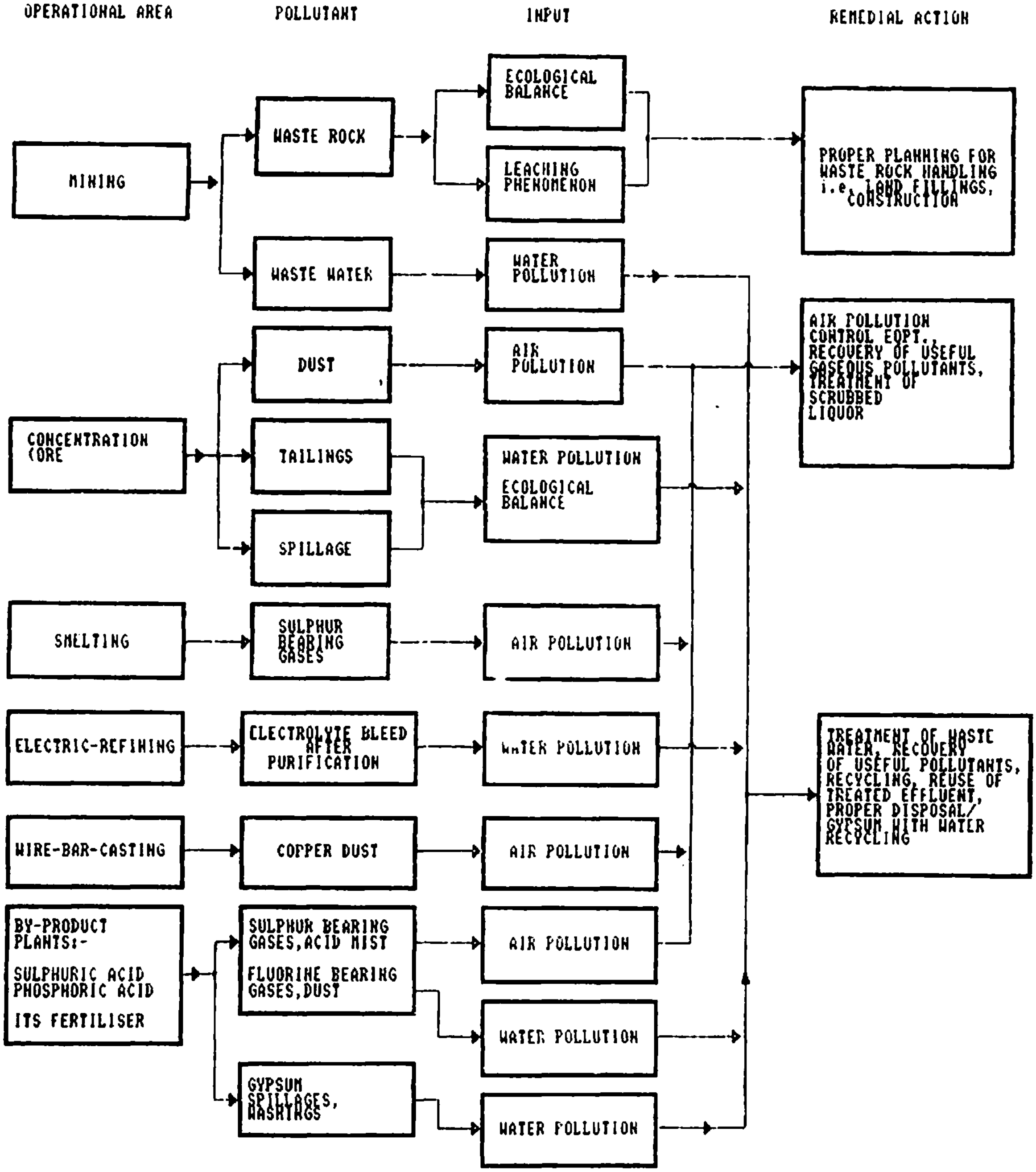


FIG. 4.1 SCENARIO OF ENVIRONMENT AT KHETRI COPPER COMPLEX

CHAPTER : 5

EFFECT OF DISPOSAL OF EFFLUENT FROM KHETRI COPPER COMPLEX ON GROUND WATER QUALITY

5.1 INTRODUCTION

Ground water is an economic resource and more than 85% of the public water supplies are obtained from wells. Ground water may become contaminated due to improper disposal of liquid wastes and defective well construction. Contamination may also take place due to movement of waste water through large openings such as animal burrows, fissures in rocks, coarse gravel formation or manmade excavations. Pollution can impair the use of water and can create hazards to public health through toxicity or the spread of disease.

Most pollution originates from the disposal of waste water following the use of water for any of a wide variety of purposes. Thus a large number of sources and causes can modify ground water quality, ranging from septic tanks to irrigated agriculture (Anon,1970 ; Raghunath,1987) .

In contrast with surface water pollution, sub surface pollution is difficult to detect, is even more difficult to control, and may persist for decades. An outline of ground water pollution with regard to different sources of pollution have been given by Raghunath, (1987).

Contamination of ground water is common in the areas surrounding city refuse dumping site. This is more so where dumping is done in low lying areas and the rate of percolation through the soil is high. In order to assess the extent of ground water pollution by leachate around the refuse dumping grounds at Jaipur (Olaniya and Saxena, 1977), 25 wells in the area were selected. The results indicate that the pollution by total dissolved solids, chlorides and iron salts is felt considerably up to a distance of about 450m. The increase in hardness and COD are also perceptible upto about the same distance.

A study on acidification of ground water and land use has been done by forsland, (1986) at Denmark. He described one of the red hearings, that of land use as an important factor in the acidification of ground water, and acidification in other areas. He has focused especially on the acid production in the soil in connection with cultivation. Also described in the possible acid production in the atmosphere arising from ultraviolet radiation of ammonia evaporated from cultivated fields. Parsons, (1986) studied the waste disposal from urbanisation and its influence on fresh water in United Kingdom. The findings of study and experience in the UK substantiate landfill as a valid option for the disposal of domestic and industrial waste, provided that both the site and the type of waste are suitable. Ground water accounts for about one third of public water supplies, and these resources have been adequately protected from pollutants emanating from waste disposal. As sites become more difficult to identify and less suitable sites have to be considered, so research has been promoted to ensure that if necessary these latter sites may be used and will satisfy the overall objective and preserving water resources.

Dewelle and Schaff , (1980) studied the ground water pollution by septic tank drainfields in central pierce county, south of the city of Tacoma. He evaluated different wells with corresponding chemical analysis obtained over 30 years period from a densely populated river basin in order to identify trends and correlations between pollution indicators. Increase in values for nitrate, chloride and specific conductance were observed and attributed to the presence of sewage effluent from septic tank drainfields.

In the southern San Fransisco Bay area, a state regulatory agency carried out a questionnaire (Oliveri, et. al., 1985) survey to determine the locations and characteristics of underground chemical storage and handling facilities at industrial sites in the area. Sampling of soil and ground water were required at sites where under ground tanks containing solvents were reported. The survey identified 1,692 tanks at 388 sites. The longest fraction were pre treatment sumps for industrial waste water, followed by fuel tanks, solvent tanks, and tanks containing corrosives. Solvent tanks were reported at 96 sites. Subsurface investigations resulted in discovery of soil or ground water contamination at 75 of the 96 sites with solvent water contamination at 75 of the 96 sites with solvent tanks, or both. Further investigations and remedial actions are under way at these sites, and new regulations have been adopted at the state and total brands to prevent future release of industrial chemicals into soil and ground water.

Synthetic nitrogenous fertilisers form key inputs of package farming for raising the vertical agricultural production Saxena and Mehra, (1991) studied the ground water pollution due to nitrogenous fertilisers. They have also discussed the health problems associated with it. Strategies to prevent,nitrate pollution are also discussed.

A study of ground water pollution in north Tripura district has been done by Kumar , et. al., (1990) . Ground water quality was assessed in north Tripura district and majority of them were found to be bacteriologically contaminated and thus unfit for drinking purposes. The bacteriological contaminated ground water was mostly due to socio economic factors. The chemical contamination in few samples was due to the weathering of various constituents of geologic stratum.

Environmental pollution studies due to effluents discharged from some mining and metallurgical industries have been done by various persons, Mitchel, (1958); Raid ,(1958) ; Mitchel , (1964) ; Palaniappan, (1972) ; Smith and Brandshaw , (1972); Wong, (1974); Tan, et. al., (1977); HO ,(1978); Sen , (1974) and Joshi , et. al. (1982).

Joshi, Thukral and Chand ,(1982) have analysed the tailing water discharged from Khetri copper complex at Khetrinagar which reveals that there is a gradual increase in the various constituents in the direction of its flow.

Drought causes famine in many parts of the country and more so in Rajasthan , where agriculture is dependent on the distribution of rainfall. Water has properties of dissolving and carrying in solution a variety of chemicals and other matters, contaminating the ground water. Ground water once polluted , it becomes a direct threat to the life of both human beings and other organism (Reddy, 1979).

Gangal and Zutshi, (1990) have done analysis of the different well water samples, which reveals that there is ground water pollution due to seepage of effluent from Khetri Copper Complex, making water unsuitable for drinking and irrigation purposes.

5.2 MATERIALS AND METHODS

The river named Singhana is bearing all the effluent from Khetri Copper Complex which is being discharged through Kharkhar nala. The pollutants percolate through subsoil into aquifer during effluent flow in the Singhana river. For analysis purpose , different wells located on the banks of river Singhana were selected. Water samples were collected from different wells, shown in fig. 5.0 . In 1988 the average rainfall in the area was 591.6 mm. The samples were collected before rains and after rains i.e. in the month of May and October 1988 respectively. The analysis of the samples collected from different wells has been done as per given in Standard Methods ,(1980). The effect of rain has been discussed in the article 5.5 of this chapter.

5.3 GROUND WATER QUALITY IN KHETRI AREA BEFORE ESTABLISHMENT OF KHETRI COPPER COMPLEX

Geological Survey of India ,(1961) carried out a complete analysis of water in the Singhana area about 2.5 km. from the Copper plant site before establishment of Khetri Copper Complex. Samples of water were collected from 74 dug wells in the area for partial chemical analysis and from 4 dugwells for complete chemical analysis.

Partial chemical analysis comprises of the determination of concentration of chloride, bicarbonate and carbonates ions, total hardness as $CaCO_3$, pH and specific conductance. From the values of specific conductance, the total dissolved solids concentration in the water can be approximately found out by multiplying a factor of 0.61. Complete chemical analysis includes in addition to the above, determination of concentration of calcium, magnesium, sodium, potassium, iron, sulphate, nitrate, nitrite, boron and dissolved silica.

The results of the chemical analysis of water samples done by GSI, (1961) is summarised in table 5.1.1 . Complete analysis of four water samples showed the following ranges: Calcium, 47-73 ppm; Magnesium , 13-32 ppm; Sodium, 22-60 ppm; Potassium ,0.8-1.6 ppm; Dissolved Silica, 40-90 ppm; Bicarbonate, 220-485 ppm; Chloride, 12-27 ppm; Sulphate, 5-15 ppm; Nitrate, 6-26 ppm; Total Iron, less than 0.36 ppm; Total Hardness as $CaCO_3$, 173-317 ppm; and Total Dissolved Solids, 275-548 ppm. Concentration of Boron was less than 0.25 ppm.

The pH value ranged between 7.1 and 8.2 indicating a mildly alkaline to acidic reaction. Only one sample from an old stope had a pH value of 4.5, indicating that the water is highly acidic in reaction. The acidity is due to the presence of sulphuric acid formed by the oxidation

Table 5.1.1
Quality of water in Khetri area in 1961.

Constituents	Number of water samples in range						
	0-50	50-100	100-250	250-500	500-1000	1000-2000	2000-2508
Chloride	46	14	12	2	–	–	–
Bicarbonate	–	1	9	59	5	.	.
Carbonate	20	–	–	–	–	–	–
Total hardness as $CACO_3$	–	–	31	38	4	–	
Specific cond. in micro mhos/Cm at 25^{o} C	–	–	–	10	49	12	3

Note: All values are in ppm except specific conductivity and subsequent leaching of the Chalcopyrite and other sulphide minerals in the mineralised zone.

5.4 GROUND WATER QUALITY AFTER ESTABLISHMENT OF KHETRI COPPER COMPLEX

In chapter 3 , the quality of ground water in Jhunjhunu district has been discussed. The quality of ground water of Khetri area, particularly for the wells , which are near to the Singhana river into which the effluent of Khetri Copper Complex is being discharged ,is compared with the quality of ground water of rest of the places of the district . It is observed that , the various constituents of ground water have increased considerably, due to seepage of contaminants into ground water.

At Pacheri Kalan ,which is at down stream side of the river Singhana , the deeper water is better than the dug wells . The electrical conductance of the shallow well water was found to be 5550 micro mhos/cm. at 25 ° C whereas for water from tubewell (deposit well) it was 2225 micro mhos/cm. at 25 ° C only . Similarly chloride and other constituents are higher in dug wells. This deterioration in the ground water quality in dug wells are due to the effluent which is being discharged from the Khetri Copper Complex . The river Singhana drains the effluent of Khetri Copper Complex which percolates into the ground water through the subsoil. Thus the ground water at the down stream of the Singhana river is getting polluted and the deterioration of the ground is taking place.

5.5 VARIATION OF GROUND WATER QUALITY DUE TO RAIN

Results of the analysis of the water samples collected from ten wells (see fig 5.0), before rain (May, 1988) and after rain (October, 1988), have been given in table 5.5.1 and 5.5.2 , respectively. From the given results it is observed that the TDS of the ten samples varies from 983 mg/l to 3106 mg/l, while after rain it varies from 1015 mg/l to 3850 mg/l. From the results it is clear that for the samples from the wells which are located on the bank of river Singhana, inspite of decreasing TDS contents due to dilution, has increased considerably. However for the wells which are away from Singhana river, TDS content has decreased considerably (see fig 5.1). For those wells which are on the banks of Singhana river, TDS has increased due to seepage of the pollutants into the ground water and for the wells which are away from Singhana river, due to seepage the pollutants have not entered into the ground water. The pollutants are adsorbed in the subsoil while percolation of effluent , which is being discharged in the river. As the water is a good solvent, the adsorbed pollutants in the subsoil gets dissolved in rain water during its percolation in the aquifer. Ultimately this rain water enters into the aquifer. Due to entrance of dissolved pollutants with rain water, various constituents of ground water increases. This is evident from the table 5.5.2 .

Various constituents of water before rain and after rain are shown in the fig 5.1 - 5.10 . Similarly it is observed that values of sodium, potassium, calcium, magnesium, total hardness, chloride, sulphate, nitrite , fluoride and metals in respect of all the wells showed a trend of increase after the rains.

5.6 CONCLUSION

Due to disposal of effluent from Khetri Copper Complex, the quality of ground water had deteriorated considerably. As the pollutants in the effluent are adsorbed in the subsoil , with rain water they leach into the ground water. Various constituents of ground water have increased after rain inspite of getting reduced due to dilution. The pollutants adsorbed in the subsoil gets dissolved in the rain water and ultimately enters into the ground water. Concentration of various constituents of ground water such as specific conductance , sodium,potassium, magnesium , total hardness, calcium, chloride ,sulphate , fluoride total dissolved solids, boron and silica have increased rain for the wells which are on the down stream side of the Singhana river.

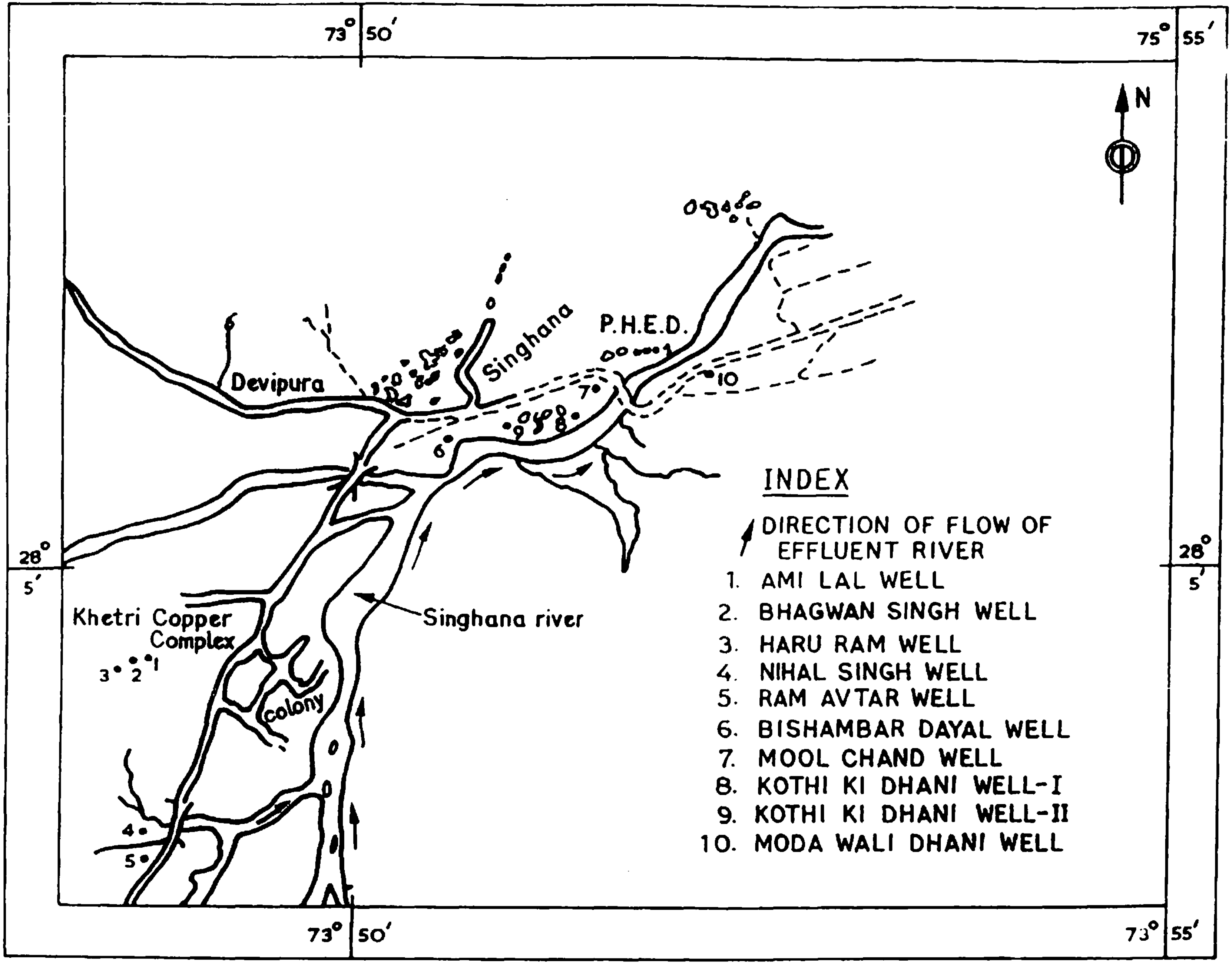


Fig. 5.0 Location of wells

Table 5.5.1
Result of Chemical Analysis Of Water samples before Rain

Well No.	TDS	Conductivity in umhos/cm at 25x c	pH	Na	K	Ca	Mg
1	1851	2284	7.4	210	2.3	193.8	108
2	1681	2174	7.7	150	2.1	213	127
3	2063	2471	7.4	70	2.0	288	177
4	1723	2186	7.4	100	3.3	224	138
5	983	1364	7.4	60	4.0	127	83
6	3106	2807	7.6	320	1.4	433	166
7	1961	2298	7.3	125	5.0	232	129
8	2029	2640	7.5	103	5.0	221	147
9	2824	3356	7.2	260	11.4	274	219
10	2547	2319	7.4	235	11.0	248	212

Table 5.5.1 (Contd.)

Well No.	Total Hardness	HCO3	Cl	SO4	NO3	F	B	SiO2
1	292	372	210	669	120	0.75	0.2	10
2	309	336	205	660	150	0.0	0.2	12
3	434	276	210	1102	20	1.0	0.2	14
4	560	264	275	668	70	0.5	0.1	15
5	254	264	167	220	125	0.2	0.1	5
6	854	372	460	1366	15	5.0	0.8	25
7	564	276	298	690	20	0.7	0.2	18
8	480	200	345	820	9	0.7	0.1	15
9	683	420	340	1290	26	4.8	1.0	15
10	600	384	300	1130	35	4.8	1.0	15

Note: All values are in ppm or mg/l except pH and conductivity.

Table 5.5.2
Results of Chemical Analysis of Water Samples after Rains

Well No.	TDS	Conductivity in umohs/cm at 25x C	pH	Na	K	Mg	Total Hardness
1	1630	2215	7.4	230	2.6	85	292
2	1550	2070	7.7	200	6.4	78	309
3	1925	2324	7.8	145	5.6	117	434
4	2300	2623	7.5	140	10.5	137	560
5	1015	1383	7.6	80	4.5	53	254
6	3850	4516	6.7	390	13.0	216	854
7	2330	2883	7.5	158	6.4	162	564
8	2210	2673	7.4	200	6.0	117	480
9	2700	3882	7.4	310	10.0	148	683
10	2630	3033	7.3	210	7.1	126	600

Table 5.5.2 (Contd.)

Well No.	Ca	HCO3	Cl	SO4	NO3	F	B	SiO2
1	172	345	275	493	100	1.0	1.5	8
2	176	280	241	524	70	4.0	1.0	10
3	264	245	260	800	50	0.5	1.0	10
4	334	220	249	1077	45	0.5	0.5	12
5	166	310	178	183	110	0.4	0.2	4
6	498	365	710	1560	1.0	15.0	1.5	30
7	298	270	385	959	5.0	0.5	0.2	15
8	288	270	348	382	4.0	0.5	1.0	12
9	440	390	380	1489	1.0	1.0	0.2	10
10	392	283	283	1284	2.0	1.0	1.0	12

Note: All values are in ppm or mg/l except pH and conductivity.

Fig 5.1 EFFECT OF RAIN ON WATER QUALITY(T.D.S.)

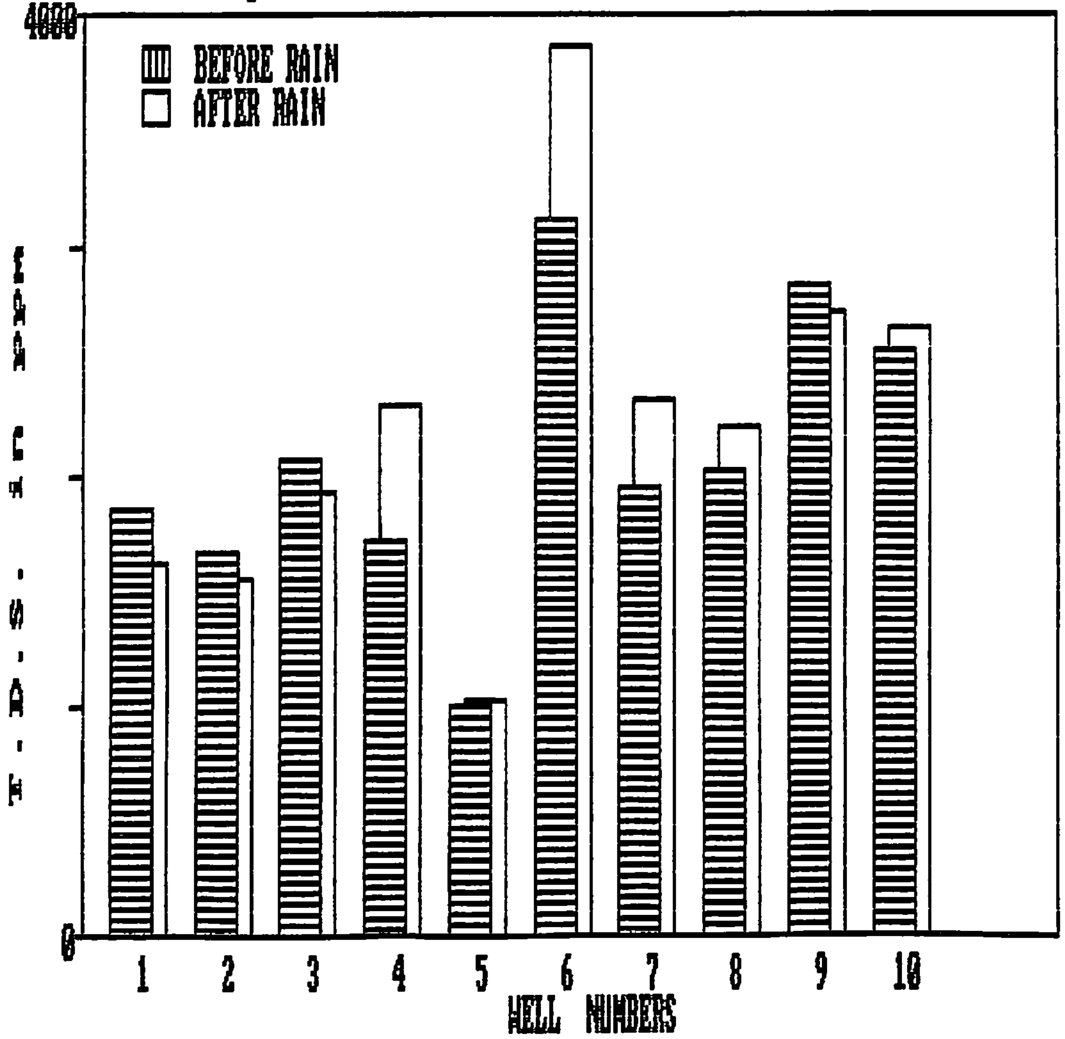


Fig.5.2 EFFECT OF RAIN ON WATER QUALITY (Na)

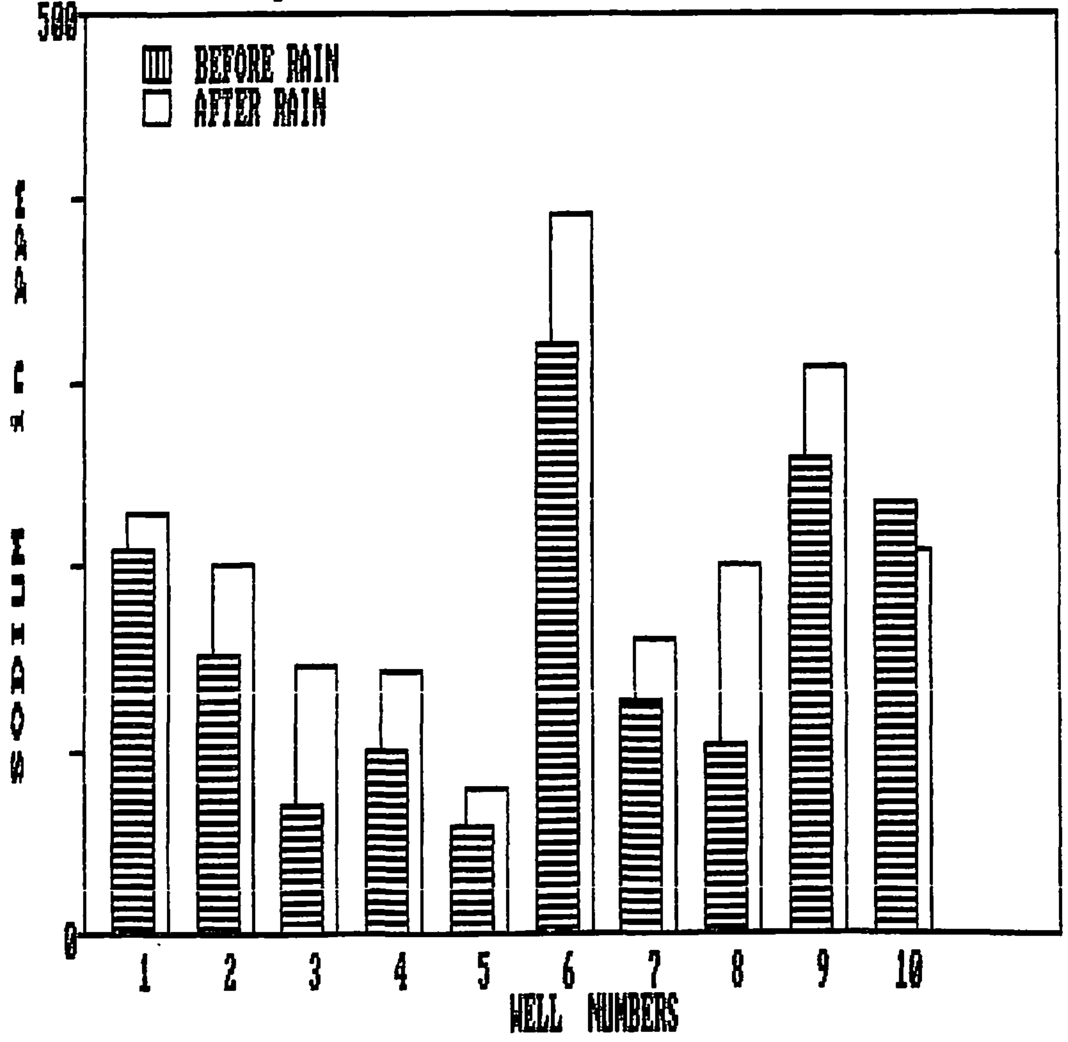


Fig.5.3 EFFECT OF RAIN ON WATER QUALITY (Mg)

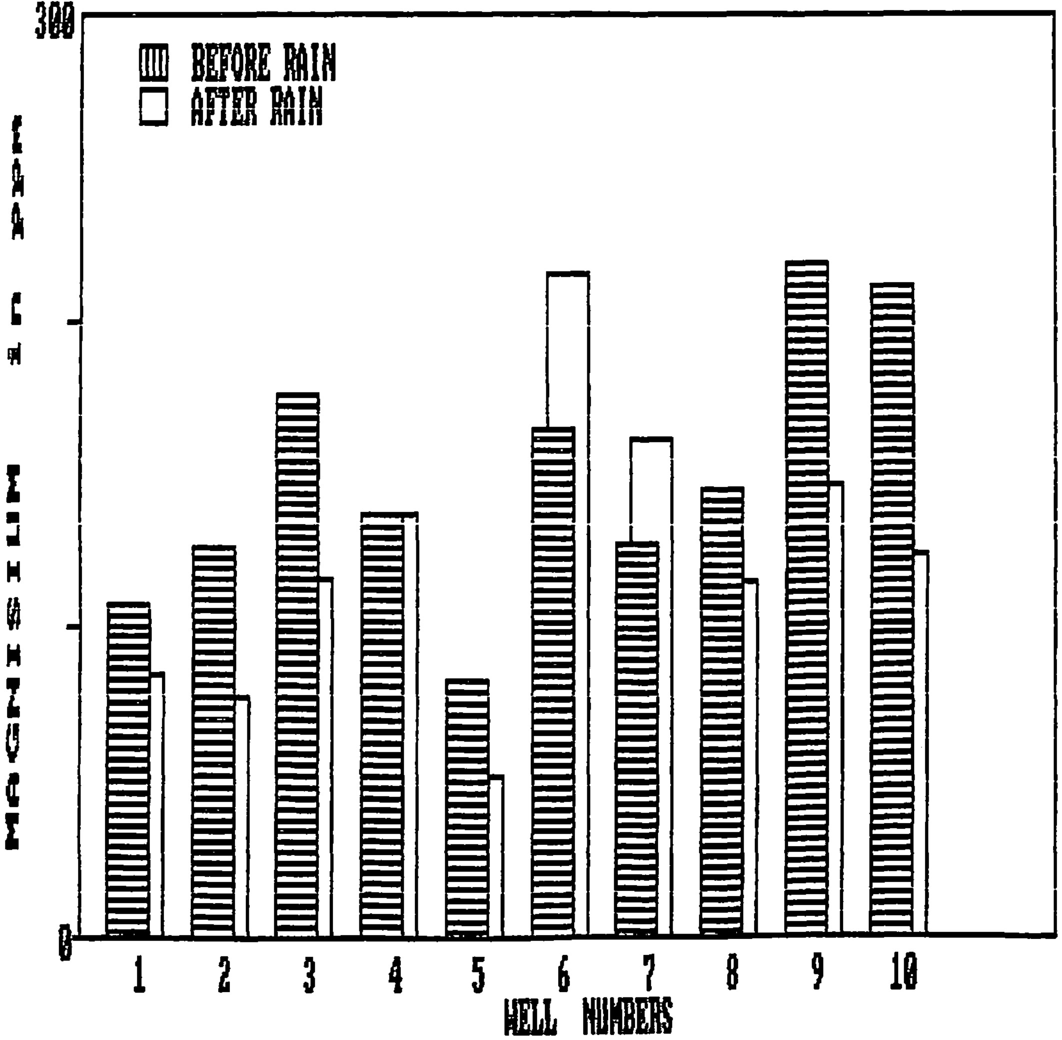


Fig.5.4 EFFECT OF RAIN ON WATER QUALITY (Ca)

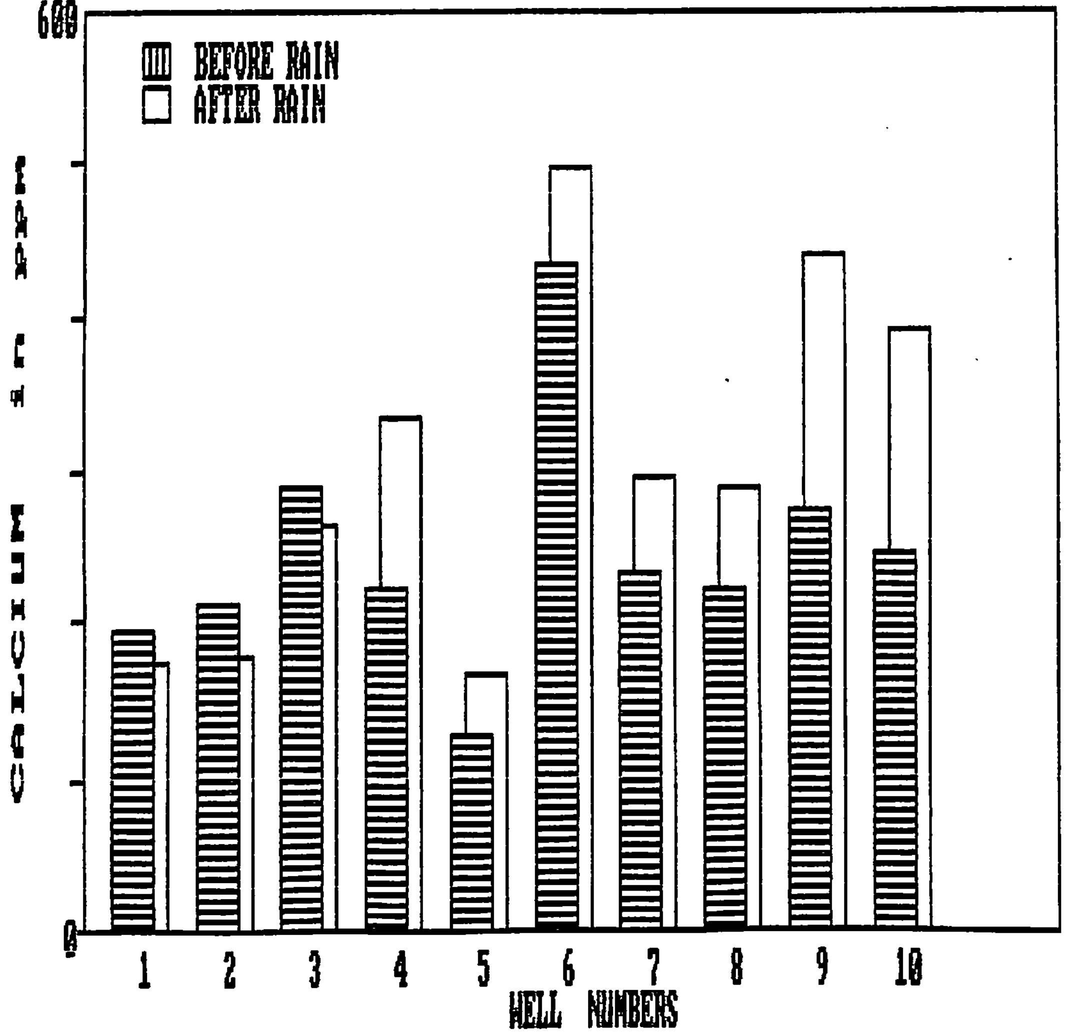


Fig.5.5 EFFECT OF RAIN ON WATER QUALITY (HCO3)

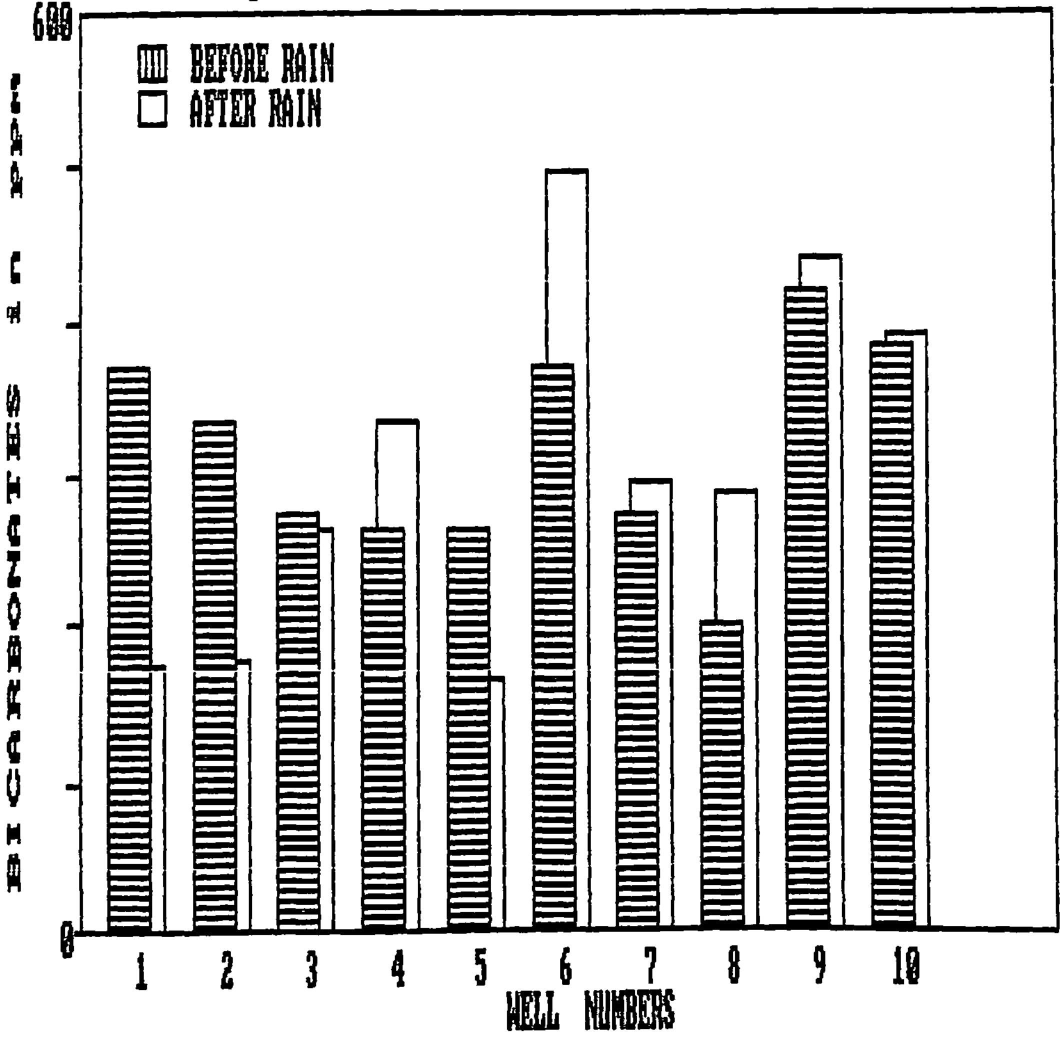


Fig.5.6 EFFECT OF RAIN ON WATER QUALITY (Cl)

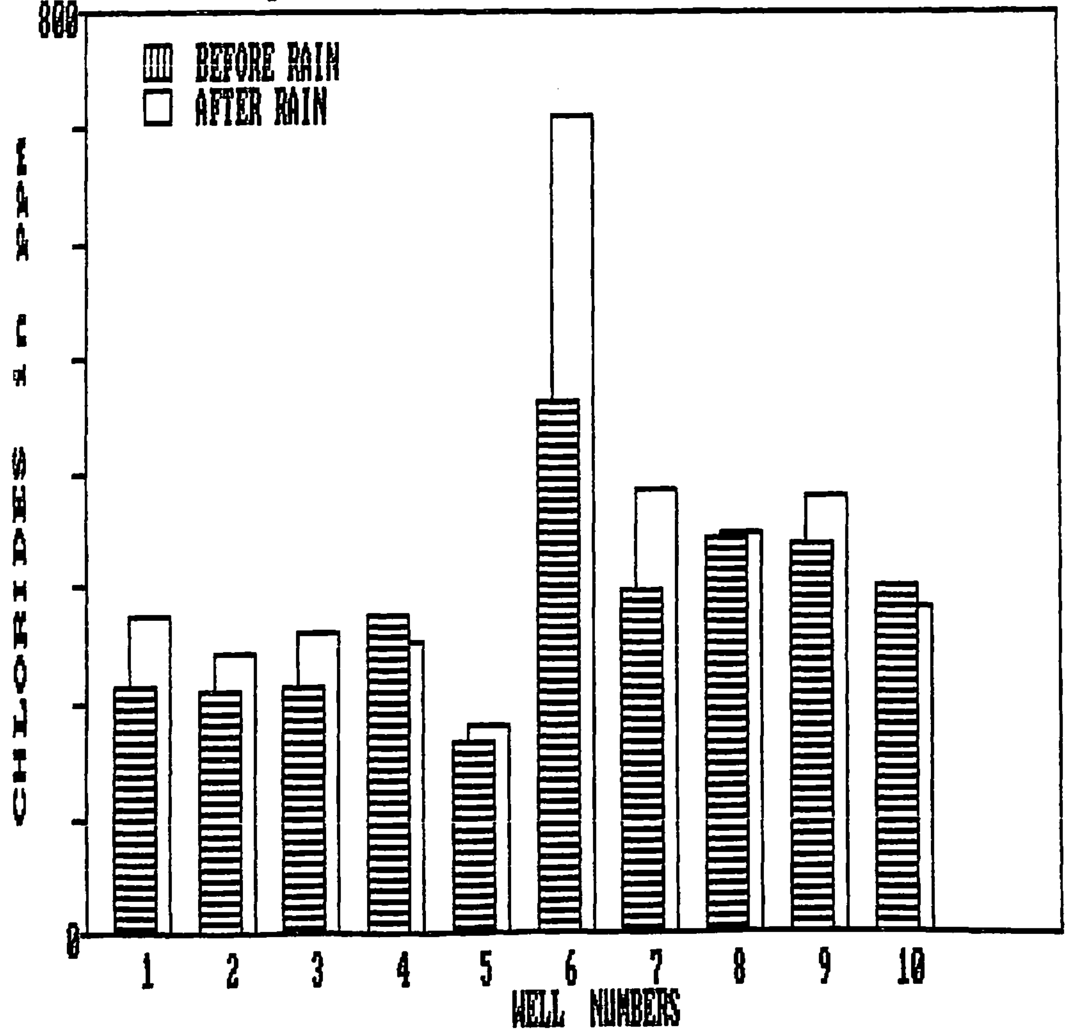


Fig.5.7 EFFECT OF RAIN ON WATER QUALITY (SO4)

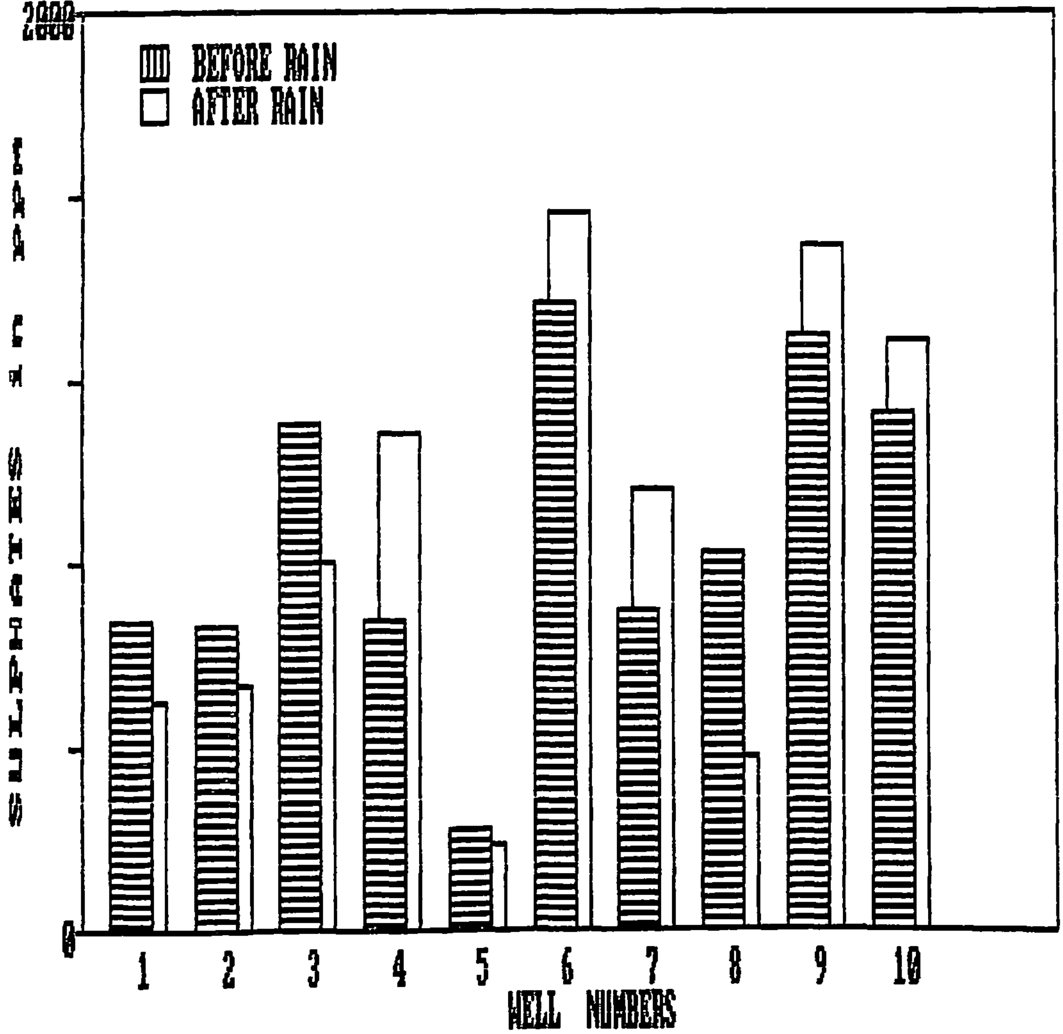


Fig.5.8 EFFECT OF RAIN ON WATER QUALITY (NO3)

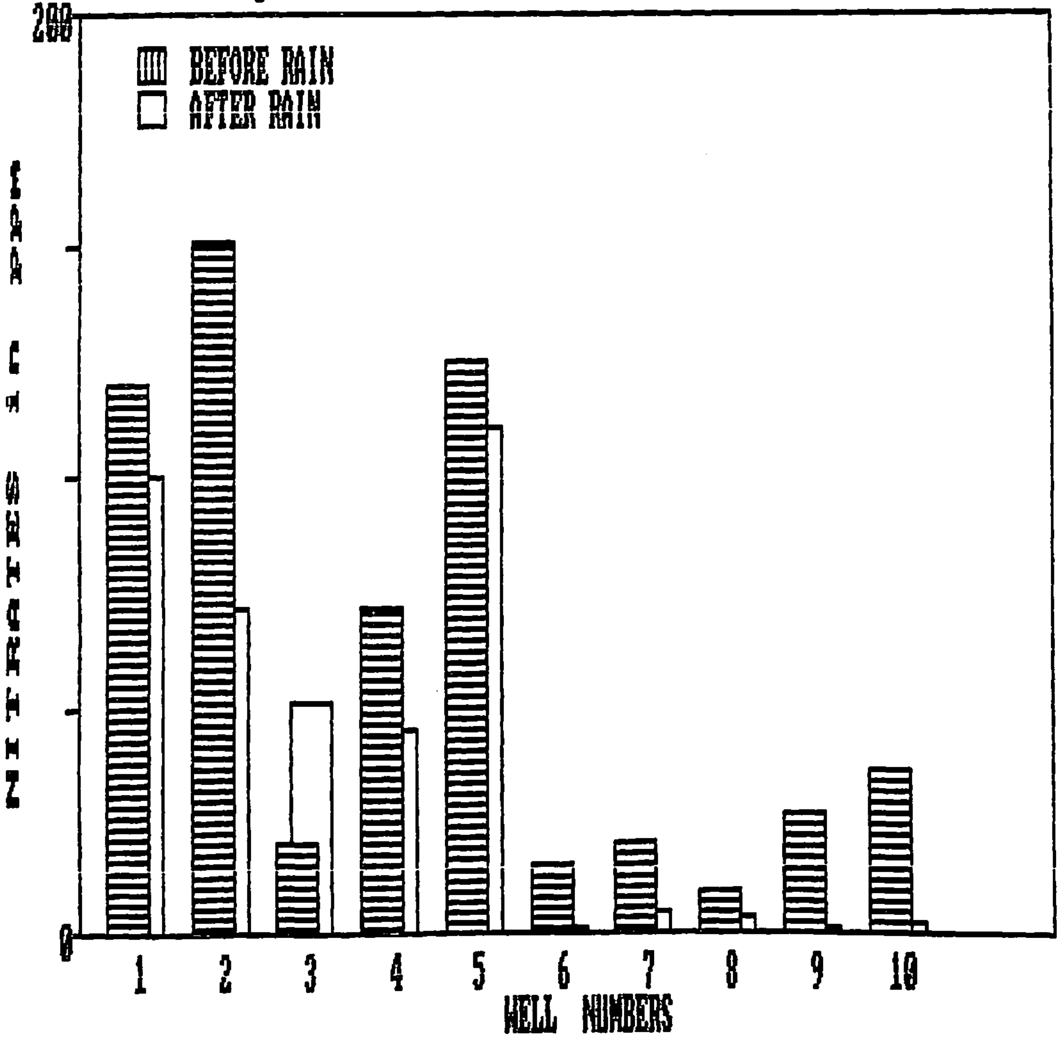


Fig.5.9 EFFECT OF RAIN ON WATER QUALITY (T.H.)

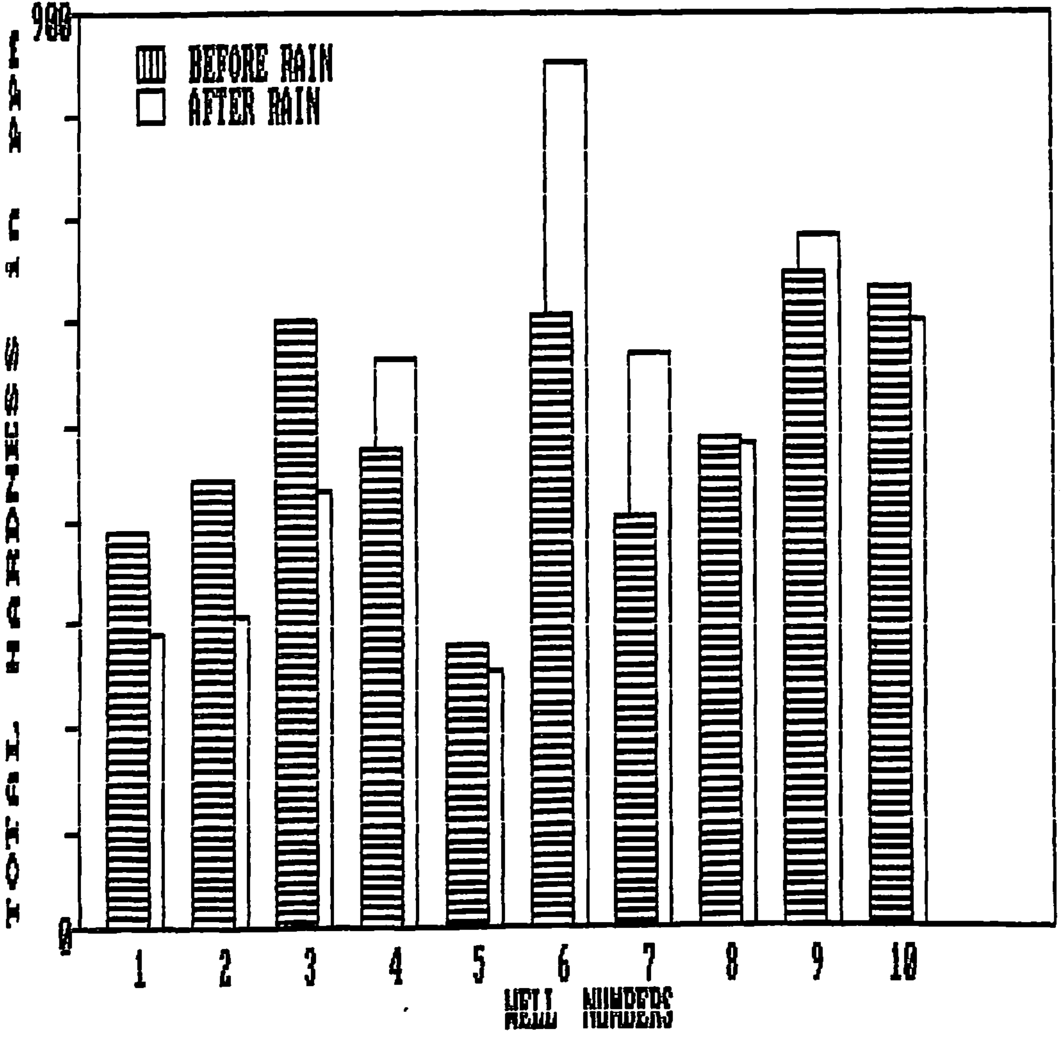
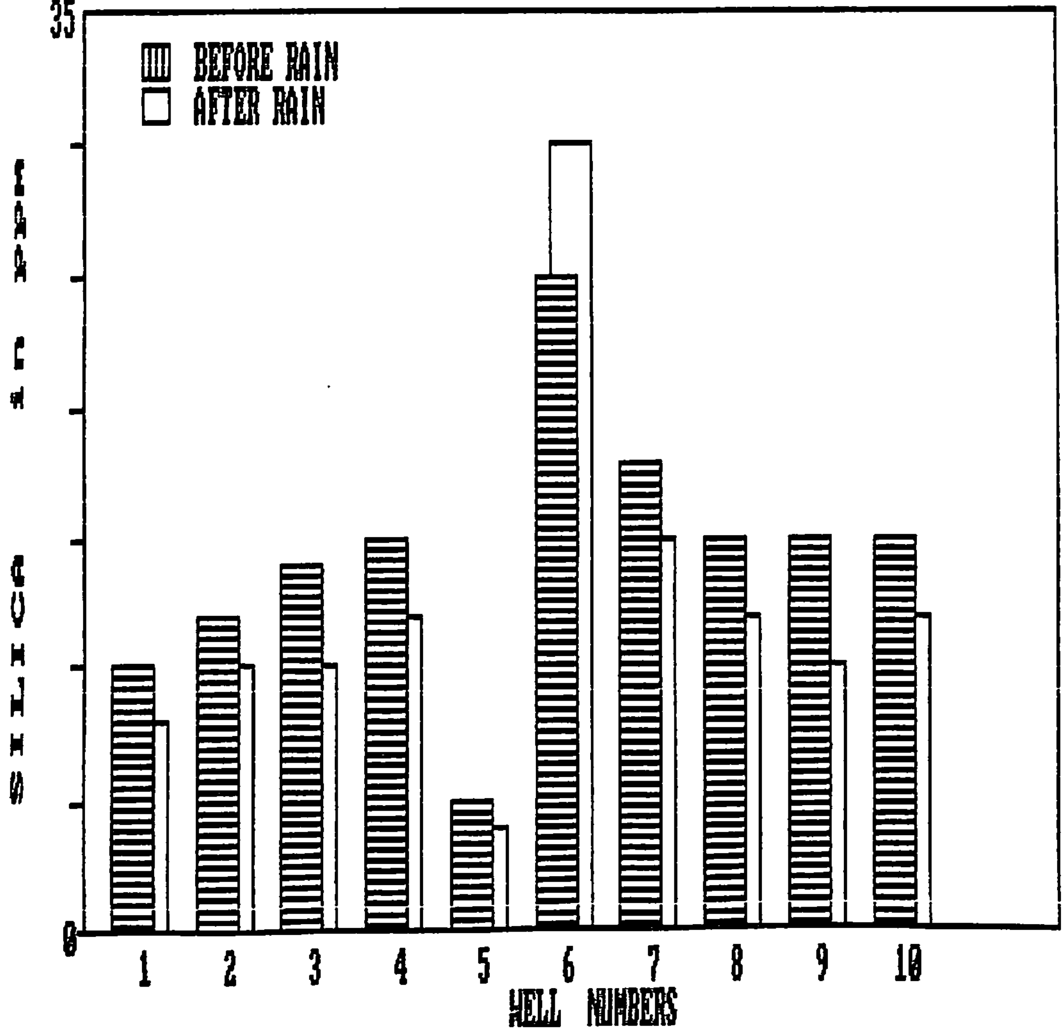


Fig.5.10 EFFECT OF RAIN ON WATER QUALITY (SiO2)



CHAPTER : 6

DEVELOPMENT OF MATHEMATICAL MODEL FOR GROUND WATER CONTAMINATION

6.1 INTRODUCTION

Ground water pollution is a serious problem due to both its immediate effects on users and its long term liability. The recent explosion of interest in ground water modelling can be attributed largely to urgent need for an objective , reliable way of predicting the movement of contaminants in ground water .In literature there is proliferation of both analytical and numerical solute transport models, all purporating to simulate contaminant movement in ground water under a variety of assumptions . In a few cases , contaminant transport models have been applied to field settings where there is information about an already existing contaminant plume. It is also tempting, to consider using models, to judge the suitability of proposed waste sites ,eg., hazardous waste sites. A generic data base might be used for this type of modelling because it would be too costly and time consuming, to collect site specific data for many sites (Pinder,1983).

Modelling studies and laboratory and field experiments have been conducted with the ultimate goal of understanding the behaviour of contaminants in ground water and for predicting the future conditions of ground water contamination. A number of books and reviews on numerical modelling of contaminant transport have been published, for example Pinder and Gray, (1977); Wang and Anderson, (1982); Bear and Venujt, (1987) and Huyakan and Pinder, (1983) . Due to inherent randomness of the transport processes , numerical models using either finite element or finite difference representations of the convective dispersive equations are inexact and contain certain errors. These errors are introduced due to assumptions made, uncertainties in model parameters, uncertainties involving the initial and boundary conditions and numerical technique used. Moreover errors in the field measurements are unavoidable . Ignoring the model errors and measurement errors would certainly diminish the effectiveness of using model studies and field observations, to understand the transport process and to predict future conditions of ground water contamination.

Guymen, (1970) and Nulluswami,(1972) used the finite element method based on the variational principle for the solution of the dispersion problem in a rectilinear flow field. The method was found to be applicable to dispersion dominant transport only .Smith, et al., (1973) compared the variational approach with the Galerkine method and concluded that the latter was more versatile .

Prakash,(1976) solved the equation for the transport of radioactive tracer through an adsorbing porous medium in the cylindrical polar system of coordinates by the finite element method. Guvansen and Volker, (1981) employed the Galarkine finite element method with special provisions to allow for the moving water table.This method was limited to the small change in the free surface only.

Hamilton, et al., (1985) selected three representative models for field comparison and concluded that the analytical models are easy to use and very inexpensive to run for uniform flow in homogeneous ,infinitely extensive aquifers.Aionala, (1987) has reviewed the work on the modelling of contaminant transport in saturated ground water systems.

David and Stolework, (1987) presented a summary table that references the various kinds of models studied and their applications in predicting chemical concentrations in ground water .Naik and Lakshminarayan, (1990) developed a model to predict the movement of contaminant in saturated aquifers. Both 1 dimensional(1D) and 2 dimensional(2D) flow field for contaminant movement are considered.

Ekebjaerg and Justesen, (1991) gave an extension of the finite difference scheme for the advection diffusion equation from 1-D into 2-D . Advection as well as diffusion are formulated as transport leading to a very efficient scheme which tends itself to vectorisation on super computers. The practibility of the scheme is tested using the lid driven cavity flow as a test case.

In this chapter an attempt has been made to develop mathematical model for contaminant transport in an aquifer. Mathematical models have been developed for three different cases ,for contaminant transport in porous medium. A computer programme has been developed in 'C' language to solve the mathematical expressions in the model.

6.2 TRANSFORMATION PROCESSES OF GROUND WATER CONTAMINATION

Because of increasingly stringent laws governing discharge of fluid wastes to surface waters, the alternative of discharge to the surface has become attractive. When the fluid waste is discharged on the land, it percolates into ground water through subsoil . The concentration of contaminants in the ground water gets reduced as number of natural purification processes takes place in the subsoil and ground water , which should be incorporated in the mathematical modelling of contaminant transport in the aquifer. The processes which are responsible for change of concentration of contaminants in subsoil ,will be discussed here before development of mathematical model.

The physical-chemical processes that prevail in the subsurface are dilution, buffering of pH, precipitation by reaction, hydrolysis, oxidation or reduction, filtration, volatilization, biological assimilation, radio active decay, membrane filtration and sorption.

6.2.1 Dilution

This process occurs in surface waters, but not effective over the short term in the vandose zone, especially in an arid region. In any location, dilution of wastes below the water table takes place for more slowly than in the surface streams. The one outstanding characteristic of contamination of ground water is the slow pace at which it is diluted and dispersed by the natural flow system. Fryberger, (1972) has represented convincing data and arguments to show how expensive and difficult, it may be to reclaim a contaminated aquifer, even considering natural attenuation due to flow and dilution.

6.2.2 Buffering or pH

Natural ground waters in arid region generally exhibit pH values between 6 and 9. The upper limit is established in nature by the reaction between carbon dioxide gas and either limestone or calcite in the soil. The lower limit found in shallow water is from non reactive rocks, such as quartz sandstone, or in ground water issuing from a mountain meadow.

The pH is a critical factor in many reactions involving contaminants, including processes that affect the stability of solid minerals and precipitants in the subsurface of a discharged fluid has pH outside of the range of 6 to 9, it is possible that drastic chemical reactions may occur, including the dissolution of such natural solids as calcium carbonate, iron oxyhydroxide, and manganese oxyhydroxide. Such reactions can exacerbate problems of contamination of ground water.

6.2.3 Precipitation by reaction

This process is important in purification of discharged fluids. In theory, it is possible to precipitate visually any dissolved contaminant if the appropriate precipitating agent is present. In nature however, the necessary precipitants do not commonly exist insufficient quantities or favourable locations to cause removal of toxic substances to safe levels. In natural ground waters and the enclosing solids, only certain species are normally present and available for reaction in meaningful concentrations. These species include dissolved calcium, magnesium, sodium, potassium, bicarbonate, sulphate, chloride and silica. In the surrounding porous solids we find the additional abundant components of iron, aluminium and possibly, carbonate and phosphate. Dangerous or undesirable contaminants that might be reduced to unsafe concentrations by that with these species include the following: Arsenic (precipitation by iron, aluminium and calcium). barium (by sulfate and carbonate), cadmium (by sulfate and carbonate), copper (by carbonate), fluoride (by calcium and phosphate), cyanide (by many metals, including iron) iron (by silica), lead(by carbonate, sulfate and phosphate), mercury (reduced from precipitated bicarbonate and chloride), molybdenum (by iron and aluminum at proper pH), sulfur (by chloride), zinc (by carbonate and silica), and radium (by sulphate and carbonate). Evidence that such precipitation reactions to occur and may control concentrations in ground water has been given by many researchers. However, despite the numerous possibilities for purification offered by precipitation reactions, many examples of contamination of ground water exist involving species that might be expected to precipitate, such examples demonstrate the failure of precipitation to protect ground water in many cases.

6.2.4 Hydrolysis and Precipitation

This type of reaction occurs when a dissolved contaminant reacts with water, with release of either a hydrogen ion or a hydroxyl ion. The best known example involves , the hydrolysis of dissolved ferric ion with precipitation of ferric hydroxide. On the acid side, molybdenum is thought to hydrolyse to molybdate ion and precipitate with compounds of iron and aluminium under acid conditions (Legendre and Runnells , 1975). In an aerated environment, such as the vandose zone in an acid region, the concentration of dissolved iron can be held to very low values by hydrolysis and precipitation of ferric oxyhydroxide (Hem ,1973). However in oxygen deficient zones, such as commonly exist in the phreatic zone, high concentrations of iron can occur in the ferrous (Fe^{2+}) form. High rates of infiltration or flooding by waters into the vandose zone, such as might occur beneath a disposal lagoon, may produce anaerobic conditions and lead to solubilization of some metals.

The apparent importance of hydrolysis in both the vandose and phreatic zones is the result of the simple requirement that water represent, in contrast to other precipitation reactions that demand the presence of specific precipitating agents.

6.2.5 Precipitation due to Oxidation or Reduction

Relatively insoluble oxides of certain contaminants are known, for example copper, iron, manganese, mercury and nickel. Aerobic conditions favourable for the development of these oxides will normally be found in the vandose zone as possibly in the upper parts of the phreatic zone. Deep in the phreatic zone or in swampy or flooded vandose environments, anaerobic conditions may prevail and head to the mobilisation of some species.

In some instances reducing conditions are more favourable for removing possible contaminants from water one example is that of chromium, which is highly soluble and mobile in the oxidised state (Cr+6, chromate or dichromate ion), but quite insoluble as the solid oxide or hydroxide of the reduced form (Cr+3). natural reducing conditions can also theoretically cause the formation of such native elements as arsenic, copper, mercury, selenium, silver, and lead, each of which is quite insoluble. We do find significant quantities of natural copper, mercury and silver, in mineral deposit and native selenium appears to be a stable phase in some series (Goering, et al., 1968). In reducing environments, bacteria can convert dissolved sulfate to sulfide and dissolved nitrate to ammonia or nitrogen gas reaction of the sulfide with certain metals will produce highly insoluble precipitates, such as the sulfides of arsenic, cadmium, copper, iron, lead, mercury molybdenum, nickel, silver and zinc.

In terms of usefulness and reliability for purification, the processes of oxidation and reduction can be of significant value if the necessary environmental conditions are maintained and managed. Considerable reliance can probably be placed on the process of oxidation for purification of wastes in the vandose zone. Processes of reduction may be more risky because some undesirable species can be mobilised, such as iron (Apgas and Langmuir, 1971) and manganese. One well known benefit of the process of reduction is the denitrification of dissolved nitrate from sewage effluent, with significant removal of nitrogen possible under a carefully programmed mode of disposal (Bouwer, 1974).

6.2.6 Mechanical Filtration

This process will generally be of help in removing dissolved contaminants. Exceptions to this might occur following the formation of precipitates by means of one of the processes mentioned earlier. Such precipitates would be filtered out mechanically as the water moves through the porous medium. Iron is the species most likely to exhibit this behaviour, it is well established that much of the total iron in aerated waters is present as particulate ferric hydroxide (Hem, 1973). Manganese probably behaves in a similar fashion. If these possible particulates sort or include other dissolved species as they form, the filtration would remove these other species as well. Of course, most particulates originally present in the discharge would be filtered out quickly during downward movement through the vandose zone.

6.2.7 Volatilization and Loss as a Gas

Some inorganic species can be effectively removed from discharged waters by volatilization. Perhaps the best known example is that of the bacterial reduction of dissolved sulfate to hydrogen sulfide gas, with less of the hydrogen sulfide to the atmosphere (Kellogg , et al., 1972). Mercury in solution can also be volatilized in anaerobic environments (Lagerwerff, 1972) or by reaction with dissolved humic acids (Alberts ,et al., 1974). Several organic compounds of arsenic are volatile, and escape of arsenic as a gas has been demonstrated for both aerobic and anaerobic solids (Woolson, et al., 1971). Based on its similarity to sulphur, we might also expect selenium to be subject to volatilization (Lakin, 1973). And of course, the microbial reduction of nitrate to ammonia a nitrogen gas is well documented (Bouwer, 1974), although the failure of this mechanism to numerous examples of pollution of ground water by nitrate (Minear and Patterson, 1973).

Volatilization as a means of purification is poorly understood, and we probably run considerable risk in relying upon it to any great extent. The extension to this would be the conversion of dissolved sulfate and nitrate to gases; these processes are known to be effective if managed properly.

6.2.8 Biological Degradation

Biological degradation or assimilation is very important in removal of organic and biologic contaminants. Many organic substances would be removed or attenuated by biological activity in the subsurface, especially in the oxidizing environment of the normal vandose zone. The biologic involvement of sulfate and nitrate have already been mentioned. In addition, arsenic, cyanide, mercury, and selenium are likely candidates for biological fixation or volatilization. Molybdenium is strongly assimilated and concentrated by plants that are nitrogen fixed (Johnson, 1966).

Biological processes could be of great value in managing discharges to the subsurface, but at present we know so little of the principles involved that each case must be studied and evaluated on its own.

6.2.9 Radioactive Decay

This mechanism is of value in the management of radioactive wastes by means of storage in the subsurface. Winograd, 1974) has discussed the attractiveness of storage of high level radioactive wastes in the vandose zone of arid environments. It seems clear that storage in their environment is possible with a high degree of safety for periods of times from thousands to hundreds of thousands of years, during which time the wastes would lose much of their activity through processes of decay. There is a substantial history of disposal of radioactive wastes to the subsurface near nuclear facilities in the United States, and in humid regions serious problems of contamination of ground water can be expected. It is the lack of recharge to more contaminants to the ground water that makes disposal to the vandose zone in arid regions is so attractive.

6.2.10 Membrane Filtration

Membrane filtration is a topic that is greatly in focus at the present time in the literature of the geochemistry of subsurface waters. Some observed data on the pressure and salinity of formational waters cannot be explained by simple gravitational flow of water or by dissolution of minerals. In such cases, the anomalous data may be related to osmotic pressures and filtration of salts across beds of shale.

Pressure difference of several hundred atmospheres can theoretically be generated across a membrane if fresh water exists on one side and a saturated one on the other (Henshaw, 1972).In terms of purification of wastes in the subsurface, it is theoretically possible that a discharged waste water could be diluted by osmotic transfer of water across a clay rich aquitard. Conversely, one can speculate on the possibility of forcing waste fluids through a clay liner on the bottom of a disposal pond, anticipating some removal of dissolved salts, and passage of a relatively more pure fluid. However at this stage in development of the technology of disposal, powerful pilot studies would be required to rest the efficiency of such a scheme.

6.2.11 Sorption

Protection of ground water by various processes of sorption is another important method. Clay, metallic oxides and hydroxides, and organic matter can all be good substrates for sorption of various dissolved species with the exception of fractured shale or sandstone, consolidated bedrock will generally not be very effective as a sorbent. Virtually every ionic species and many non electrolytes will be solved and removed to some extent as ground water moves through an aquifer, of the ions, only chloride, and to a lesser extent sulfate and nitrate, seem to pass through soils and aluminium without significant sorption.

The troubling aspect, of sorption as a means of purifying waste waters in the vandose zone is that the process can be highly specific in its action, both as to the dissolved substance and the solid substrate. Molybdenum offers an interesting example. Dissolved molybdenum is sorbed strongly by most soils that exhibit an acidic reaction with water, but molybdenum will move freely through alkaline soils (Katz and Runnells, 1974). Similarly, fluoride is sorbed much more extensively, by acidic soils than by alkaline soils (Bower and Thatcher, 1967). Perhaps the most revealing study of the effect of pH on sorption of ions is that (Griffin, et al., 1976), in which they determined the extent of removal by clay minerals of a solute or heavy metals from sanitary landfills. They found a very great variation in the extent of sorption, depending on the metal involved and the pH of the solution.

It is clear that the processes of sorption depend on the type of contaminant and on the physical and chemical properties of both solution and porous medium. Under favourable circumstances sorption can be wonderfully effective in purifying waters, as evidenced by the extensive use of ion exchange media in water treatment. One should keep in mind, however, that when a contaminant ion is sorbed, some other change must also take place to compensate for loss of the charged species from solution. In ion exchange reactions, a different ion is released by the solid to the solution. the ions released to water from a previously uncontaminated soil or alluvium will almost certainly be less harmful than most of the contaminants of concern here. We can place considerable reliance on the processes of sorption to help us to protect ground water, but each case will be different and tests must be run to assure an adequate degree of absorption and retention.

6.3 GROUND WATER MODELLING

Ground water modelling is a tool that can help to analyse many ground water problems. Models are useful for reconnaissance studies preceding field investigations, for interpretive studies following the field programme, and for predictive studies to estimate future field behavior. In addition to these applications,models are useful for studying various types of flow behavior by examining hypothetical aquifer problems . Before attempting such studies ,however one must be familiar with ground water modelling concepts,model usage and modelling limitations.

6.3.1 Types of Ground water Models

A variety of types of ground water models have been developed . There are four general types of ground water models. The problem of ground water flow is normally described by one equation, usually in terms of hydraulic head.The resulting model providing a solution for this equation is referred to as a GROUND WATER FLOW MODEL.If the problem involves water quality,then one or more additional equation(s) is/are provided. Such a model is referred to as a SOLUTE TRANSPORT MODEL. Problems involving heat also require an equation in addition to the ground water flow equation similar to the solute transport equation but now in terms of temperature.This model is referred to as a HEAT TRANSPORT MODEL. Finally,a DEFORMATION MODEL combines a ground water flow model with a set of equations that describe aquifer deformation.

Ground water flow models have been extensively used for such problems as regional aquifer studies, basin analysis and near well performance.More solute transport models have been used to aid in understanding and predicting the effects of problems involving hazardous wastes.Some of the applications include sea water intrusion, underground storage of radioactive wastes, movement of leachate from sanitary land fills,ground water contamination from holding ponds and waste injection through deep wells.Heat transport models have been applied to problems concerning geothermal energy ,heat storage in aquifers,and thermal problems associated with high level radioactive waste storage.Deformation models have been used to examine field problems where fluid withdrawl has decreased pressures and caused consolidation.This compaction of sediments results in subsidence at the land surface.

This classification of ground water models are by no means complete.All of the above models can be further subdivided into those describing porous media and those describing fractured media. Ground water models can be combined with statistical techniques in an effort to characterise uncertainty in model parameters.In addition,there are other models that deal with multifluid flow (eg. oil and water)and multiphase flow (eg. unsaturated zone problems).Some resource management models combine flow models and linear programs,which are used to optimize certain decision parameters like pumping rates.

6.3.2 Limitations and Sources of Error in Modelling

In order to avoid model misuse, it is important to know and understand the limitations and possible sources of error in numerical models. All numerical models are based on a set of simplifying assumptions, which limit their use for certain problems. To avoid applying an otherwise valid model to an inappropriate field situation, it is not only important to understand the field behavior but also to understand all of the assumptions that form the basis of the model. An areal (two-dimensional) model, for example, should be applied with care to a three dimensional problem involving a series of aquifers, hydrologically connected by confining beds, since the model results may not be indicative of the field's behavior. Errors of this type are considered

CONCEPTUAL ERRORS.

In addition to these limitations, there are several potential sources of error in the numerical model results. First, replacement of the differential equations of the model by a set of algebraic equations introduces TRUNCATION ERROR; that is, the exact solution of the algebraic equations differs some what from the solution of the original differential equations . Second, the exact solution of the algebraic equations is not obtained due to ROUND OFF ERROR ,as a result of finite accuracy of computer calculations. Finally and perhaps most important ,aquifer description data (for example, transmissivities, storage coefficients ,porosity,permeability and the distribution of heads within the aquifer,etc.) are seldom known accurately or completely, thus producing DATA ERROR.

The level of truncation error in computed results may be estimated by repeating runs or portion of runs with smaller space and/or time increments. Significant sensitivity of computed results to changes in these increment sizes indicates a significant level of truncation error and the corresponding need for smaller spatial and/or time increments.Compared to the other error sources, round-off error is generally negligible.

Error caused by erroneous aquifer description data is difficult to assess since the true aquifer description is never known.A combination of core analysis,aquifer tests and geological studies often give valuable insight into the nature of transmissivity ,storage coefficients, and aquifer geometry. However,much of this information may be very local in extent and should be regarded carefully when used in a model of a large area.

6.3.3 Numerical Modelling

Numerical models provide the most general tool for the quantitative analysis of ground water applications. They are not subject to many of the restrictive assumptions required for familiar analytical solutions. In spite of the flexibility of numerical models, their mathematical basis is actually less sophisticated than that of the analytical methods. Unfortunately, to the would-be-model user numerical methods seem complex. This perception results from two primary causes; the first is that the number of alternatives methods appears to be very large. Actually, the number of basic alternative methods is few; only the number of minor variations is large. Each of these variations contributes to the second cause, unfamiliar terminology, by introducing new names and jargon. To develop a numerical model of a physical system (in our case, an aquifer), it is first necessary to understand how that system behaves. This understanding takes the form of laws and concepts (e.g., Darcy's law and the concept of storage). These concepts and laws are then translated into mathematical expressions, usually partial differential equations, with boundary and initial conditions . Numerical methods provide a means for solving these equations in their most general form. Numerical solution normally involves approximating continuous (defined at every point) partial differential equations with a set of discrete equations in time and space. Thus, the region and time period of interest are divided in some fashion, resulting in an equation or set of equations for each subregion and time step. These discrete equations are combined to form a system of algebraic equations that must be solved for each time step.

6.4 MATHEMATICAL MODEL FOR GROUND WATER CONTAMINATION

The purpose of model that simulates contaminant transport in ground water, is to compute the concentration of a dissolved chemical species in an aquifer at any specified place and time . As transport due to convection and dispersion depends on the velocity of ground water flow , the mathematical model must solve at least two simultaneous partial differential equations , one is the equation of flow ,from which ground water velocities are obtained ,and the second is the solute transport equation ,describing the chemical concentration in ground water. Mathematical modelling of ground water contamination begins with differential equations that express conservation of mass, momentum and chemical species.Then these equations are approximated over the various subdomains being considered and then these approximate equations are solved. The mathematical simulation of subsurface contaminant plume is obtained by solving the partial differential flow equations, subject to boundary and initial conditions.

The theory behind the equation describing solute transport has been well documented in literature (Bear,1979), changes in chemical concentration occurs within a dynamic ground water system primarily as results of four distinct processes:

(1) Convective transport , in which dissolved chemicals are moving with the flowing ground water,

(2) Hydrodynamic dispersion, in which molecular and ionic diffusion and small scale variations in the velocity of flow through porous media causes , the paths of dissolved molecules and ions to diverge or spread from the average direction of ground water flow,

(3) Fluid sources, where water of one composition is introduced into and mixed with water of different composition, and

(4) Reactions in which some amount of a particular dissolved chemical species may be added to or removed from the ground water due to chemical, biological and physical reactions in the water, or between the water and the solid aquifer materials.

A generalised form of the solute transport equation, in which the above terms are incorporated to represent chemical reactions and solute concentrations both in the pore fluid and on the solid surface is as follows (Grove ,1976 ; Bear,1979):

$$\frac{\delta}{\delta t}[\ nC + (1-n)S\ ] + \frac{\delta}{\delta xi}[\ nC.ui \ - nDij.\frac{\delta C}{\delta xi}\ ] = \text{CHEM} + Q \qquad ....(6.1)$$

Where , C is the concentration of the dispersing mass in the liquid phase i.e. the mass of solute per unit volume of solution (ML^{-3}), S is the concentration of dispersing mass in solid phase i.e. the mass of the solute absorbed per unit volume of the porous medium (ML^{-3}), n is the porosity of the porous medium ($L^3 L^{-3}$) .

Dij (i,j =1,2,3) is the hydrodynamic dispersion coefficient tensor (L^2T^{-1}) ; ui is the Seepage Velocity in ith direction and xi (i=1,2,3) is the cartesean co-ordinate. CHEM is the rate of production / decay of the solute in reactions ($ML^{-3} T^{-1}$).

Q is the injection or withdrawal rate. $Q = (q_1 - q_2)C^*$; where, q_1 is the volumetric fluid injection rate of the fluid per unit volume of the medium (T^{-1}),q_2 is the volumetric fluid withdrawal rate of the fluid per unit volume of the medium (T^{-1}) and C^* is the concentration of the source fluid.

The general mathematical equation describing fluid and mass transport in granular materials are applicable to both the gaseous and aqueous phases. The differential equation describing a homogeneous and isotropic convective dispersion system may be expressed as :

$$\frac{\delta}{\delta xi}\left(Dij\frac{\delta C}{\delta xi} - ui.C\right) = \frac{\delta C}{\delta t} + Q \qquad \ldots.(6.2)$$

This equation is obtained from equation (6.1) after neglecting the change in concentration of contaminant in solid phase and any production /decay of the solute . For a unidirectional steady flow in x direction (i =1) , the equation (6.2) becomes

$$DL \frac{\delta^2 C}{\delta x^2} + DT \frac{\delta^2 C}{\delta x^2} - u \frac{\delta C}{\delta x} = \frac{\delta C}{\delta t} + Q \qquad \ldots.(6.3)$$

where, DL, (=D11) ,DT (=D22) are the dispersion coefficients in longitudinal and transverse direction, respectively .

If there is no lateral variation in concentration, then we can neglect the term DT and considering DL = D, now the equation (6.3) becomes

$$D \frac{\delta^2 C}{\delta x^2} - u \frac{\delta C}{\delta x} = \frac{\delta C}{\delta t} + Q \qquad \ldots.(6.4)$$

The first term in the above equation represents the transport of contaminant due to dispersion and second term represents the transport of contaminant due to convection. The third term in the equation (6.4) indicates the contaminant storage in the region occupied by the fluid (liquid phase) and the fourth term represents injection or withdrawl rate of the source fluid .

Other transformation processes such as chemical reaction, adsorption and radioactive decay which take place in the control region should also be considered. To consider the chemical reactions and/or adsorption in the transport equation(6.4),it is assumed that changes in contaminants concentration resulting from chemical reaction and/or adsorption are additional components in the dispersion equation.

For an adsorbing dispersion system in which the concentration of the contaminant in the liquid and solid phases are denoted by C and S, respectively. Considering both liquid and solid phases,the equation (6.4)is written as

$$D \frac{\delta^2 C}{\delta x^2} - u \frac{\delta C}{\delta x} = \frac{\delta C}{\delta t} + \frac{1-n}{n} . \frac{\delta S}{\delta t} + Q \qquad ....(6.5)$$

where, n is the porosity of the porous medium. The fourth term in the equation (6.5) represents the contaminant storage in the control region, occupied by the particles in solid phase.

The relation between 'C' and 'S' under equilibrium conditions and non equilibrium conditions may be given by following equations. The equilibrium isotherm

$$S = a'C \qquad ....(6.6a)$$

or the non equilibrium relationship

$$(\delta S/\delta t) = a(C - bS) \qquad ....(6.6b)$$

where, a , a' and b are the reaction rate constants.The equation (6.6b) represents a first order reversible reaction.Now if the concentration of the contaminant in the solid phase is much less than the concentration in the liquid phase, that is $bS << C$, the equation (6.6b) changes to

$$(\delta S/\delta t) = aC \qquad \ldots.(6.6c)$$

The equation (6.6c) represents an irreversible reaction of first order.If a contaminant undergoes radioactive decay during its transport through a nonadsorbing porous medium, then the change in concentration of contaminant may be expressed as

$$(\delta C/\delta t) = -\mu C \qquad \ldots.(6.7)$$

where, 'μ' is the radioactive decay constant. It is inversely proportional to the half life of the particular contaminant and is defined by the relation,

$$\exp.(-\mu T) = 1/2 \qquad \ldots.(6.8)$$

where, T is the time required to reduce the concentration of contaminant by half (due to radioactive decay alone). To consider presence of radioactive decay in transport equation (6.4), it is assumed that changes in contaminant concentration, resulting from chemical reaction and/or adsorption are additional components in the dispersion equation .When the radioactive decay is considered, the dispersion equation (6.4) becomes

$$D \frac{\delta^2 C}{\delta x^2} - u \frac{\delta C}{\delta x} - \mu C = \frac{\delta C}{\delta t} + Q \qquad \ldots .(6.9)$$

During contaminant transport both radioactive decay and adsorption of a solute take place in the porous medium flow, then the concentration equation(6.5) becomes

$$D \frac{\delta^2 C}{\delta x^2} - u \frac{\delta C}{\delta x} - \mu C - \mu \frac{1-n}{n} S = \frac{\delta C}{\delta t} + \frac{1-n}{n} \frac{\delta S}{\delta t} + Q \qquad \ldots .(6.10)$$

The third and fourth terms in the above equation (6.10) represent radioactive decay of solute in liquid and solid phases, respectively .

For the complete solution of contaminant transport in porous medium problem, in which dispersion ,adsorption and radioactive decay of solute take place,as discussed above, involves the solution of partial differential equation(6.10) and any one of the reaction rate constant equation(6.6) along with appropriate initial and boundary conditions on both C and S for prescribed medium and fluid parameters.

Now we will discuss ,above developed expressions (mathematical model) for the following three cases:

Case -I. Contaminant transport in porous medium subject to initial concentration of contaminant, both in liquid and solid phases are zero, and concentration at end boundary is zero.

Case -II. Contaminant transport in porous medium when reversible reaction takes place inside the fluid and zero flux at the end boundary.

Case -III. Contaminant transport in porous medium when heterogeneous chemical reaction takes place at end boundary.

6.4.1 Mathematical Model for Case -1

The mathematical model being discussed here involves simultaneous dispersion and adsorption in steady unidirectional seepage flow through semi infinite, homogeneous and isotropic subjected to known input concentration of contaminants .

Consider a semiinfinite porous medium in a unidirectional flow field in which the input concentration of contaminant vary exponentially is given by

$$C = Co\ e^{yt} \qquad \ldots.(6.11)$$

where, Co is the reference concentration and y is a constant.

When we consider both dispersion and adsorption simultaneously ,the concentration equation (6.5) is applicable . Here it is assumed that rate of injection of fluid equals the rate of withdrawal of the fluid i.e. , $q_1 = q_2$. The relation between the concentration of contaminant in the liquid and that in the solid phase is of non equilibrium type and the adsorption equation that relates C to S,under non equilibrium conditions, is given by nonequilibrium relationship.

$$\frac{\delta S}{\delta t} = a(C-bS) \qquad \text{....(6.12)}$$

As discussed earlier the simultaneous dispersion and adsorption problem for the flow system under consideration may be expressed by the equation.

$$D.\frac{\delta^2 C}{\delta x^2} - u\frac{\delta C}{\delta x} = \frac{\delta C}{\delta t} + \frac{1-n}{n}\frac{\delta S}{\delta t} \qquad \text{....(6.13)}$$

The initial and boundry conditions for the concentration of the solute in the liquid and solid phases are:

$$C(x,0) = 0 \qquad x \geq 0 \qquad \text{....(6.14)}$$

$$C(0,t) = C_o e^{\gamma t} \qquad t > 0 \qquad \text{....(6.15)}$$

$$C(\infty,t) = 0 \qquad t \geq 0 \qquad \text{....(6.16)}$$

$$S(x,0) = 0 \qquad x \geq 0 \qquad \text{....(6.17)}$$

The above conditions indicate that the solute concentration in both phases is initially zero and the concentration at end boundry remains zero. So to solve the porous media flow problem we have to solve the above equations (6.12) ,(6.13) and equations (6.14) to (6.17), for prescribed values of fluid and porous medium parameters.

6.4.2 Mathematical Model for Case II

The mathematical model being discussed here involves a reversible reaction inside the liquid and the flux at the end boundry is zero. Remaining conditions are same as in Case I. The initial and boundry conditions on the concentration of the solute in the liquid and solid phases can be given as follows.

For the given conditions, we have the following governing equations as discussed earlier:

$$\frac{\delta S}{\delta t} = a\,(C-bS) \qquad \ldots.(6.12)$$

and

$$D.\frac{\delta^2 C}{\delta x^2} - u\frac{\delta C}{\delta x} = \frac{\delta C}{\delta t} + \frac{1-n}{n}\frac{\delta S}{\delta t} \qquad \ldots.(6.13)$$

and the initial and boundry conditions are :

$$C(x,0) = 0 \qquad x \geq 0 \qquad \ldots.(6.18)$$

$$C(0,t) = Co\, e^{\gamma t} \qquad t > 0 \qquad \ldots.(6.19)$$

$$\frac{\delta C}{\delta x}(\infty,t) = 0 \qquad t \geq 0 \qquad \ldots.(6.20)$$

$$S(x,0) = 0 \qquad x \geq 0 \qquad \ldots.(6.21)$$

The above conditions indicate that the solute concentration in both phases is initially zero, same as case I, and flux at end boundry is also zero . So to solve the porous media flow problem we have to solve the above equations (6.12) ,(6.13) and equations (6.18) to (6.21), for prescribed values of fluid and porous medium parameters.

6.4.3 Mathematical Model for Case - III

The theory that follows is continued to simultaneously dispersion and adsorption in steady unidirectional seepage flow through semi infinite, homogeneous and isotropic porous media. The dispersion systems to be considered are subject to input concentration of contaminant that vary exponentially with time. A heterogeneous chemical reaction takes place at the end boundary. Other conditions are similar as for case -I and case -II. The governing equations are as follows:

$$\frac{\delta S}{\delta t} = a\,(C-bS) \qquad \ldots.(6.12)$$

$$D.\frac{\delta^2 C}{\delta X^2} - u\frac{\delta C}{\delta x} = \frac{\delta C}{\delta t} + \frac{1-n}{n}\frac{\delta S}{\delta t} \qquad ....(6.13)$$

and the initial and boundary conditions are :

$$C(x,0) = 0 \qquad x \geq 0 \qquad ....(6.22)$$

$$C(o,t) = Co\ e^{yt} \qquad t > 0 \qquad ....(6.23)$$

$$\frac{\delta C}{\delta x}(\infty,t) = -kC(\infty,t) \qquad t > 0 \qquad ....(6.24)$$

$$S(x,0) = 0 \qquad x > 0 \qquad ....(6.25)$$

$$S(\infty,t) = 0 \qquad t \geq 0 \qquad ....(6.26)$$

where, k is the heterogeneous chemical reaction rate constant of first order.

The above conditions indicate that the solute concentration in both phases is initially zero and heterogeneous chemical reaction takes place at end boundary. So to solve the porous media flow problem we have to solve the above equations (6.12) ,(6.13) and equations (6.22) to (6.26), for prescribed values of fluid and porous medium parameters.

Mathematical analysis of the mathematical models for the above three cases will be done in chapter -7.

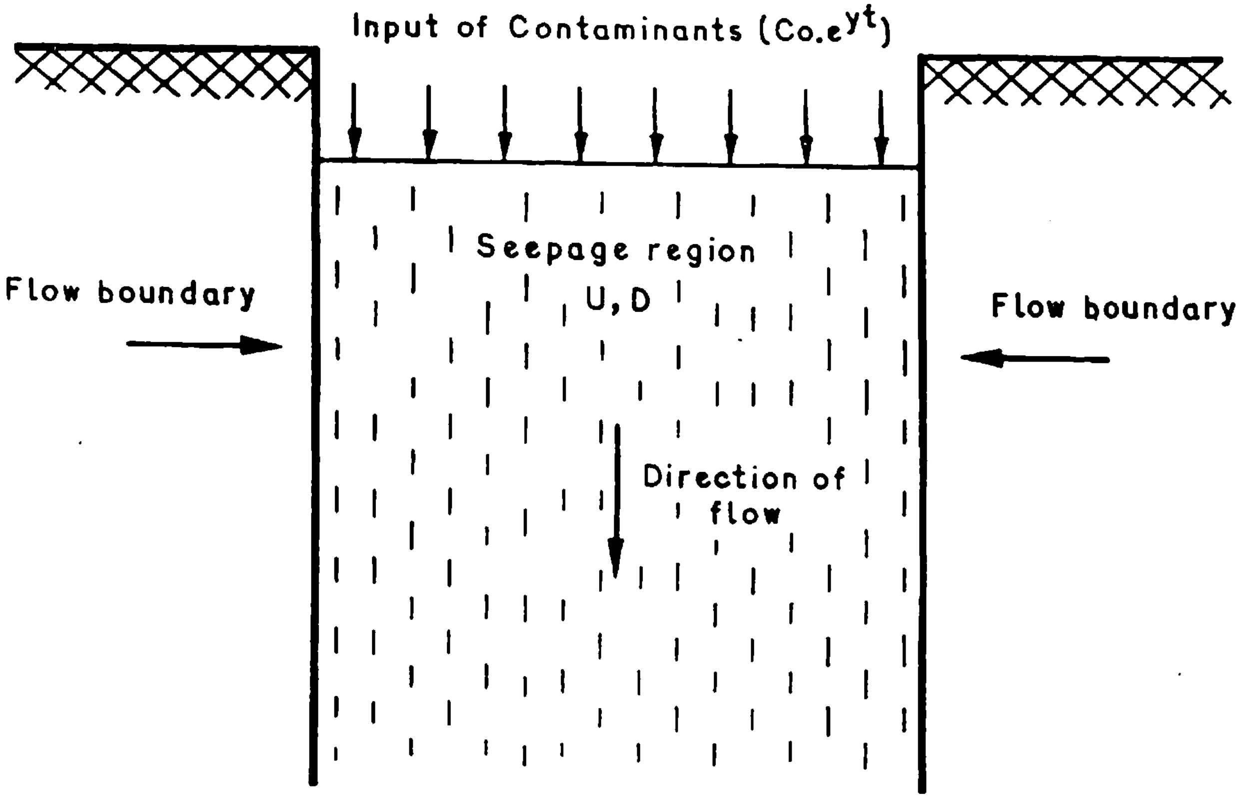


Fig. 6.0 Diagram showing semi infinite porous medium in unidirectional flow field.

6.5 CONCLUSION

In this chapter mathematical models for contaminant transport in porous medium for three cases have been developed. The three cases are :

1. Contaminant transport in porous medium subject to initial concentration of contaminant, both in liquid and solid phases are zero, and concentration at end boundry is zero.

2. Contaminant transport in porous medium when reversible reaction takes place inside the fluid and zero flux at the end boundry.

3. Contaminant transport in porous medium when heterogeneous chemical reaction takes place at end boundry.

Different physical, chemical and biological transformation processes involved in the ground water contamination have also been discussed in this chapter. The mathematical analysis of the mathematical models will be done in chapter - 7.

CHAPTER : 7

MATHEMATICAL ANALYSIS OF THE MODEL FOR CONTAMINANT TRANSPORT IN POROUS MEDIUM

The analysis of the mathematical model as discussed in chapter 6, will be done in this chapter. The mathematical solution of the model discussed for all the three case will be done by applying some standard tranformations and Laplace transformation. The simplified equations will be solved with the help of computer program developed in 'C' language given in appendix A1. The developed model will be applied to the Khetri Copper Complex.

7.1 SOLUTION OF THE MATHEMATICAL MODEL FOR CASE -I

To analyse the mathematical model discussed in article 6.4.1. , we have to solve the equations (6.12) and (6.13), subject to initial and boundary conditions given by equations (6.14)-(6.17), for prescribed values of media and fluid parameters. The governing equations are as follows:

$$\frac{\delta S}{\delta t} = a(C-bS) \qquad \ldots.(6.12)$$

$$D.\frac{\delta^2 C}{\delta x^2} - u\frac{\delta C}{\delta x} = \frac{\delta C}{\delta t} + \frac{1-n}{n}\frac{\delta S}{\delta t} \qquad \ldots.(6.13)$$

And subjected to following initial and boundary conditions for the solute in the liquid and solid phases.

$$C(x,0) = 0 \quad ; \quad x \geq 0 \qquad \ldots.(6.14)$$

$$C(0,t) = Co\ e^{\gamma t} \quad ; \quad t > 0 \qquad \ldots.(6.15)$$

$$C(\infty,t) = 0 \quad ; \quad t \geq 0 \qquad \ldots.(6.16)$$

$$S(x,0) = 0 \quad ; \quad x \geq 0 \qquad \ldots.(6.17)$$

Now, by putting

$$V = C-bS \qquad \ldots.(7.1)$$

equation (6.12) becomes

$$\frac{\delta S}{\delta t} = aV \qquad \ldots.(7.2)$$

The equation (7.1), can be written as

$$C= V+bS \qquad \ldots.(7.3)$$

Differenciating equation (7.3) w.r.t., t partially,

$$\frac{\delta C}{\delta t} = \frac{\delta V}{\delta t} + b\frac{\delta S}{\delta t}$$

and, putting the value of $\delta S/\delta t$ from equation (7.2),

$$\frac{\delta C}{\delta t} = \frac{\delta V}{\delta t} + a.b.V \qquad \ldots.(7.4)$$

Differenciating equation (7.1) w.r.t., x partially ,

$$\frac{\delta V}{\delta x} = \frac{\delta C}{\delta x} - b.\frac{\delta S}{\delta x} \qquad \ldots.(7.5)$$

Again differenciating equation (7.5) w.r.t., x partially,

$$\frac{\delta^2 C}{\delta x^2} = \frac{\delta^2 V}{\delta x^2} - b\frac{\delta^2 S}{\delta x^2} \qquad \ldots.(7.6)$$

Since the variation of contaminant concentration in solid phase is much less than the variation of contaminant concentration in liquid phase,

$$b\frac{\delta S}{\delta x} << \frac{\delta C}{\delta x} \qquad \ldots.(7.7)$$

and,

$$\frac{\delta^2 S}{\delta x^2} << \frac{\delta^2 C}{\delta x^2}. \qquad \ldots.(7.8)$$

From equations (7.5) to (7.8) , we have

$$\frac{\delta V}{\delta x} = \frac{\delta C}{\delta x} \qquad \ldots.(7.9)$$

and

$$\frac{\delta^2 V}{\delta x^2} = \frac{\delta^2 C}{\delta x^2} \qquad \ldots.(7.10)$$

By substituting the relevant expressions from the equations (7.1) to (7.10), in equations (6.12) to (6.17), we get

$$\frac{\delta S}{\delta t} = aV \qquad \ldots.(7.11)$$

$$D.\ \frac{\delta^2 V}{\delta x^2} - u\frac{\delta V}{\delta x} = \frac{\delta V}{\delta t} + a\left(b + \frac{1-n}{n}\right)V \qquad \ldots.(7.12)$$

and

$$V(x,0) = 0 \quad ; \quad x>0 \qquad \ldots.(7.13)$$

$$V(0,t) = Co\ e^{yt} \quad ; \quad t>0 \qquad \ldots.(7.14)$$

$$V(\infty,t) = 0 \quad ; \quad t\geq 0 \qquad \ldots.(7.15)$$

To simplify the above equations, using the transformation

$$V = V^* \exp\left[\frac{u}{2D}x - \left[\frac{u^2}{4D} + a\left(b+\frac{1-n}{n}\right)\right]t\right] \qquad \ldots.(7.16)$$

And substituting in equations (7.12) to (7.15), we get

$$\frac{\delta^2 V^*}{\delta x^2}(x,t) = \frac{1}{D}\frac{\delta V^*}{\delta t}(x,t) \qquad \ldots.(7.17)$$

$$V^*(x,0) = 0 \quad ; \quad x>0 \qquad \ldots.(7.18)$$

$$V^*(0,t) = Co \exp\left[\frac{u^2}{4D} + a\left(b+\frac{1-n}{n}\right) + y\right]t$$

$$; \quad t>0 \qquad \ldots.(7.19)$$

$$V^*(\infty,t) = 0 \quad ; \quad t\geq 0 \qquad \ldots.(7.20)$$

Now applying the Laplace transformation w.r.t. t only, to the equation (7.17) and initial and boundary conditions

(7.18) to (7.20), we get

$$L\left[\frac{\delta^2 V^*}{\delta x^2}(x,t)\right] = L\left[\frac{1}{D}\ \frac{\delta V^*}{\delta t}(x,t)\right]$$

$$\frac{d^2 \bar{V}^*}{dx^2}(x,p) = \frac{P}{D}\ \bar{V}^*(x,p) \qquad \text{....(7.21)}$$

$$\bar{V}^*(0,p) = \frac{Co}{\left[p - \left(\frac{u^2}{4D} + a\left(b + \frac{1-n}{n}\right) + y\right)\right]} \qquad \text{....(7.22)}$$

or

$$\bar{V}^*(o,p) = \frac{Co}{(p-w)} \qquad \text{....(7.23)}$$

$$\text{where,}\quad w = \left[\frac{u^2}{4D} + a\left(b + \frac{1-n}{n}\right) + y\right] \qquad \text{....(7.24)}$$

and

$$\bar{V}^*(\infty,p) = 0 \qquad \text{....(7.25)}$$

where, p is the parameter of transformation and bar indicates the transformed functions. The equation (7.21) is the ordinary differential equation of second order with the constant coefficient. Considering p as constant w.r.t. x, now to solve equation (7.21), let A and B be the arbitrary constants and m_1 & m_2 be the roots of auxiliary equation, then

$$\bar{V}^* = A\ e^{m_1 x} + B\ e^{m_2 x} \qquad ....(7.26)$$

$$\bar{V}^* = A\ e^{\sqrt{p/D}\,.x} + B\ e^{-\sqrt{p/D}\,.x} \qquad ....(7.27)$$

where, $m_1,\ m_2 = +\sqrt{P/D},\ -\sqrt{p/D}$

On applying boundary conditions (7.23) and (7.25), we get

$$A = 0 \quad \text{and} \quad B = \frac{Co}{(p-w)}$$

Thus,

$$\bar{V}^* = \frac{Co}{(p-w)}\ e^{-\sqrt{p/D}\ x} \qquad ....(7.28)$$

Now, taking inverse Laplace transformation of equation (7.28), we get

$$L^{-1}\ [\bar{V}^*] = L^{-1} \left[\frac{Co}{(p-w)}\ e^{-\sqrt{p/D}\,.x} \right]$$

$$V^*(x,t) = \frac{Co}{2} \left[\exp.\ [wt - x.(\frac{w}{D})^{1/2}]\ .\text{erfc}[\ \frac{x-2t(Dw)^{1/2}}{2(Dt)^{1/2}}\ ] + \exp.\ [wt+x(\frac{w}{D})^{1/2}]\ .\text{erfc}\ [\ \frac{x+2t(Dw)^{1/2}}{2(Dt)^{1/2}}\ ] \right] \qquad ....(7.29)$$

The details of the calculation of inverse Laplace transformation is given in appendix A0. Now from equation (7.16) and (7.24), we have

$$V = V^*\ \exp\ \{\frac{u}{2D}.x - wt + yt\}$$

Putting the value of V^* in equation(7.29), we get

$$V = \frac{Co}{2} \exp\left(\frac{u}{2D} x - wt + yt\right)\left[\exp\left[wt - x(w/D)^{1/2}\right] . \operatorname{erfc}\left[\frac{x - 2t(Dw)^{1/2}}{2(Dt)^{1/2}}\right] + \exp\left[wt + x(w/D)^{1/2}\right] . \operatorname{erfc}\left[\frac{x + 2t(Dw)^{1/2}}{2(Dt)^{1/2}}\right]\right] \quad \ldots.(7.30)$$

By further simplifying equation (7.30), we get

$$V = \frac{Co}{2} \exp\left[\frac{u}{2D} x - x(w/D)^{1/2} + yt\right] . \operatorname{erfc}\left[\frac{x - 2t(Dw)^{1/2}}{2(Dt)^{1/2}}\right] + \frac{Co}{2} \exp\left[\frac{u}{2D} x + x(w/D)^{1/2} + yt\right] . \operatorname{erfc}\left[\frac{x + 2t(D/w)^{1/2}}{2(Dt)^{1/2}}\right] \ldots(7.31)$$

Again simplifying equation(7.31), we get

$$V = \frac{Co}{2} . \exp(yt)\left[\exp\left(x\left(\frac{u - (4Dw)^{1/2}}{2D}\right)\right) \operatorname{erfc}\left[\frac{x - 2t(Dw)^{1/2}}{2(Dt)^{1/2}}\right] + \exp\left(x\left(\frac{u + (4Dw)^{1/2}}{2D}\right)\right) \operatorname{erfc}\left[\frac{x + 2t(Dw)^{1/2}}{2(Dt)^{1/2}}\right]\right] \ldots.(7.32)$$

Now, substituting $\alpha = 2(Dw)^{1/2}$,

i.e. , $\alpha = \{4Dw\}^{1/2} = [4D\{\frac{u_2}{4D} + a(b + \frac{1-n}{n}) + y\}]^{1/2}$

or

$$\alpha = [u^2 + 4aD\ (b + \frac{1-n}{n}) + 4Dy\ ]^{1/2}$$

Now,substituting the value of α in equation(7.32), we get

$$V(x,t) = \frac{Co}{2} \, .\exp\,(yt) \left[\exp\left[\frac{u-\alpha}{2D}.\, x\right] .\,\mathrm{erfc}\left(\frac{x-\alpha t}{2(Dt)^{1/2}}\right) \right.$$

$$\left. + \quad \exp\left[\frac{(u+\alpha)}{2D}.x\right] .\,\mathrm{erfc}\left(\frac{x+\alpha t}{2(Dt)^{1/2}}\right) \right] \qquad \ldots.(7.33)$$

Substituting the value of $V(x,t)$ from equation(7.33) in equation (7.4) and integrating both the sides with respect to t, from 0 to t , and using the respective initial and boundry conditions (6.14) and (7.13),we have

$$C(x,t) = V(x,t) + ab \int_{o}^{t} V\,(x,s)ds \qquad \ldots.(7.34)$$

where ,s is the variable for integration.

The last term (integral term) in the right hand side of equation (7.34) , can not be integrated analytically due to comlexity of the expression V(x,t). Therefore, the above said integral has been evaluated by numerical integration. The composite Simpson's integration rule has been applied for variable step size thickness in terms of t. A computer program has been developed to find the value of C(x,t) from equation (7.34) for different sets of values of x and t, for different values of media and fluid parameters. listing of computer program alongwith its flow chart is given in appendix A1. The quantitative analysis of the result has been discussed in article 7.4 .

7.2 SOLUTION OF THE MATHEMATICAL MODEL FOR CASE -II

To analyse the mathematical model discussed in article 6.4.2 , we have to solve the equation (6.12) and (6.13), subject to boundary conditions given by equation (6.18)-(6.21), for prescribed values of media and fluid parameters. The governing equations are as follows:

$$\frac{\delta S}{\delta t} = a(C-bS) \qquad \ldots.(6.12)$$

$$D.\frac{\delta^2 C}{\delta x^2} - u\frac{\delta C}{\delta x} = \frac{\delta C}{\delta t} + \frac{1-n}{n}\frac{\delta S}{\delta t} \qquad \ldots.(6.13)$$

and subjected to following initial and boundary conditions of the solute in the liquid and solid phases.

$$C(x,0) = 0 \quad ; \quad x \geq 0 \qquad \ldots.(6.18)$$

$$C(0,t) = Co\ e^{\gamma t} \quad ; \quad t > 0 \qquad \ldots.(6.19)$$

$$\frac{\delta C}{\delta t}(\infty,t) = 0 \quad ; \quad t \geq 0 \qquad \ldots.(6.20)$$

$$S(x,0) = 0 \quad ; \quad x \geq 0 \qquad \ldots.(6.21)$$

Now by putting ,value of V from equation (7.1) in equations (6.12) and (6.13), we get

$$\frac{\delta S}{\delta t} = aV \qquad \ldots.(7.2)$$

and

$$D.\ \frac{\delta^2 V}{\delta x} - u\ \frac{\delta V}{\delta x} = \frac{\delta V}{\delta t} + \left(b + \frac{1-n}{n}\right).aV \qquad \ldots.(7.35)$$

Now,putting value of V from equation (7.1) in equations (6.18) to (6.21), we get

$$V(x,0) = 0 \qquad x > 0 \qquad \ldots.(7.36)$$

$$V(0,t) = Co\ e^{\gamma t} \qquad t > 0 \qquad \ldots.(7.37)$$

Now differenciating the equation (7.1) w.r.t. x , partially

$$\frac{\delta V}{\delta x} = \frac{\delta C}{\delta x} - b\ \frac{\delta S}{\delta x}$$

Since the variation of contaminant concentration in solid phase is much less than the variation of contaminant concentration in liquid phase,

$$\text{i.e.,} \qquad \frac{\delta S}{\delta x} << \frac{\delta C}{\delta x}$$

Thus,

$$\frac{\delta V}{\delta x}(\infty,t) = 0 \qquad ; \qquad x \geq 0 \qquad \ldots.(7.38)$$

To simplify the above equations, using the transformation

$$V = V^* \exp\left(\frac{u}{2D} x - \left[\frac{u^2}{4D} + a\left(b+\frac{1-n}{n}\right)\right]t\right) \qquad ....(7.39)$$

in equations (7.35) to (7.38), we get

$$\frac{\delta^2 V^*}{\delta x^2}(x,t) = \frac{1}{D}\,\frac{\delta V^*}{\delta t}(x,t) \qquad ....(7.40)$$

$$V^*(x,0) = 0 \qquad ; \qquad x>0 \qquad ....(7.41)$$

$$V^*(0,t) = Co \exp\left[\frac{u^2}{4D} + a\left(b + \frac{1-n}{n}\right) + y\right]t \quad ....(7.42)$$

$$\frac{\delta V^*}{\delta x} = -\frac{u}{2D} V^* \qquad ; \qquad \text{at } x=\infty, t \geq 0 \qquad ....(7.43)$$

Applying the Laplace transformation w.r.t. t only , to the equations (7.40) to (7.43), we get

$$\frac{d^2\bar{V}^*}{dx^2}(x,p) = \frac{p}{D}\bar{V}^*(x,p) \qquad ....(7.44)$$

$$\bar{V}^*(0,p) = \frac{Co}{p-w} \qquad ....(7.45)$$

where, $w = \frac{u^2}{4D} + a\left(b + \frac{1-n}{n}\right) + y$

$$\frac{dV^*}{dx}(\infty, p) = -\frac{u}{2D}(\infty, p) \qquad ....(7.46)$$

where, p is the parameter of transformation, bar indicates the transformed function. The equation(7.44), is the ordinary differential equation of second order with constant coefficient. To Solve the equation (7.44), let A and B are the constants and m1 &m2 are the roots of the auxilliary equation, then

$$\bar{V}* = A\ e^{m1x} + B\ e^{m2x}$$

Now m1 ,m2 = $\sqrt{p/D}$,$-\sqrt{p/D}$,then

$$\bar{V}* = A\ e^{\sqrt{p/D}\,.x} + B\ e^{-\sqrt{p/D}\,.x}$$

Applying boundary condition (7.45) and (7.46) to the above equation . For the finite solution of the equation,we get

$$A = 0\ , \quad \text{and} \qquad B = \frac{Co}{(p-w)}$$

now,

$$\bar{V}* = \frac{Co}{(p-w)}\,.e^{-\sqrt{p/D}\,.x} \qquad \ldots.(7.47)$$

The nature of the exprssion of $\bar{V}*$ in the equation (7.47) is the same as in the equation (7.28) of case I . The solution for this case can be obtained similar as previous case.

7.3 SOLUTION OF THE MATHEMATICAL MODEL FOR CASE -III

To analyse the mathematical model discussed in article 6.4.3 , we have to solve the equation (6.12) and (6.13), subject to boundary conditions given by equation (6.22) to (6.26), for prescribed values of media and fluid parameters. The governing equations are as follows:

$$\frac{\delta S}{\delta t} = a(C-bS) \qquad \ldots.(6.12)$$

$$D.\frac{\delta^2 C}{\delta x^2} - u\frac{\delta C}{\delta x} = \frac{\delta C}{\delta t} + \frac{1-n}{n}\frac{\delta S}{\delta t} \qquad \ldots.(6.13)$$

and, initial and boundary conditions are:

$$C(x,0) = 0 \quad ; \quad x \geq 0 \qquad \ldots.(6.22)$$

$$C(0,t) = Co.e^{\gamma t} \quad ; \quad t > 0 \qquad \ldots.(6.23)$$

$$\frac{\delta C}{\delta x}(\infty,t) = -kC(\infty,t) \quad ; \quad t > 0 \qquad \ldots.(6.24)$$

$$S(x,0) = 0 \quad ; \quad x > 0 \qquad \ldots.(6.25)$$

$$S(\infty,t) = 0 \quad ; \quad t \geq 0 \qquad \ldots.(6.26)$$

where, k is the heterogeneous chemical reaction rate constant of first order.

Now by putting value of V from equation (7.1) in equations (6.12) and (6.13), and in the initial and boundary conditions(6.22) to (6.26), we get

$$D \frac{\delta^2 V}{\delta x^2} - u \frac{\delta V}{\delta x} = \frac{\delta V}{\delta t} + a\left(b + \frac{1-n}{n}\right).\ V \qquad \ldots.(7.50)$$

and

$$V(x,0) = 0 \qquad ; \quad x \geq 0 \qquad \ldots.(7.51)$$

$$V(0,t) = Co\ e^{yt} \qquad ; \quad t \geq 0 \qquad \ldots.(7.52)$$

$$\frac{\delta V}{\delta x}(\infty,t) = -kV(\infty,t) \qquad ; \quad t \geq 0 \qquad \ldots.(7.53)$$

To Simplify above equations using the transformation

$$V = V^*(x,t)\ \exp\left[\frac{u}{2D}x - [\frac{u^2}{4D} + a(b + \frac{1-n}{n}))]t\right]$$

or

$$V(x,t) = V^*\ (x,t)\ \exp(\frac{u}{2D}x - w't\ ) \qquad \ldots.(7.54)$$

where, $$w' = \left[\frac{u^2}{4D} + a\ (\ b + \frac{1-n}{n}\ )\right] \qquad \ldots.(7.55)$$

Substituting the value of V from equation(7.54) in equation (7.50) to (7.53) , we get

$$\frac{\delta^2 V^*}{\delta x^2}(x,t) = \frac{1}{D}\ \frac{\delta V^*}{\delta t}\ (x,t) \qquad \ldots.(7.56)$$

and

$$V^*(x,0) = 0 \qquad \ldots.(7.57)$$

$$V^*(0,t) = Co\ \exp\ [w'+y)t$$

or

$$V^*(0,t) = Co\ \ e^{wt} \qquad \ldots.(7.58)$$

where, $(w'+y) = w$

and

$$\frac{\delta V^*}{\delta x}(\infty,t) + \frac{u}{2D} V^*(\infty,t) + kV^*(\infty,t) = 0 \qquad \ldots.(7.59)$$

Now, applying Laplace Transformation w.r.t. t only, to the boundary value problem, equations (7.56) to (7.59), we get

$$\frac{d^2\bar{V}^*}{dx^2}(x,p) - \frac{p}{D}\bar{V}^*(x,p) = 0 \qquad \ldots.(7.60)$$

$$\bar{V}^*(0,p) = Co/(p-w) \qquad \ldots.(7.61)$$

$$\frac{d\bar{V}^*}{dx}(\infty,t) + \frac{u}{2D}\bar{V}^*(\infty,t) + k\bar{V}^*(\infty,t) = 0 \qquad \ldots.(7.62)$$

now putting the value of k' given by equation (7.64) in the equation (7.62),we get

$$\frac{dV^*}{dx}(\infty,t) + k'\bar{V}^*(\infty,t) = 0 \qquad \ldots.(7.63)$$

$$k' = \frac{u}{2D} + k \qquad \ldots.(7.64)$$

where, p is the parameter of transformation and bar indicates the transformed functions.The equation (7.60) is the ordinary differential equation of second order with the constant coefficient. Considering p as constant w.r.t. x, now to solve equation (7.60), let A and B be the arbitrary constants and m_1 & m_2 be the roots of auxiliary equation, then

$$\bar{V}^* = A\,e^{m_1 x} + B\,e^{m_2 x}$$

or

$$\bar{V}^* = A\, e^{\sqrt{p/D}\,.x} + B\, e^{-\sqrt{p/D}\,.x} \qquad ....(7.65)$$

where, $m_1,\ m_2 = +\sqrt{P/D}\ ,\ -\sqrt{p/D}$

Now applying boundry conditions(7.61) and (7.63). For the finite (or $\bar{V}^*$ is bounded) solution of the equation(7.65), we get

$$A = 0 \qquad \text{and} \qquad B = \frac{Co}{(p-w)}$$

now,

$$\bar{V}^* = \frac{Co}{(p-w)}\ .e^{-\sqrt{p/D}\,.x} \qquad ....(7.66)$$

The nature of the exprssion of $\bar{V}^*$ in the equation (7.66) is the same as in the equation (7.28) of case I . The solution for this case can be obtained similar as previous case I.

We see that the final expression for concentration of contaminant for all three cases is same . Thus the concentration of contaminant is not affected by end boundry conditions i.e. zero flux at end boundry in case -I and heterogenious chemical reaction at end boundry in case - III. In our expression if we consider non equilibrium relationship $\delta S/\delta t = aC$ (i.e. b=0), we get similar expression as obtained by Marino ,(1974). If we take b=0 and a is approximated to Kd (linear equilibrium isotherm) , then we get similar expression as obtained by Nayak and Lakshminarayan, (1990) for one dimensional case.

7.4 DISCUSSION OF THE RESULTS

The mathematical model developed for predicting the possible concentration of a dissolved substance in unidirectional steady seepage flow through semi-infinite homogeneous and isotropic porous media can be used to predict the ground water contamination, due to the disposal of effluent from industries on land. The model can be used to select the site of disposal of effluent, so that the ground water source for water supply should not get contaminated. The developed mathematical model should prove to be useful for quantitative prediction of the ground water supplies resulting from seepage of high salt concentration in drainage ditches, canals and streams. The model can be also used to predict the contamination of ground water due to leaching of water into ground water from buried waste.

Mathematical solutions are developed for predicting possible concentration of given contaminant in steady seepage flow through semi infinite , homogeneous and isotropic porous medium, subject to source concentration that vary exponentially with time. The concentration of contaminants in porous medium is given by equation (7.34). This equation reveals that the concentration of the contaminant in the aquifer varies exponentially with y i.e. the nature of variation of concentration of contaminant in the aquifer will be similar as the variation of the contaminant source. If variation of contaminant source is exponential then the variation in contaminant concentration in the aquifer will also be exponential. If y=0 i.e. the contaminant source is constant , then the variation in contaminant concentration in the aquifer will not be exponential. To see these results quantitatively , Plots " C/Co Vs time" and "C/Co Vs depth" have been drawn in fig. 7.7 and fig. 7.10 respectively for different values of y .From the fig.7.7 it is clear that the variation of C/Co with time at a particular depth is linear and value of C/Co increases with an increase in the value of y at same depth and time. The variation of the C/Co at different depths is exponential for a particular time .

Dispersion refers to mixing and spreading due to molecular motion and deviation of fluid velocity in the pores from the mean value. Dispersivity depends on the velocity of flow. Some contaminant will decay/produced (for example radio nucleides) , over time by conversion to other species. Some species also interact with the soil and are adsorbed onto the surface of soil particles. Although many of these reactions have been studied under laboratory conditions, transfer of lab informations to field situation is difficult. The reaction mechanism is extremely important for the accurate description of contaminant transport, but its complex parameterization has far led to rather crude incorporation of the process into numerical models.

The variation of C/Co for different values of 'a', the reaction constant has been plotted with respect to time at a particular depth in fig. 7.8 . Variation of C/Co for different values of 'a' at different depths at a particular time, have been plotted in fig. 7.5 . At the same time plots have also been drawn for different values of 'b' with respect to time and depth in fig. 7.3 and fig. 7.5 respectively. Value of C/Co decreases with an increase in the value of 'a' and 'b' at same depth and time.

The seepage velocity u, is the rate of discharge of percolating water through unit cross-sectional area of voids perpendicular to the direction of the flow. The variation of contaminant concentration in the aquifer with different values of seepage velocity 'u' have been shown in fig. 7.4 and fig.7.9 . The variation of C/Co at different intervals of time at a particular depth , is linear and it increases with increase in seepage velocity. The variation of C/Co at different depths at a particular time is hyperbolic as shown in fig. 7.9. At a particular time , at the same depth C/Co increases as seepage velocity increases.

The permeability or the ease with which it permits the passage or seepage of contaminants (in liquid form) in the aquifer depends upon porosity. The more is the porosity the more will be the permeability. The porosity of different types of aquifer materials have been discussed in chapter2. For sandy soil the seepage will be more, at the same time seepage from the clay will be less. When porosity is 0 i.e. all the pores are filled then, theoretically there will be no seepage. This is evident from the model developed. To study the effects of porosity on contaminant transport, plots have been drawn C/Co Vs time and C/Co Vs depth in fig. 7.1 and fig. 7.6 respectively.

The results obtained for case -II and case -III are found to be similar as case -I. The variation of C/Co with time and depth for case -II and case -III will be similar as for case -I . The mathematical expressions and results are generalisation of results of Marino ,(1974); Hamilton , et al. (1985) ; Nayak and Lakshminarayan , (1990) and others.

Fig 7.1 C/Co vs Depth Plot for diff. values of "n" (T = 50 Years)

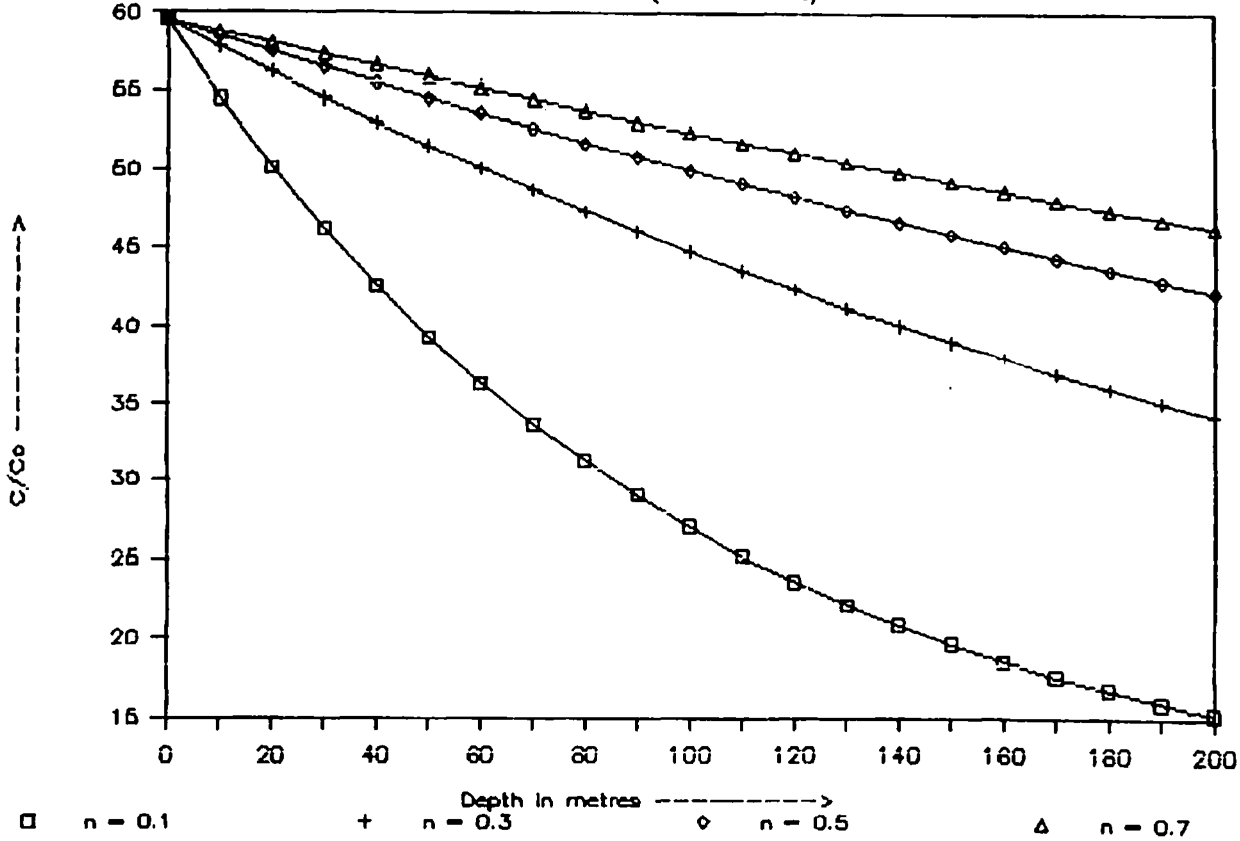


Fig 7.2 C/Co vs Depth Plot for diff.
VALUES OF "a" (T=50 YEARS)

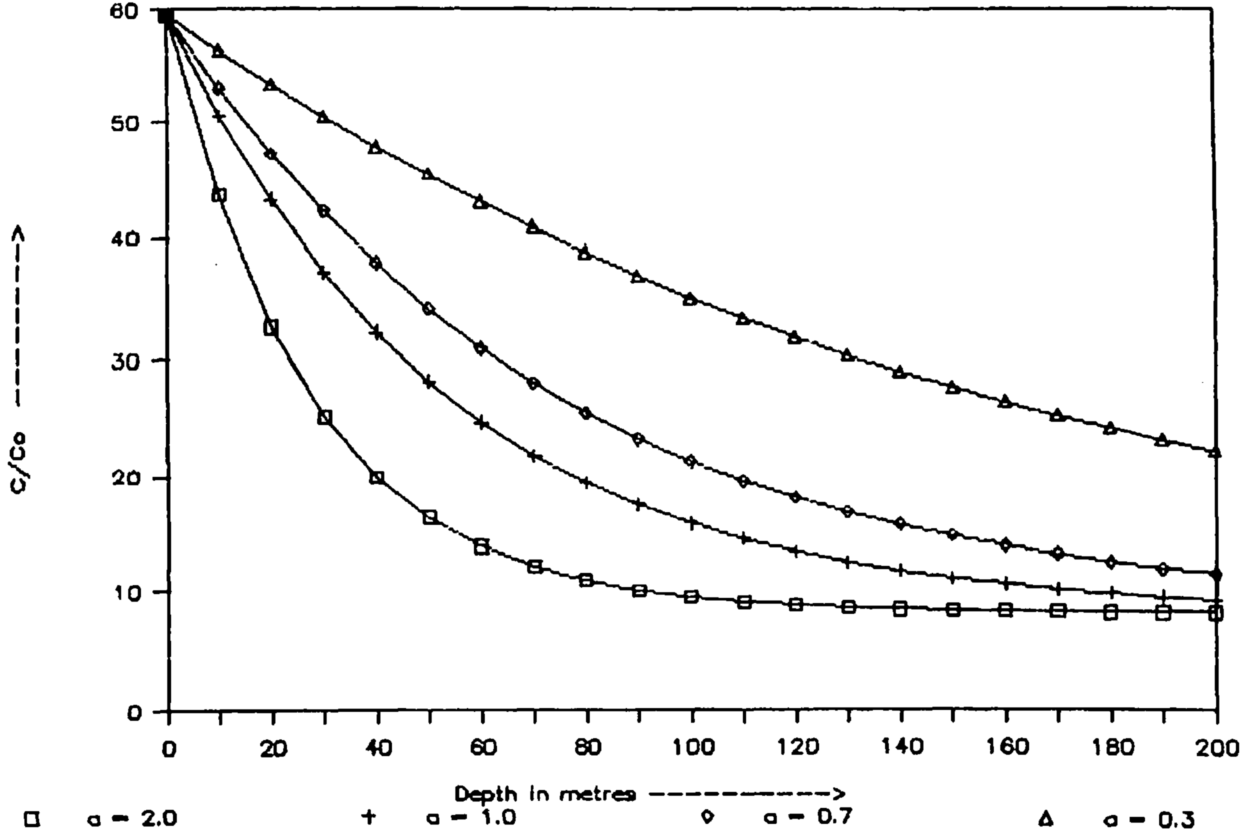


Fig 7.3 C/Co Vs Depth Plot for diff.

VALUES OF "b" (T=50 YEARS)

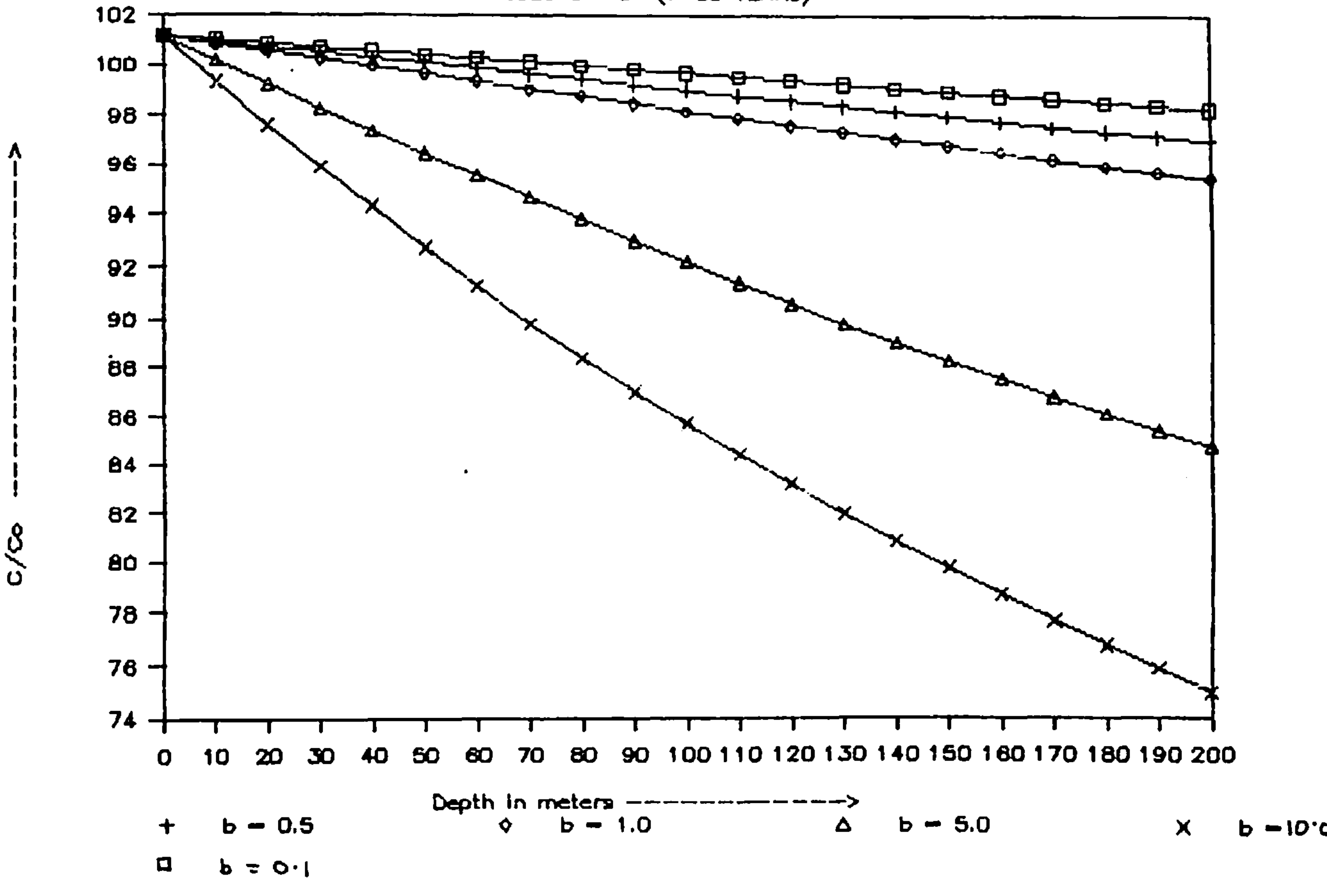


Fig. 7.4 VARIATION OF C/Co AT DEPTH 50m

WITH TIME FOR DIFF. VALUES OF 'u'

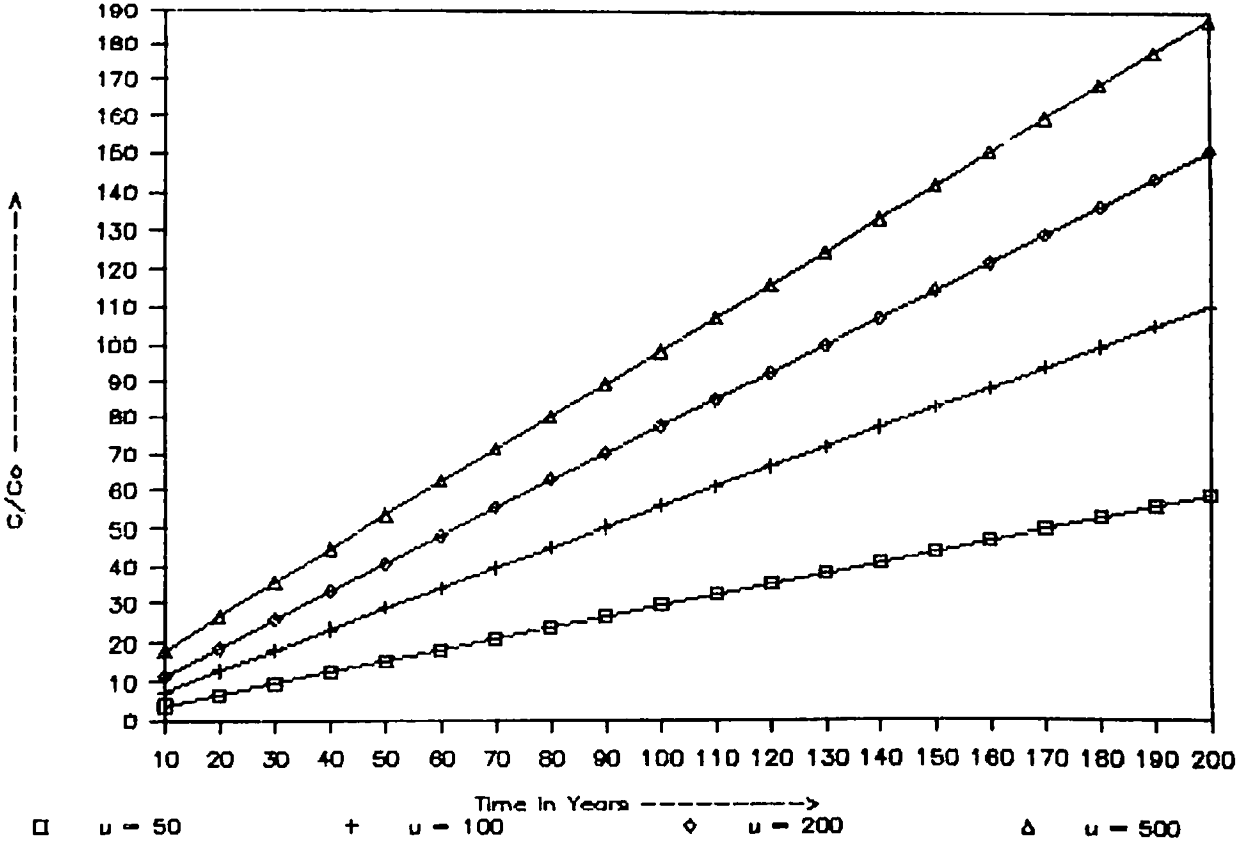


Fig.7.5 VARIATION OF C/Co AT DEPTH 50m

WITH TIME FOR DIFF. VALUES OF 'b'

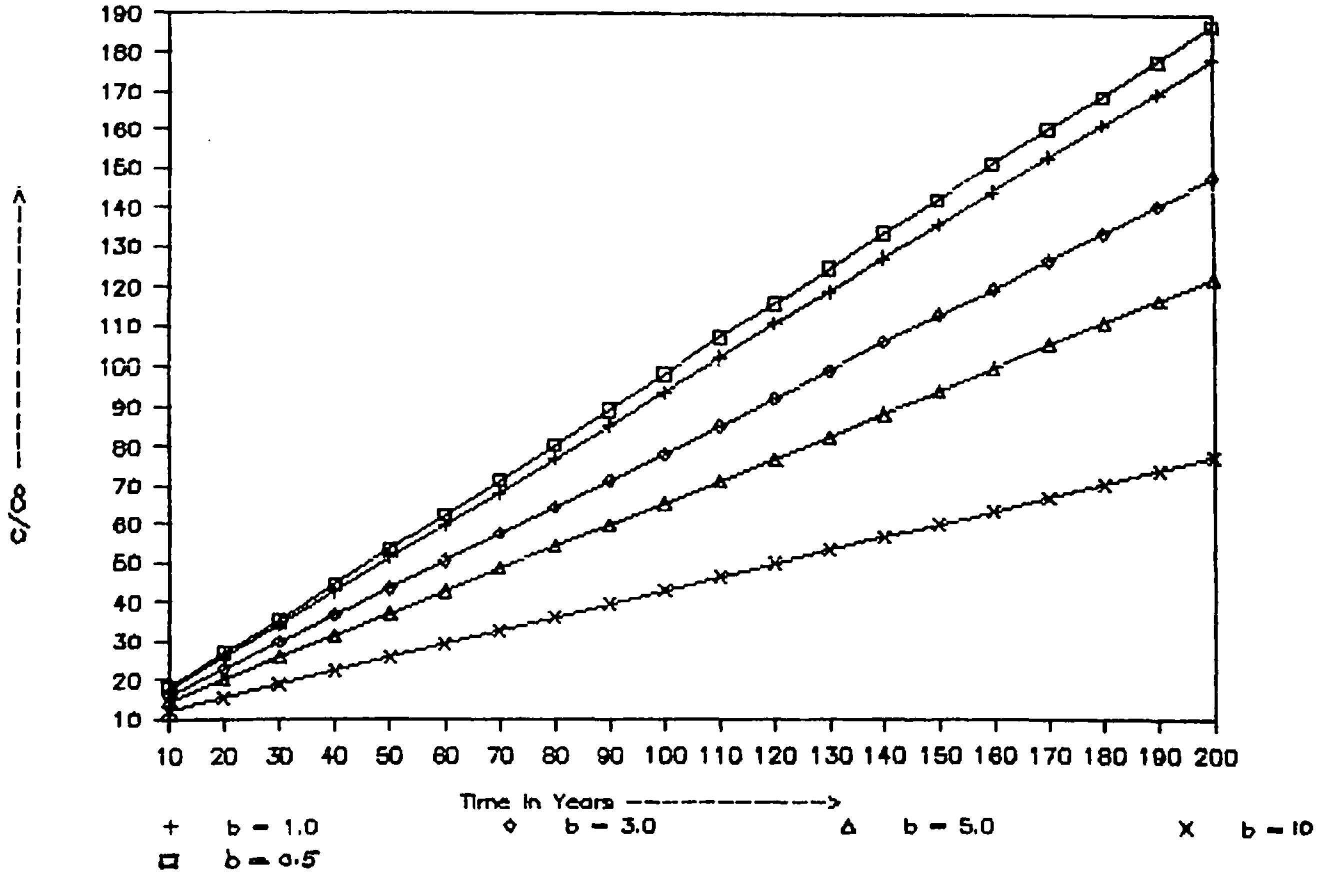


Fig. 7.6 VARIATION OF C/Co AT DEPTH 50m

WITH TIME FOR DIFF. VALUES OF 'n'

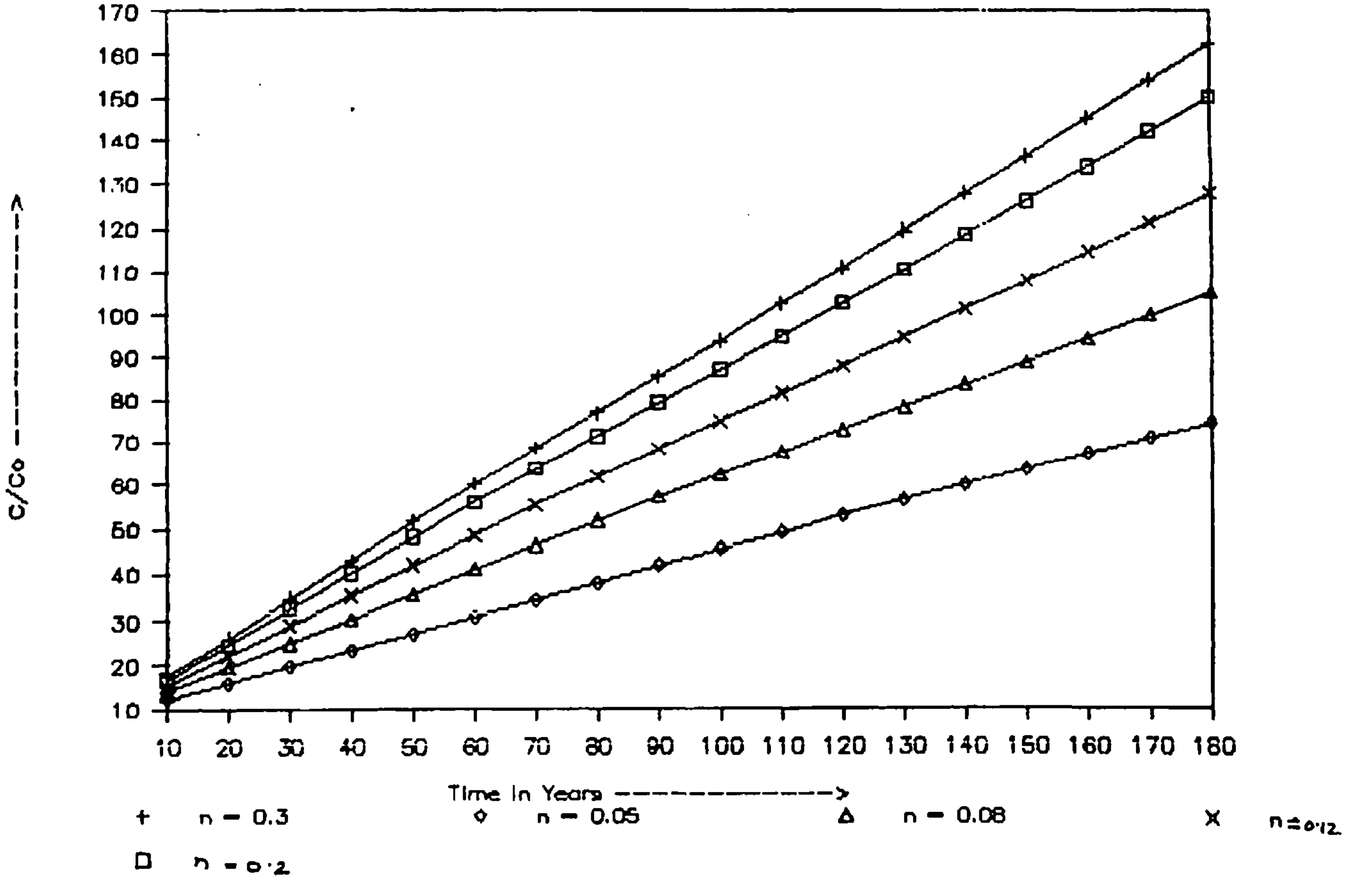


Fig. 7.7 VARIATION OF C/Co AT DEPTH 50m

WITH TIME FOR DIFF.VALUES OF 'y'

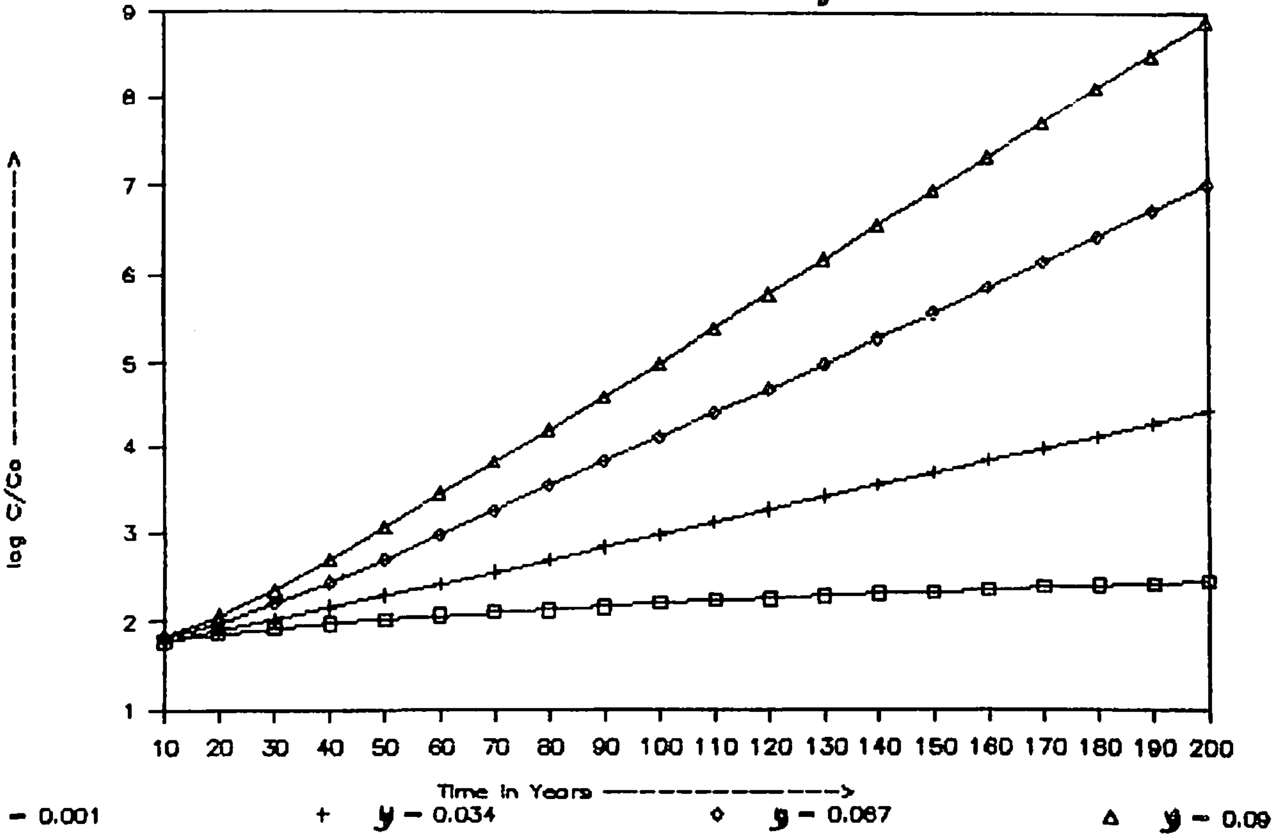


Fig 7.8 VARIATION OF C/Co AT DEPTH 50m

WITH TIME FOR DIFF. VALUES OF 'a'

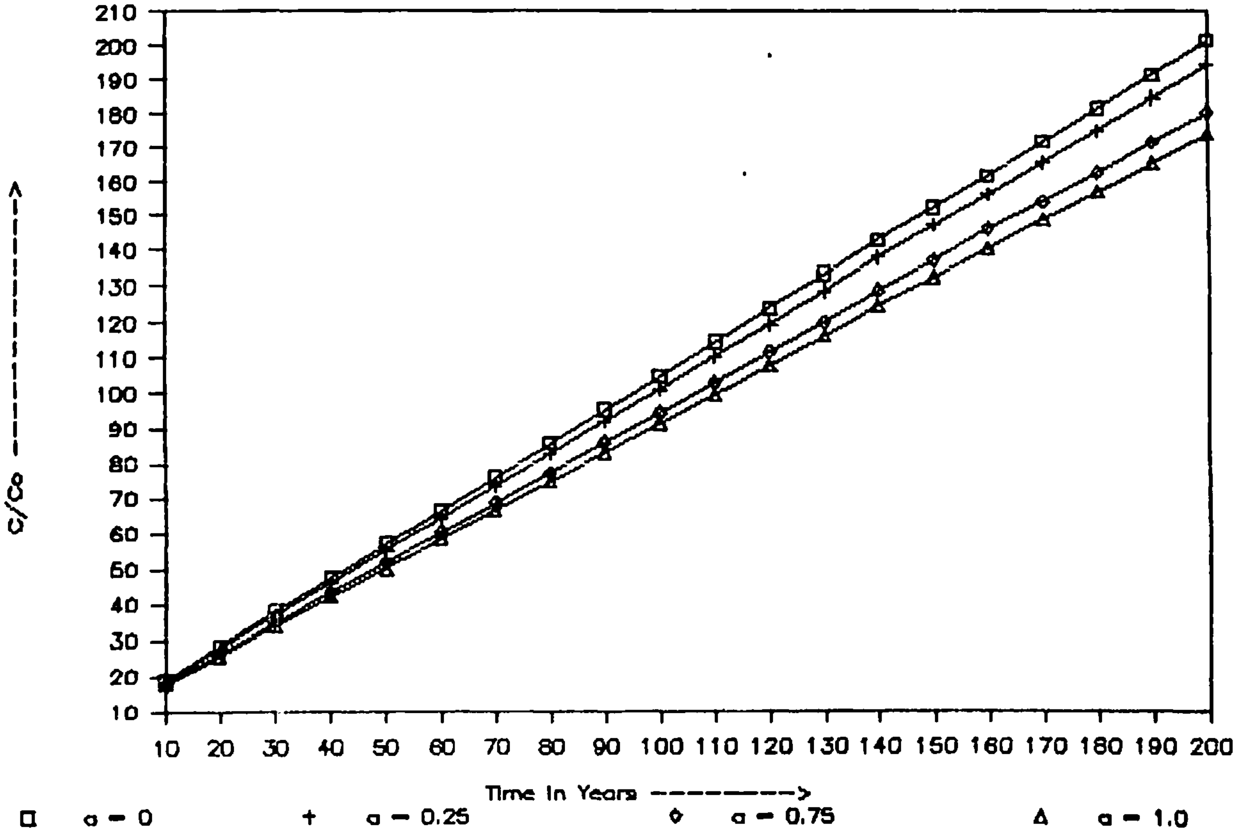


Fig 7.9 VARIATION OF C/Co AT T=50 YRS.
WITH DEPTH FOR DIFF. VALUES OF 'u'

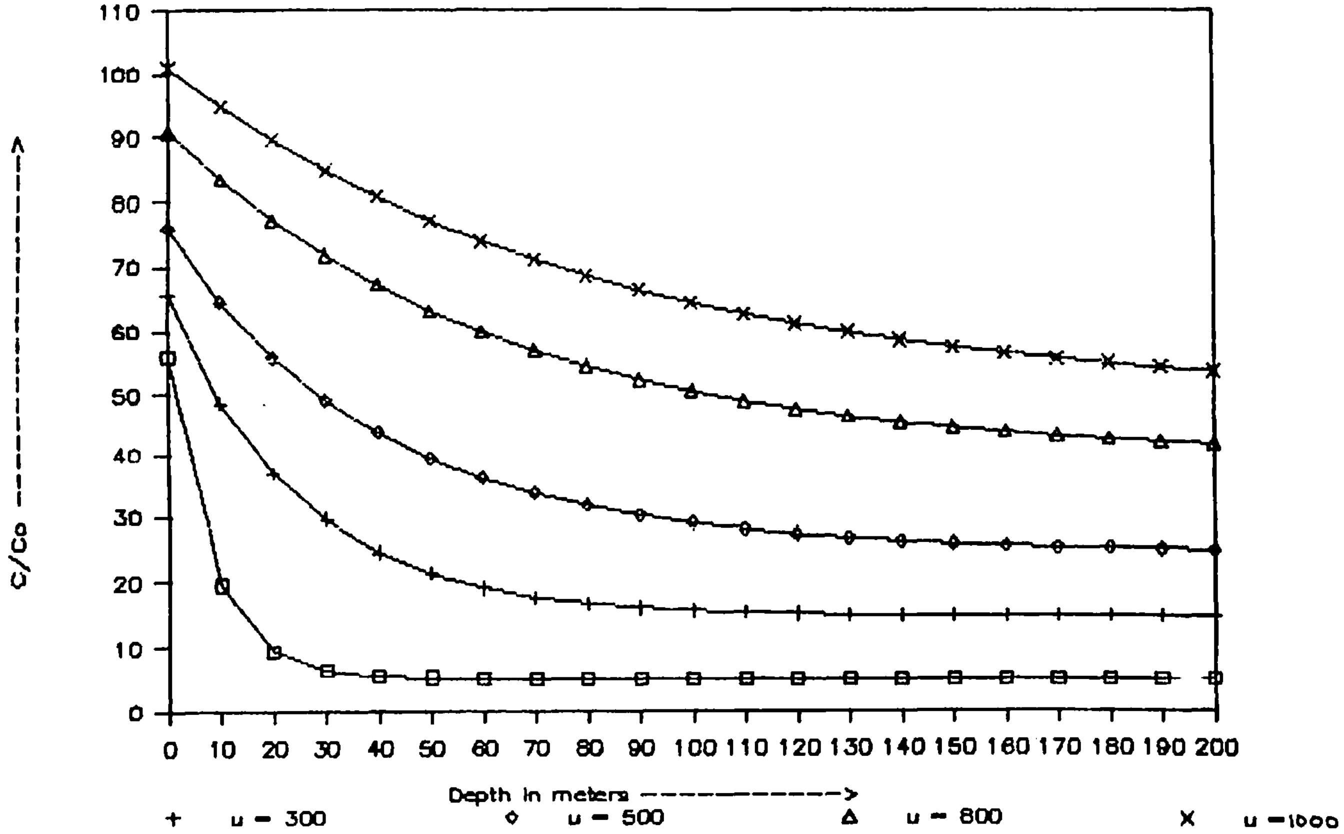
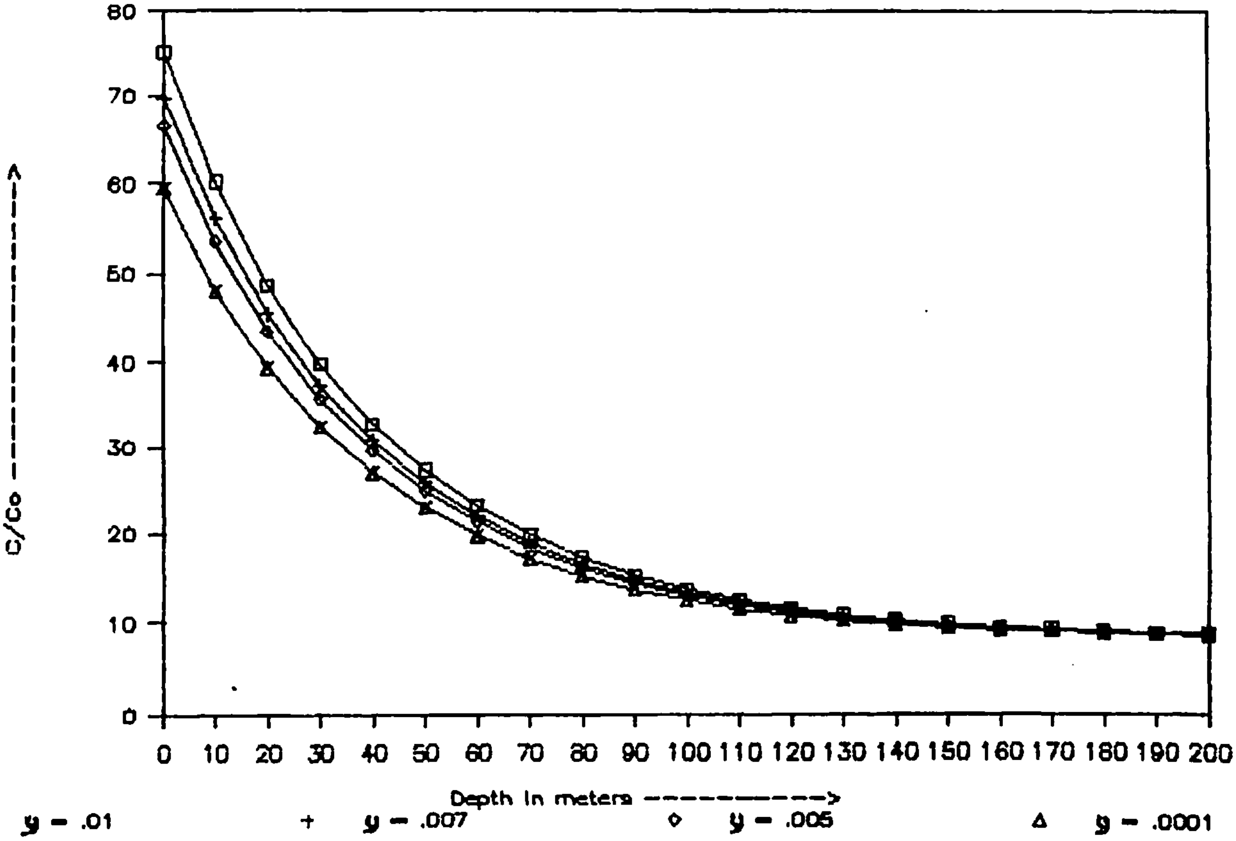


Fig 7.10 VARIATION OF C/Co AT T=50 YRS

WITH DEPTH FOR DFF. VALUES OF GAMMA



7.5 APPLICATION OF THE MATHEMATICAL MODEL FOR KHETRI COPPER COMPLEX

The tailing from Khetri Copper Complex is discharged in a tailing pond. The tailing pond is situated in between hillocks as shown in fig. 7.11 . The ground water contamination from tailing/oxidation pond occurs as the result of seepage of contaminants from it ,due to which the quality of ground water near tailing/oxidation pond is getting deteriorated continuously. The quality of water in the wells near disposal pond reveals that there is continuous deterioration of ground water quality as discussed in chapter 5.

The developed mathematical model can be used to investigate the physical mechanism involved in the transport of contaminants at this site. With the help of above model, we can predict that ,for how much period tailings can be disposed at the same site such that quality of ground water will not become toxic . When the ground water intends to become toxic the site of disposal pond should be changed. The disposal pond site should be located at the d/s side of the sites, from where the ground water is being taken for public water supply, since the contaminants will travel d/s side of the slope of the aquifer. This should also be kept in mind before the selection of the disposal pond site, that the

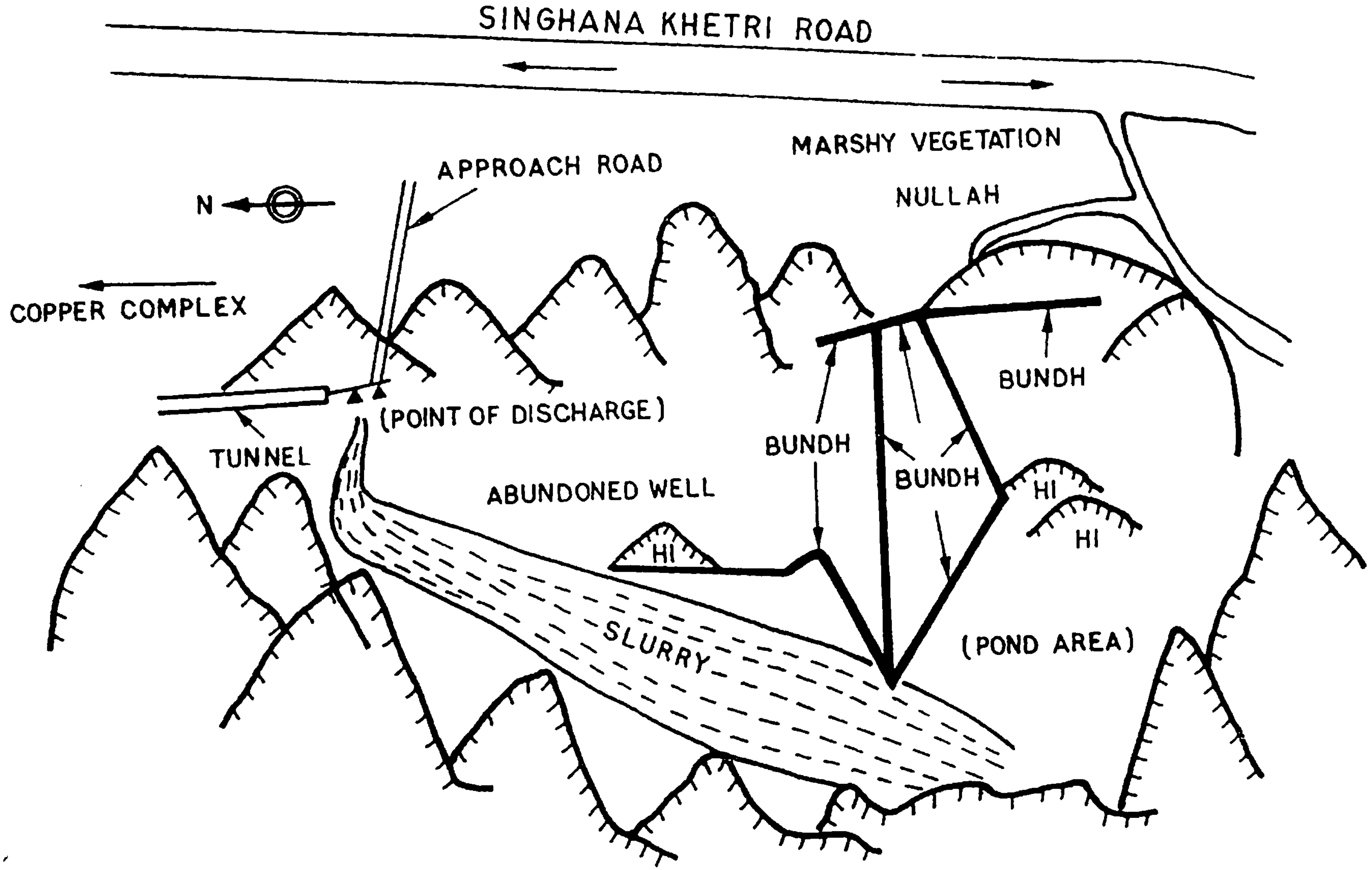


Fig. 6.11 Disposal of Tailing at Khetri Copper Complex

public water supply in the d/s side should be far away from the disposal pond site of tailing.

7.6 CONCLUSION

In this chapter analysis of the mathematical models for all three cases have been carried out. Models have been simplified with the help of some well known transformations and Laplace transformation. A computer programme in 'C' languagge has been developed to solve the final expression for concentration of contaminant in porous medium (aquifer). The quantitative analysis of the models have been done by drawing different plots between C/Co (ratio of contaminant concentration and initial concentration) and depths , and between C/Co and time , for different values of medium and fluid parameters. The solute transport is affected by the nature of subsoil. The propagation of contaminant can be retarded considerably by providing clay strata in the aquifer as porosity of clay soil is much less.

The analytical expressions developed in this chapter will be useful in making quantitative predictions on the possible contamination of aquifer for water supplies due to percolation /seepage from waste sources such as disposal drainage ditches, canals ,streams and ground water movement through buried waste. The developed mathematical model has been applied to Khetri Copper Complex, to predict the aquifer contamination and selection of site for safe disposal of tailing.

CHAPTER : 8

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations of the study in this thesis work are as follows:

1. Khetri Copper Complex is the major constituent of Hindustan Copper Limited , a government of India enterprise, established in November 1967 . Khetri Copper Complex is situated 190 km. west of Delhi and 180 km. north of Jaipur, (latitude 29°6'2" N and longitude 75°50'22"E) in Jhunjhunu district ,Rajasthan at the altitude of 310 m. above mean sea level . .

2. The climate of the Jhunjhunu district belongs to semi arid type. Mean daily maximum and minimum temperatures in June (hottest month) are 41.1° C and 28.5° C respectively and in January (coldest month) mean daily maximum and minimum temperature are 22.5° C and 4.2° C respectively.

3. Geomorphologically,the Jhunjhunu district can be broadly divided into three distinct units namely

a) the hilly area in the south eastern part.

b) the undulating area with small isolated hills in the south western part and

c) the desertic plane in the northern part .

4. The average rainfall in the Jhunjhunu district is 527 mm. Rainfall pattern at Jhunjhunu district expresses the concentration of total annual rainfall in four months from June to September.About 85.58% of the annual rainfall is provided in these four months,while remaining eight months represents dry period.Thus a high level of management is required to utilise the soil moisture.It will be therefore, very important to design run-off storage tanks in such areas,such that the water can be properly utilised in the deficit period without causing significant reduction in crop yield.

5. The principal river in the Khetri area is the Singhana river which flows from near the hillfoot of Bhopalgarh South of Khetri.Above Singhana it is joined by several tributaries.The most important of which is the Kharkhar nala.Among the minor tributaries are those following past Kurana,Manuta and Gotro.All the streams in the area are emphemeral in character and rise in freshest at times of intense precipitation.However, the flood water is soon dissipated within a distance of about 30km from Khetri.The Singhana river drains the waste water of Khetri Copper Complex.

6. The surface geology in most of the Jhunjhunu district is concealed under a cover of wind blown sand.The Khetri area is underlain by recent to subrecent alluvium and blown sand overlying the Ajabgarh rocks of the Delhi system comprising quartzites, schists, phyllites, cale-granullites etc.The post Delhi intrusives are represented by epidiosites.

7. The main source of ground water in the area is from precipitation which aggregates to about 527mm per annum. The ground water occurs under water table conditions in most of the Khetri area, except in parts of the alluvium where it possibly exists under very slight pressure conditions.

8. The depth of water table varies widely depending upon topography,drainage system,geology and depth of bedrock.In general depth of water table varies 10 m to 50 m below ground level.In the vicinity of Khetri and in Kharkhar valley the water table has a slope of about 10 m to 20 m per km.

9. The ultimate source of recharge of ground water is precipitation.Part of the rainfall that falls on the land surface,reaches the zone of saturation by downward percolation and a part by infiltration from emphemeral streams.High velocity winds prevail in the district Jhunjhunu most of the period of year.This wind energy

can be utilised as non conventional energy source.In this district windmills may be used for lifting the ground water from tubewells.

10. There is no major pollution hazards in the ground water of Jhunjhunu district.In the north-northwest part of the district the problem of excessive TDS,fluoride and nitrate were found.The area lying in the vicinity of river Kantli shows good ground water quality for agricultural purposes.In general the quality of ground water in the district Jhunjhunu is suitable for drinking and irrigation purposes.The area where TDS,nitrate and fluoride are in excess than permissible limit. Some purification should be done before supplying the ground water for community water supply.

11. The study of correlation analysis reveals that high positive correlations ($r \geq 0.6$)have been found between 9 pairs of parameters, these are Ca -Mg ; CO_3 -HCO_3 ; Ca -TH ;Mg -TH ;Sp.Cond. -F ; Sp.Cond. -HCO_3 ;Mg -NO_3 ;F -CO_3 ;F -HCO_3 , out of which the highest correlation coefficient was found ($r = 0.858$) between calcium and total hardness . The result of correlation analysis among different water quality parameters will facilitate in rapid monitoring of water quality and control of ground water pollution.

12. The study of characteristics of effluent from Khetri Copper Complex, reveals that the quality of waste water received from different operations in the Khetri Copper Project is different ,which makes the combined effluent complex.The tailing obtained from concentrator is disposed in tailing pond , located between hillocks after treating it in settling tanks. And the waste water from other processes is disposed in the main channel from where it goes to Singhana river through Kharkhar nala .

13. There is scarcity of water in Khetri area. The daily consumption of industrial water is 31,000 m^3. This is obtained from tubewells sunk into aquifers in the Chaonra and Jodhpura formations at two sites , some 25 km. and 42 km. away respectively . The potable water is obtained from tubewells sunk into the bed of Kharakhar river, the daily consumption being 9,000 m^3.

14. Due to disposal of effluent from Khetri copper complex the quality of ground water has deteriorated considerably . Various constituents of ground water have increased after rains , inspite of getting reduced due to dilution. The pollutants adsorbed in the subsoil get dissolved in the rain water and ultimately enter into ground water. Concentration of various constituents of ground water such as specific

conductance , sodium,potassium, magnesium , total hardness, calcium, chloride ,sulphate , fluoride total dissolved solids, boron and silica have increased after rains for the wells which are on the down stream side of the Singhana river.

15. Proper treatment of effluent from Khetri Copper Complex should be done before the disposal of effluent into the main channel .

16. Identification of the areas and level of ground water contamination , and movement of contaminants in the aquifers can be predicted with the help of mathematical models. Mathematical models have been developed for predicting a possible concentration of contaminant in steady flows through aquifer, subject to source concentration that vary exponentially with time.

17. The developed mathematical model will be useful in making quantitative predictions on the possible contamination of aquifer for water supplies due to percolation /seepage from waste sources such as disposal drainage ditches, canals ,streams and ground water movement through buried waste.

18. The mathematical model will be helpful in deciding the location of the disposal pond site . The prediction of the time in which the aquifer will get contaminated can be done with this model .Thus the disposal site should be changed before the contamination of aquifer takes place.

19. The solute transport in porous media largely depends upon adsorption capacity of the solid matrix. The solute transport is affected by the nature of sub soil. Seepage of contaminant can be retarded considerably by providing clay strata in the aquifer as porosity of clay soil is much less.

APPENDIX - A0

****

INVERSION OF LAPLACE TRANSFORM

****

In chapter7 , the equation (7.28) has been solved by the method of inverse Laplace transform. i.e.

$$V^* = L^{-1}\left[\frac{e^{-\alpha\sqrt{p}}}{p-w}\right] \quad ; \text{ where } \alpha = \frac{x}{\sqrt{D}}$$

Applying the convolution theorem [McCollin and Brown,(1965)] .

Assuming

$$\overline{F_1}\ (p) = e^{-\alpha\sqrt{p}} \quad \text{and} \quad \overline{F_2}\ (p) = \frac{1}{(p-w)}$$

and inverse Laplace transform of $\overline{F}_1\ (p)$ and $\overline{F}_2\ (p)$

$$F_1\ (p) = L^{-1}\left[e^{-\alpha\sqrt{p}}\right] = \frac{\alpha}{2\sqrt{\pi}}\ \frac{e^{-\alpha^2/4t}}{t^{3/2}} \qquad \ldots.(1)$$

$$F_2\ (p) = L^{-1}\left[\frac{1}{(p-w)}\right] = e^{wt} \qquad \ldots.(2)$$

now

$$\overline{V}^* = \overline{F_1}\ (p).\overline{F_2}\ (p) \qquad \ldots.(3)$$

From convolution theorem

$$V^* = L^{-1}\left[\overline{V}^*\right] = L^{-1}\left[\overline{F}_1\ (p).\overline{F}_2\ (p)\right]$$

APPENDIX - A0

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Assuming

$$\overline{F_1}\,(p) = e^{-\alpha\sqrt{p}} \quad \text{and} \quad \overline{F_2}\,(p) = \frac{1}{(p-w)}$$

and inverse Laplace transform of $\overline{F}_1\,(p)$ and $\overline{F}_2\,(p)$

$$F_1\,(p) = L^{-1}\left[e^{-\alpha\sqrt{p}}\right] = \frac{\alpha}{2\sqrt{\pi}}\;\frac{e^{-\alpha^2/4t}}{t^{3/2}} \qquad \ldots.(1)$$

$$F_2\,(p) = L^{-1}\left[\frac{1}{(p-w)}\right] = e^{wt} \qquad \ldots.(2)$$

now

$$\overline{V}^* = \overline{F_1}\,(p).\overline{F_2}\,(p) \qquad \ldots.(3)$$

From convolution theorem

$$V^* = L^{-1}\left[\overline{V}^*\right] = L^{-1}\left[\overline{F}_1\,(p).\overline{F}_2\,(p)\right]$$

or

$$V^* = \int_0^t e^{w(t-u)} \frac{\alpha \, . \, e^{-\alpha^2/4u}}{2\sqrt{\pi} \, . \, u^{3/2}} \, du \qquad ....(4)$$

or

$$V^* = \frac{\alpha}{2\sqrt{\pi}} \int_0^t e^{w(t-u)} \, . \, \frac{e^{-\alpha^2/4u}}{u^{3/2}} \, du \qquad ....(5)$$

or

$$V^* = \frac{e^{wt}}{\sqrt{\pi}} \int_0^t \exp -\left(\frac{\alpha^2}{4u} + wu\right) . \frac{\alpha}{2u^{3/2}} \, du \qquad ....(6)$$

or

$$V^* = \frac{e^{wt}}{\sqrt{\pi}} \int_0^t \exp -\left(\frac{\alpha^2}{4u} + wu\right) . \left[\left(\frac{\alpha}{4u^{3/2}} + \frac{1}{2}\sqrt{\frac{w}{u}}\right) + \left(\frac{\alpha}{4u^{3/2}} - \frac{1}{2}\sqrt{\frac{w}{u}}\right)\right] du \qquad ....(7)$$

$$V^* = \frac{e^{wt}}{\sqrt{\pi}} \left[I_1 + I_2 \right] \qquad ....(8)$$

where,

$$I_1 = \int_0^t \exp -\left(\frac{\alpha^2}{4u} + wu\right) . \left(\frac{\alpha}{4u^{3/2}} + \frac{1}{2}\sqrt{\frac{w}{u}}\right) du \qquad ....(9)$$

and

$$I_2 = \int_0^t \exp -\left(\frac{\alpha^2}{4u} + wu \right) . \left(\frac{\alpha}{4u^{3/2}} - \frac{1}{2}\sqrt{\frac{w}{u}} \right) du \quad ....(10)$$

Now

$$I_1 = \int_0^t \exp -\left(\frac{\alpha^2}{4u} + wu \right) . \left(\frac{\alpha}{4u^{3/2}} + \frac{1}{2}\sqrt{\frac{w}{u}} \right) du$$

or

$$I_1 = e^{-aw} \int_0^t \exp - \left(\frac{\alpha}{2\sqrt{u}} - \sqrt{wu} \right)^2 . \left(\frac{\alpha}{4u^{3/2}} + \frac{1}{2}\sqrt{\frac{w}{u}} \right) du \quad ....(11)$$

Let

$$\frac{\alpha}{2\sqrt{u}} - \sqrt{wu} = y$$

or

$$- \left(\frac{\alpha}{4u^{3/2}} + \sqrt{\frac{w}{u}} \right) du = dy \qquad ....(12)$$

By putting the value of y and dy in equation (11), we get

$$I_1 = e^{-aw} \int_{\left(\frac{\alpha}{2\sqrt{t}} - \sqrt{wt}\right)}^{\infty} e^{-y^2} du$$

or

$$I_1 = e^{-aw} \cdot \operatorname{erfc}\left(\frac{\alpha}{2\sqrt{t}} - \sqrt{wt}\right) \cdot \frac{\sqrt{\pi}}{2} \qquad \ldots.(13)$$

Similarly by putting

$$\frac{\alpha}{2\sqrt{u}} + \sqrt{wu} = y'$$

or

$$-\left(\frac{\alpha}{4u^{3/2}} - \sqrt{\frac{w}{u}}\right) du = dy' \qquad \ldots.(14)$$

in equation (19), we get

$$I_2 = e^{aw} \cdot \operatorname{erfc}\left(\frac{\alpha}{2\sqrt{t}} + \sqrt{wt}\right) \cdot \frac{\sqrt{\pi}}{2} \qquad \ldots.(15)$$

where, [$\operatorname{erfc}(y) = 1 - \operatorname{erf}(y)$]

Now substituting the value of I_1 and I_2 from equations(13) and (15) in equation (8), we get

$$V^* = \frac{e^{wt}}{\sqrt{\pi}} \left[(e^{-\alpha\sqrt{w}}) \cdot \operatorname{erfc}\left(\frac{\alpha}{2\sqrt{t}} - \sqrt{wt}\right) \cdot \frac{\sqrt{\pi}}{2} + e^{\alpha\sqrt{w}} \cdot \operatorname{erfc}\left(\frac{\alpha}{2\sqrt{t}} + \sqrt{wt}\right) \cdot \frac{\sqrt{\pi}}{2} \right]$$

or

$$\begin{aligned} V^{*} = \frac{1}{2} \Bigg[& e^{(wt-\alpha\sqrt{w})} \,.\, \operatorname{erfc}\left(\frac{\alpha}{2\sqrt{t}} - \sqrt{wt}\right) + \\ & e^{(wt+\alpha\sqrt{w})} \,.\, \operatorname{erfc}\left(\frac{\alpha}{2\sqrt{t}} + \sqrt{wt}\right) \Bigg] \qquad \ldots.(16) \end{aligned}$$

APPENDIX - A1

****

COMPUTER PROGRAMME FOR NUMERCAL SOLUTION OF CONTAMINANT TRANSPORT MODEL FOR CASE-1

****

```
#include <stdio.h>
#include<math.h>
double   ul,ll,upper,lower,o,b,u,d,n,a;
int      a1,c,h1,inter,counter,choice;
double  sum,conc1[100][100],area,x,t,joint[100][100],t1,h,count,fun();
char    choice1,choice2;
main()
{
system("cls");
 printf("THIS PROGRAM WILL SHOW THE VARIATION OF THE TERM CONC./C0\n");
 printf("OF A CERTAIN GROUND WATER POLLUTANT WITH TIME AND POSITION\n");
 printf("ALL PARAMETERS ARE TO BE INPUTTED IN SI UNITS\n\n");
printf("ENTER  CHOICE : X CONSTANT & T VARYING------ 1\n");
printf("                T CONSTANT & X VARYING------ 2\n");
scanf("%d",&choice);
if (choice==1)
{
printf("This part of the program  will give  a table of conc./c0\n");
 printf("with varying time and varying values of the six constants\n");
 printf("one at a time at a certain depth from which  graphs \n");
printf("can be drawn corresponding to that depth for analysis. \n\n");
again:
printf("What is the depth at which you want to analyse the effect of\n")
printf("the constants?\n\n");
scanf("%lf",&x);
printf("For varying gamma,print the character 'o'\n");
printf("else print the other characters as they appear i.e. b,u,d,n
& a.\n\n");
scanf("%s",&choice1);
switch (choice1)
{
case 'o':
{
printf("What are the values of b,u,d,n and a respectively?\n");
scanf("%lf%lf%lf%lf%lf",&b,&u,&d,&n,&a);
printf("give the upper and the lower limits of the variation and the
no.of intervals.\n");
scanf("%lf %lf %d",&ul,&ll,&h1);
printf("What are the upper  and the lowerlimits of t?\n");
```

```
scanf("%lf %lf",&upper,&lower);
printf("How many number of intervals do you want for the 't'
values?\n\n\n");
scanf("%d",&inter);
printf("                     TABLE \n");
printf("CONCENTRATION OF THE CONTAMINANTS AT DEPTH = %lf
metres\n\n\n",x);
printf("The constant 'gamma' is changing.\n\n");
printf("CONSTANTS: b=%lf,u=%lf\n",b,u);
printf("           d=%lf,n=%lf,a=%lf\n",d,n,a);
printf("--------------------------------------------------------
----------------------------------\n");
printf("   TIME                  CONC./CO     AT   GAMMA=         \n");
printf("                  ----------------------------------------
---------------------------\n");
printf("                  %lf            %lf          %lf
 %lf         %lf \n",ll,ll+(ul-ll)/4,ll+(ul-ll)/2,ll=(3*(ul-ll))/4,ul);
printf("--------------------------------------------------------------
---------------------\n\n");
for(counter=1,o=ll;o<=ul+(ul-ll)/4;o+=(ul-ll)/h1,counter++)
{
 for(c=1,t=lower;t<=upper;t+=(upper-lower)/inter,c++)
 {
 joint[counter][c]=fun(x,t);
  count=10*t;
  h=t/count;
  sum=0;
 for(a1=2,t1=h;a1<=count,t1<t;a1++,t1+=h)
  {
   if (a1%2==0)
    {
    sum+=4*fun(x,t1);
    }
  else
{
  sum+=2*fun(x,t1);
}
  area=(h/3)*(fun(x,h)+sum+fun(x,t));
}
conc1[counter][c]=joint[counter][c]+area;
}
}

for(c=1,t=lower;c<=inter+1,t<=upper;t+=(upper-lower)/inter,c++)
{
printf("  %lf            %lf           %lf          %lf          %lf
           %lf \n",t,conc1[1][c],conc1[2][c],conc1[3][c],conc1[4][c],
conc1[5][c]);
 }
printf("---------------------------------------------------------------
-------------------------------------\n");
printf("--------------------------------------------------------------
```

```
-----------------------------------\n");
printf("\n\n\n\n\n\n");
 system("cls");
   break;
}
case 'b':
{
printf("What are the values of gamma,u,d,n and a respectively?\n");
scanf("%lf%lf%lf%lf%lf",&o,&u,&d,&n,&a);
printf("give the upper and the lower limits of the variation and the
 no.of intervals.\n");
scanf("%lf %lf %d",&ul,&ll,&h1);
printf("What are the upper  and the lowerlimits of t?\n");
scanf("%lf %lf",&upper,&lower);
printf("How many number of intervals do you want for the 't'
values?\n\n\n");
scanf("%d",&inter);
printf("                    TABLE \n");
printf("CONCENTRATION OF THE CONTAMINANTS AT DEPTH = %lf
metres\n\n\n",x);
printf("The constant 'b' is changing.\n\n");
printf("CONSTANTS: gamma=%lf,u=%lf\n",o,u);
printf("          d=%lf,n=%lf,a=%lf\n",d,n,a);
printf("---------------------------------------------------------------------
-----------------------------------\n");
printf("   TIME                  CONC./CO     AT    'B'=         \n");
printf("                -------------------------------------------
-----------------------------------\n");
printf("                %lf             %lf             %lf             %lf
         %lf \n",ll,ll+(ul-ll)/4,ll+(ul-ll)/2,ll+(3*(ul-ll))/4,ul);
printf("---------------------------------------------------------------------
-------------------------------------\n\n");
for(counter=1,b=ll;b<=ul+(ul-ll)/4;b+=(ul-ll)/h1,counter++)
{
 for(c=1,t=lower;t<=upper;t+=(upper-lower)/inter,c++)
 {
 joint[counter][c]=fun(x,t);
  count=10*t;
  h=t/count;
  sum=0;
 for(a1=2,t1=h;a1<=count,t1<t;a1++,t1+=h)
  {
   if (a1%2==0)
    {
    sum+=4*fun(x,t1);
    }
  else
{
  sum+=2*fun(x,t1);
}
  area=(h/3)*(fun(x,h)+sum+fun(x,t));
}
```

```
concl[counter][c]=joint[counter][c]+area;
}
}
for(c=1,t=lower;c<=inter+1,t<=upper;t+=(upper-lower)/inter,c++)
{
printf("   %lf              %lf               %lf            %lf          %lf
        %lf\n",t,concl[1][c],concl[2][c],concl[3][c],concl[4][c],
concl[5][c]);
 }
printf("--------------------------------------------------------------
-------------------\n");
printf("--------------------------------------------------------------
-------------------\n");
printf("\n\n\n\n\n\n");
 system("cls");
   break;
}
case 'u':
{
printf("What are the values of ,gamma,b,d,n and a respectively?\n");
scanf("%lf%lf%lf%lf%lf",&o,&b,&d,&n,&a);
printf("give the upper and the lower limits of the variation and
 the no.of intervals.\n");
scanf("%lf %lf %d",&ul,&ll,&h1);
printf("What are the upper  and the lowerlimits of t?\n");
scanf("%lf %lf",&upper,&lower);
printf("How many number of intervals do you want for the 't'
values?\n\n\n");
scanf("%d",&inter);
printf("                    TABLE \n");
printf("CONCENTRATION OF THE CONTAMINANTS AT DEPTH = %lf
metres\n\n\n",x);
printf("The constant 'u' is changing.\n\n");
printf("CONSTANTS: b=%lf,gamma=%lf\n",b,o);
printf("           d=%lf,n=%lf,a=%lf\n",d,n,a);
printf("------------------------------------------------------------------
-----------------------------------\n");
printf("   TIME                    CONC./CO     AT    'U'=        \n");
printf("                           ----------------------------------------
------------------------------------\n");
printf("                   %lf            %lf            %lf            %lf
     %lf \n",ll,ll+(ul-ll)/4,ll+(ul-ll)/2,ll+(3*(ul-ll))/4,ul);
printf("-------------------------------------------------------------------
------------------\n\n");
for(counter=1,u=ll;u<=ul+(ul-ll)/4;u+=(ul-ll)/h1,counter++)
{
 for(c=1,t=lower;t<=upper;t+=(upper-lower)/inter,c++)
 {
 joint[counter][c]=fun(x,t);
  count=10*t;
  h=t/count;
  sum=0;
```

```
 for(a1=2,t1=h;a1<=count,t1<t;a1++,t1+=h)
  {
   if (a1%2==0)
    {
    sum+=4*fun(x,t1);
    }
  else
{
  sum+=2*fun(x,t1);
}
  area=(h/3)*(fun(x,h)+sum+fun(x,t));
}
conc1[counter][c]=joint[counter][c]+area;
}
}
for(c=1,t=lower;c<=inter+1,t<=upper;t+=(upper-lower)/inter,c++)
{
printf("   %lf            %lf            %lf           %lf
  %lf          %lf  \n",t,conc1[1][c],conc1[2][c],conc1[3][c],
conc1[4][c],conc1[5][c]);
 }
printf("-------------------------------------------------------
-------------------------\n");
printf("-------------------------------------------------------
-------------------------\n");
printf("\n\n\n\n\n\n");
 system("cls");
   break;
}
case 'd':
{
printf("What are the values of gamma,b,u,n and a respectively?\n");
scanf("%lf%lf%lf%lf%lf",&o,&b,&u,&n,&a);
printf("give the upper and the lower limits of the variation and
the no.of intervals.\n");
scanf("%lf %lf %d",&ul,&ll,&h1);
printf("What are the upper  and the lowerlimits of t?\n");
scanf("%lf %lf",&upper,&lower);
printf("How many number of intervals do you want for the 't'
values?\n\n\n");
scanf("%d",&inter);
printf("                         TABLE \n");
printf("CONCENTRATION OF THE CONTAMINANTS AT DEPTH = %lf
metres\n\n\n",x);
printf("The constant 'd' is changing.\n\n");
printf("CONSTANTS: b=%lf,u=%lf\n",b,u);
printf("         gamma=%lf,n=%lf,a=%lf\n",o,n,a);
printf("---------------------------------------------------------
---------------------\n");
printf("   TIME                   CONC./CO    AT   'D'=       \n");
printf("                   -----------------------------------------
-----------------------\n");
```

```
printf("                    %lf              %lf            %lf             %lf
    %lf\n",ll,ll+(ul-ll)/4,ll+(ul-ll)/2,ll+(3*(ul-ll))/4,ul);
printf("---------------------------------------------------------------------
--------------\n\n");
for(counter=1,d=ll;d<=ul+(ul-ll)/4;d+=(ul-ll)/hl,counter++)
{
 for(c=1,t=lower;t<=upper;t+=(upper-lower)/inter,c++)
 {
 joint[counter][c]=fun(x,t);
  count=10*t;
  h=t/count;
  sum=0;
 for(a1=2,t1=h;a1<=count,t1<t;a1++,t1+=h)
  {
   if (a1%2==0)
    {
    sum+=4*fun(x,t1);
    }
  else
{
  sum+=2*fun(x,t1);
}
  area=(h/3)*(fun(x,h)+sum+fun(x,t));
}
concl[counter][c]=joint[counter][c]+area;
}
}
for(c=1,t=lower;c<=inter+1,t<=upper;t+=(upper-lower)/inter,c++)
{
printf("   %lf          %lf            %lf          %lf
    %lf          %lf     \n",t,concl[1][c],concl[2][c],concl[3][c],
concl[4][c],concl[5][c]);
 }
printf("-----------------------------------------------------------------------
-------------------------\n");
printf("----------------------------------------------------------------------
---------------------------\n");
printf("\n\n\n\n\n\n");
 system("cls");
   break;
}
case 'n':
{
printf("What are the values of gamma,b,u,d and a respectively?\n");
scanf("%lf%lf%lf%lf%lf",&o,&b,&u,&d,&a);
printf("give the upper and the lower limits of the variation and the
no.of intervals.\n");
scanf("%lf %lf %d",&ul,&ll,&hl);
printf("What are the upper  and the lowerlimits of t?\n");
scanf("%lf %lf",&upper,&lower);
printf("How many number of intervals do you want for the 't'
values?\n\n\n");
```

```
scanf("%d",&inter);
printf("                         TABLE \n");
printf("CONCENTRATION OF THE CONTAMINANTS AT DEPTH = %lf
metres\n\n\n",x);
printf("The constant 'n' is changing.\n\n");
printf("CONSTANTS: b=%lf,u=%lf\n",b,u);
printf("           d=%lf,gamma=%lf,a=%lf\n",d,o,a);
printf("--------------------------------------------------------------
----------------\n");
printf("  TIME                    CONC./CO    AT   'N'=        \n");
printf("                 ---------------------------------------------
---------------\n");
printf("                   %lf             %lf            %lf           %lf
     %lf     \n",t,ll,ll+(ul-ll)/4,ll+(ul-ll)/2,ll+(3*(ul-ll))/4,ul);
printf("--------------------------------------------------------------------
-----------\n\n");
for(counter=1,o=ll;o<=ul+(ul-ll)/4;o+=(ul-ll)/hl,counter++)
{
 for(c=1,t=lower;t<=upper;t+=(upper-lower)/inter,c++)
 {
 joint[counter][c]=fun(x,t);
  count=10*t;
  h=t/count;
  sum=0;
 for(a1=2,t1=h;a1<=count,t1<t;a1++,t1+=h)
  {
   if (a1%2==0)
    {
    sum+=4*fun(x,t1);
    }
  else
{
  sum+=2*fun(x,t1);
}
  area=(h/3)*(fun(x,h)+sum+fun(x,t));
}
conc1[counter][c]=joint[counter][c]+area;
}
}
for(c=1,t=lower;c<=inter+1,t<=upper;t+=(upper-lower)/inter,c++)
{
printf("  %lf           %lf             %lf           %lf          %lf
         %lf  \n",t,conc1[1][c],conc1[2][c],conc1[3][c],
conc1[4][c],conc1[5][c]);
 }
printf("-----------------------------------------------------------\n");
printf("-----------------------------------------------------------\n");
printf("\n\n\n\n\n\n");
 system("cls");
   break;
}
case 'a':
```

```
{
printf("What are the values of gamma,b,u,d and n  respectively?\n");
scanf("%lf%lf%lf%lf%lf",&o,&b,&u,&d,&n);
printf("give the upper and the lower limits of the variation and
the no.of intervals.\n");
scanf("%lf %lf %d",&ul,&ll,&h1);
printf("What are the upper  and the lowerlimits of t?\n");
scanf("%lf %lf",&upper,&lower);
printf("How many number of intervals do you want for the 't'
values?\n\n\n");
scanf("%d",&inter);
printf("                    TABLE \n");
printf("CONCENTRATION OF THE CONTAMINANTS AT DEPTH = %lf metres\n\n\n",x);
printf("The constant 'a' is changing.\n\n");
printf("CONSTANTS: b=%lf,u=%lf\n",b,u);
printf("           d=%lf,gamma=%lf,n=%lf\n",d,o,n);
printf("---------------------------------------------------------
----------------\n");
printf("  TIME                  CONC./CO    AT   'A'=        \n");
printf("                  ---------------------------------------
-----------------\n");
printf("                 %lf           %lf          %lf          %lf
    %lf\n",ll,ll+(ul-ll)/4,ll+(ul-ll)/2,ll+(3*(ul-ll))/4,ul);
printf("-------------------------------------------------------
------------------\n\n");
for(counter=1,o=ll;o<=ul+(ul-ll)/4;o+=(ul-ll)/h1,counter++)
{
 for(c=1,t=lower;t<=upper;t+=(upper-lower)/inter,c++)
 {
 joint[counter][c]=fun(x,t);
  count=10*t;
  h=t/count;
  sum=0;
 for(a1=2,t1=h;a1<=count,t1<t;a1++,t1+=h)
  {
   if (a1%2==0)
    {
    sum+=4*fun(x,t1);
    }
  else
{
  sum+=2*fun(x,t1);
}
  area=(h/3)*(fun(x,h)+sum+fun(x,t));
}
concl[counter][c]=joint[counter][c]+area;
}
}
for(c=1,t=lower;c<=inter+1,t<=upper;t+=(upper-lower)/inter,c++)
{
printf("  %lf           %lf            %lf            %lf           %lf
      %lf     \n",t,concl[1][c],concl[2][c],concl[3][c],concl[4][c],
```

```
conc1[5][c]);
 }
printf("-------------------------------------------------------\n");
printf("-------------------------------------------------------\n");
printf("\n\n\n\n\n\n");
 system("cls");
   break;
}
}
printf("Do you want the  analysis for a different value of 'x'?
(y/n)\n");
scanf("%s",&choice2);
if (choice2=='y')
goto again;
else
printf("Thank you.See you again.\n");
}
else if (choice==2)
{
printf("This part of the program will tabulate the conc/c0 values\n");
 printf("with varying depth and varying values of the six constants\n");
 printf("one at a time at a certain time from which graphs \n");
printf("can be drawn corresponding to that time \for(or analysis.\n");
again1:
printf("What is the time  at which you want to analyse the effect of\n");
printf("the constants?\n\n");
scanf("%lf",&t);
printf("For varying gamma,print the character 'o'\n");
printf("else print the other characters as they appear i.e.
 b,u,d,n & a.\n\n");
scanf("%s",&choice1);
switch (choice1)
{
case 'o':
{
printf("What are the values of b,u,d,n and a respectively?\n");
scanf("%lf%lf%lf%lf%lf",&b,&u,&d,&n,&a);
printf("give the upper and the lower limits of the variation and
the no.of intervals.\n");
scanf("%lf %lf %d",&ul,&ll,&h1);
printf("What are the upper  and the lower limits of x?\n");
scanf("%lf %lf",&upper,&lower);
printf("How many number of intervals do you want for the 'x'
values?\n\n\n");
scanf("%d",&inter);
printf("                    TABLE \n");
printf("CONCENTRATION OF THE CONTAMINANTS AT TIME = %lf
seconds \n\n\n",t);
printf("The constant 'gamma' is changing.\n\n");
printf("CONSTANTS: b=%lf,u=%lf\n",b,u);
printf("          d=%lf,n=%lf,a=%lf\n",d,n,a);
printf("---------------------------------------------------------------
```

```
------\n");
printf("   DEPTH                     CONC./CO     AT   GAMMA=         \n");
printf("                      ------------------------------------------------
-------\n");
printf("                       %lf            %lf            %lf          %lf
      %lf  \n",ll,ll+(ul-ll)/4,ll + (ul-ll)/2,ll+(3*(ul-ll))/4, ul);
printf("------------------------------------------------------------------
-----------------------------------------\n\n");
for(counter=1,o=ll;o<=ul+(ul-ll)/4;o+=(ul-ll)/h1,counter++)
{
 for(c=1,x=lower;x<=upper;x+=(upper-lower)/inter,c++)
 {
 joint[counter][c]=fun(x,t);
  count=10*t;
  h=t/count;
  sum=0;
 for(a1=2,t1=h;a1<=count,t1<t;a1++,t1+=h)
  {
   if (a1%2==0)
    {
    sum+=4*fun(x,t1);
    }
  else
{
  sum+=2*fun(x,t1);
}
  area=(h/3)*(fun(x,h)+sum+fun(x,t));
}
conc1[counter][c]=joint[counter][c]+area;
}
}
for(c=1,x=lower;c<=inter+1,x<=upper;x+=(upper-lower)/inter,c++)
{
printf("  %lf         %lf            %lf           %lf          %lf
    %lf    \n",x,conc1[1][c],conc1[2][c],conc1[3][c],conc1[4][c],
conc1[5][c]);
 }
printf("------------------------------------------------------------------
-----------------------------------\n");
printf("-----------------------------------------------------------------
-----------------------------------\n");
printf("\n\n\n\n\n\n");
 system("cls");
   break;
}
case 'b':
{
printf("What are the values of gamma,u,d,n and a respectively?\n");
scanf("%lf%lf%lf%lf%lf",&o,&u,&d,&n,&a);
printf("give the upper and the lower limits of the variation and the
 no.of intervals.\n");
scanf("%lf %lf %d",&ul,&ll,&h1);
```

```
printf("What are the upper  and the lower limits of x?\n");
scanf("%lf %lf",&upper,&lower);
printf("How many number of intervals do you want for the 'x'
values?\n\n\n");
scanf("%d",&inter);
printf("                        TABLE \n");
printf("CONCENTRATION OF THE CONTAMINANTS AT TIME = %lf
seconds \n\n\n",t);
printf("The constant 'b' is changing.\n\n");
printf("CONSTANTS:gamma=%lf,u=%lf\n",o,u);
printf("             d=%lf,n=%lf,a=%lf\n",d,n,a);
printf("-------------------------------------------------------------
-------------------------------------------------\n");
printf("   DEPTH                   CONC./CO     AT    B=          \n");
printf("                -------------------------------------------
------------------------------------------------\n");
printf("                %lf              %lf           %lf          %lf
    %lf \n",ll,ll+(ul-ll)/4,ll + (ul-ll)/2,ll+(3*(ul-ll))/4, ul);
printf("--------------------------------------------------------------------
----------------------------------------\n\n");
for(counter=1,b=ll;b<=ul+(ul-ll)/4;b+=(ul-ll)/hl,counter++)
{
 for(c=1,x=lower;x<=upper;x+=(upper-lower)/inter,c++)
 {
 joint[counter][c]=fun(x,t);
  count=10*t;
  h=t/count;
  sum=0;
 for(a1=2,t1=h;a1<=count,t1<t;a1++,t1+=h)
  {
   if (a1%2==0)
    {
    sum+=4*fun(x,t1);
    }
  else
{
  sum+=2*fun(x,t1);
}
  area=(h/3)*(fun(x,h)+sum+fun(x,t));
}
conc1[counter][c]=joint[counter][c]+area;
}
}
for(c=1,x=lower;c<=inter+1,x<=upper;x+=(upper-lower)/inter,c++)
{
printf("  %lf              %lf             %lf             %lf              %lf
      %lf    \n",x,conc1[1][c],conc1[2][c],conc1[3][c],conc1[4][c],
conc1[5][c]);
 }
printf("----------------------------------------------------------------------
------------------------------\n");
printf("----------------------------------------------------------------------
```

```
-------------------------------\n");
printf("\n\n\n\n\n\n");
 system("cls");
   break;
}
case 'u':
{
printf("What are the values of gamma,b,d,n and a respectively?\n");
scanf("%lf%lf%lf%lf%lf",&o,&b,&d,&n,&a);
printf("give the upper and the lower limits of the variation and the
 no.of intervals.\n");
scanf("%lf %lf %d",&ul,&ll,&h1);
printf("What are the upper  and the lower limits of x?\n");
scanf("%lf %lf",&upper,&lower);
printf("How many number of intervals do you want for the 'x'
values?\n\n\n");
scanf("%d",&inter);
printf("                    TABLE \n");
printf("CONCENTRATION OF THE CONTAMINANTS AT TIME = %lf
seconds \n\n\n",t);
printf("The constant 'u' is changing.\n\n");
printf("CONSTANTS: b=%lf,gamma=%lf\n",b,o);
printf("           d=%lf,n=%lf,a=%lf\n",d,n,a);
printf("-----------------------------------------------------------------
---------------------------------------\n");
printf("   DEPTH                     CONC./CO    AT   U=        \n");
printf("                   ----------------------------------------------
-----------------------------------------\n");
printf("                   %lf            %lf            %lf            %lf
      %lf \n",ll,ll+(ul-ll)/4,ll + (ul-ll)/2,ll+(3*(ul-ll))/4, ul);
printf("-----------------------------------------------------------------
-----------------------------------------\n\n");
for(counter=1,u=ll;u<=ul+(ul-ll)/4;u+=(ul-ll)/h1,counter++)
{
 for(c=1,x=lower;x<=upper;x+=(upper-lower)/inter,c++)
 {
 joint[counter][c]=fun(x,t);
  count=10*t;
  h=t/count;
  sum=0;
 for(a1=2,t1=h;a1<=count,t1<t;a1++,t1+=h)
  {
   if (a1%2==0)
    {
    sum+=4*fun(x,t1);
    }
  else
{
  sum+=2*fun(x,t1);
}
  area=(h/3)*(fun(x,h)+sum+fun(x,t));
}
```

```
conc1[counter][c]=joint[counter][c]+area;
}
}
for(c=1,x=lower;c<=inter+1,x<=upper;x+=(upper-lower)/inter,c++)
{
printf("  %lf              %lf              %lf            %lf            %lf
        %lf    \n",x,conc1[1][c],conc1[2][c],conc1[3][c],conc1[4][c],
conc1[5][c]);
 }
printf("----------------------------------------------------------------
-------------------------------\n");
printf("----------------------------------------------------------------
----------------------------------\n");
printf("\n\n\n\n\n\n");
 system("cls");
   break;
}
case 'd':
{
printf("What are the values of gamma,b,u,n and a respectively?\n");
scanf("%lf%lf%lf%lf%lf",&o,&b,&u,&n,&a);
printf("give the upper and the lower limits of the variation and the
 no.of intervals.\n");
scanf("%lf %lf %d",&ul,&ll,&h1);
printf("What are the upper  and the lower limits of x?\n");
scanf("%lf %lf",&upper,&lower);
printf("How many number of intervals do you want for the 'x'
values?\n\n\n");
scanf("%d",&inter);
printf("                    TABLE \n");
printf("CONCENTRATION OF THE CONTAMINANTS AT  TIME= %lf seconds
 \n\n\n",t);
printf("The constant 'd' is changing.\n\n");
printf("CONSTANTS: b=%lf,u=%lf\n",b,u);
printf("          gamma=%lf,n=%lf,a=%lf\n",o,n,a);
printf("-------------------------------------------------------------------
-----------------------------------------\n");
printf("   DEPTH                     CONC./CO     AT  D=        \n");
printf("                          -------------------------------------------
------------------------------------------\n");
printf("                %lf               %lf             %lf           %lf
       %lf \n",ll,ll+(ul-ll)/4,ll + (ul-ll)/2,ll+(3*(ul-ll))/4, ul);
printf("-------------------------------------------------------------------
-------------------------------------------\n\n");
for(counter=1,d=ll;d<=ul+(ul-ll)/4;d+=(ul-ll)/h1,counter++)
{
 for(c=1,x=lower;x<=upper;x+=(upper-lower)/inter,c++)
 {
 joint[counter][c]=fun(x,t);
  count=10*t;
  h=t/count;
  sum=0;
```

```
 for(a1=2,t1=h;a1<=count,t1<t;a1++,t1+=h)
  {
   if (a1%2==0)
    {
    sum+=4*fun(x,t1);
    }
  else
{
  sum+=2*fun(x,t1);
}
  area=(h/3)*(fun(x,h)+sum+fun(x,t));
}
conc1[counter][c]=joint[counter][c]+area;
}
}
for(c=1,x=lower;c<=inter+1,x<=upper;x+=(upper-lower)/inter,c++)
{
printf("  %lf            %lf            %lf            %lf            %lf
          %lf    \n",x,conc1[1][c],conc1[2][c],conc1[3][c],conc1[4][c],
conc1[5][c]);
 }
printf("---------------------------------------------------------------------
-----------------------------\n");
printf("---------------------------------------------------------------------
-----------------------------\n");
printf("\n\n\n\n\n\n");
 system("cls");
   break;
}
case 'n':
{
printf("What are the values of gamma,b,u,d and a respectively?\n");
scanf("%lf%lf%lf%lf%lf",&o,&b,&u,&d,&a);
printf("give the upper and the lower limits of the variation
 and the no.of intervals.\n");
scanf("%lf %lf %d",&ul,&ll,&h1);
printf("What are the upper  and the lower limits of x?\n");
scanf("%lf %lf",&upper,&lower);
printf("How many number of intervals do you want for the 'x'
values?\n\n\n");
scanf("%d",&inter);
printf("                    TABLE \n");
printf("CONCENTRATION OF THE CONTAMINANTS AT  TIME= %lf
seconds \n\n\n",t);
printf("The constant 'n' is changing.\n\n");
printf("CONSTANTS: b=%lf,u=%lf\n",b,u);
printf("          gamma=%lf,d=%lf,a=%lf\n",o,d,a);
printf("---------------------------------------------------------------------
------------------------------------\n");
printf("   DEPTH                    CONC./CO    AT  N=        \n");
printf("                 -----------------------------------------------
-----------------------------------------------\n");
```

```
printf("                    %lf                    %lf                %lf               %lf
       %lf \n",ll,ll+(ul-ll)/4,ll + (ul-ll)/2,ll+(3*(ul-ll))/4, ul);
printf("----------------------------------------------------------------
----------------------------------------\n\n");
for(counter=1,n=ll;n<=ul+(ul-ll)/4;n+=(ul-ll)/h1,counter++)
{
 for(c=1,x=lower;x<=upper;x+=(upper-lower)/inter,c++)
 {
 joint[counter][c]=fun(x,t);
  count=10*t;
  h=t/count;
  sum=0;
 for(a1=2,t1=h;a1<=count,t1<t;a1++,t1+=h)
  {
   if (a1%2==0)
    {
    sum+=4*fun(x,t1);
    }
  else
{
  sum+=2*fun(x,t1);
}
  area=(h/3)*(fun(x,h)+sum+fun(x,t));
}
conc1[counter][c]=joint[counter][c]+area;
}
}
for(c=1,x=lower;c<=inter+1,x<=upper;x+=(upper-lower)/inter,c++)
{
printf("   %lf            %lf              %lf              %lf             %lf
        %lf    \n",x,conc1[1][c],conc1[2][c],conc1[3][c],
conc1[4][c],conc1[5][c]);
 }
printf("-------------------------------------------------------------
----------------------------------------\n");
printf("--------------------------------------------------------------
--------------------------------------\n");
printf("\n\n\n\n\n\n");
 system("cls");
   break;
}
case 'a':
{
printf("What are the values of gamma,b,u,d & n  respectively?\n");
scanf("%lf%lf%lf%lf%lf",&o,&b,&u,&d,&n);
printf("give the upper and the lower limits of the variation and the
 no.of intervals.\n");
scanf("%lf %lf %d",&ul,&ll,&h1);
printf("What are the upper  and the lower limits of x?\n");
scanf("%lf %lf",&upper,&lower);
printf("How many number of intervals do you want for the 'x'
values?\n\n\n");
```

```
scanf("%d",&inter);
printf("                           TABLE \n");
printf("CONCENTRATION OF THE CONTAMINANTS AT  TIME= %lf
seconds \n\n\n",t);
printf("The constant 'a' is changing.\n\n");
printf("CONSTANTS: b=%lf,u=%lf\n",b,u);
printf("            gamma=%lf,n=%lf,d=%lf\n",o,n,d);
printf("--------------------------------------------------------
-----------------------------------\n");
printf("   DEPTH                        CONC./C0     AT  A=        \n");
printf("                         ---------------------------------------
-------- -----------------------------\n");
printf("                       %lf            %lf            %lf            %lf
      %lf \n",ll,ll+(ul-ll)/4,ll + (ul-ll)/2,ll+(3*(ul-ll))/4, ul);
printf("---------------------------------------------------------------
--------------------------------------\n\n");
for(counter=1,a=ll;a<=ul+(ul-ll)/4;a+=(ul-ll)/hl,counter++)
{
 for(c=1,x=lower;x<=upper;x+=(upper-lower)/inter,c++)
 {
 joint[counter][c]=fun(x,t);
  count=10*t;
  h=t/count;
  sum-0;
 for(al=2,tl=h;al<=count,tl<t;al++,tl+=h)
  {
   if (al%2==0)
    {
    sum+=4*fun(x,tl);
    }
  else
{
  sum+=2*fun(x,tl);
}
  area=(h/3)*(fun(x,h)+sum+fun(x,t));
}
concl[counter][c]=joint[counter][c]+area;
}
}
for(c=1,x=lower;c<=inter+1,x<=upper;x+=(upper-lower)/inter,c++)
{
printf("  %lf           %lf            %lf            %lf            %lf
     %lf    \n",x,concl[1][c],concl[2][c],concl[3][c],concl[4][c],
concl[5][c]);
 }
printf("------------------------------------------------------------
-----------------------------------\n");
printf("------------------------------------------------------------
-----------------------------------\n");
printf("\n\n\n\n\n\n");
 system("cls");
   break;
```

```
}
}
printf("Do you want the  analysis for a different value of 't'?
(y/n)\n");
scanf("%s",&choice2);
if (choice2=='y')
goto again1;
else
printf("Thank you.See you again.\n");
}
}
double fun(x,t)
double x,t;
{
double   l1,q1,r1,point1,joint1,p10,m1,prap;
m1=exp(o*t)/2;
prap=(u*u) + (4*d*((a*(1-n))-(b*n))/n);
p10=sqrt(prap);
l1=exp((x*(u-p10))/(2*d));
q1=(x-(p10*t))/(2*(sqrt(d*t)));
r1=exp((x*(u+p10))/(2*d));
point1=(x+(p10*t))/(2*(sqrt(d*t)));
joint1=m1*((l1*erfc(q1))+(r1*erfc(point1)));
return joint1;
}
```

****

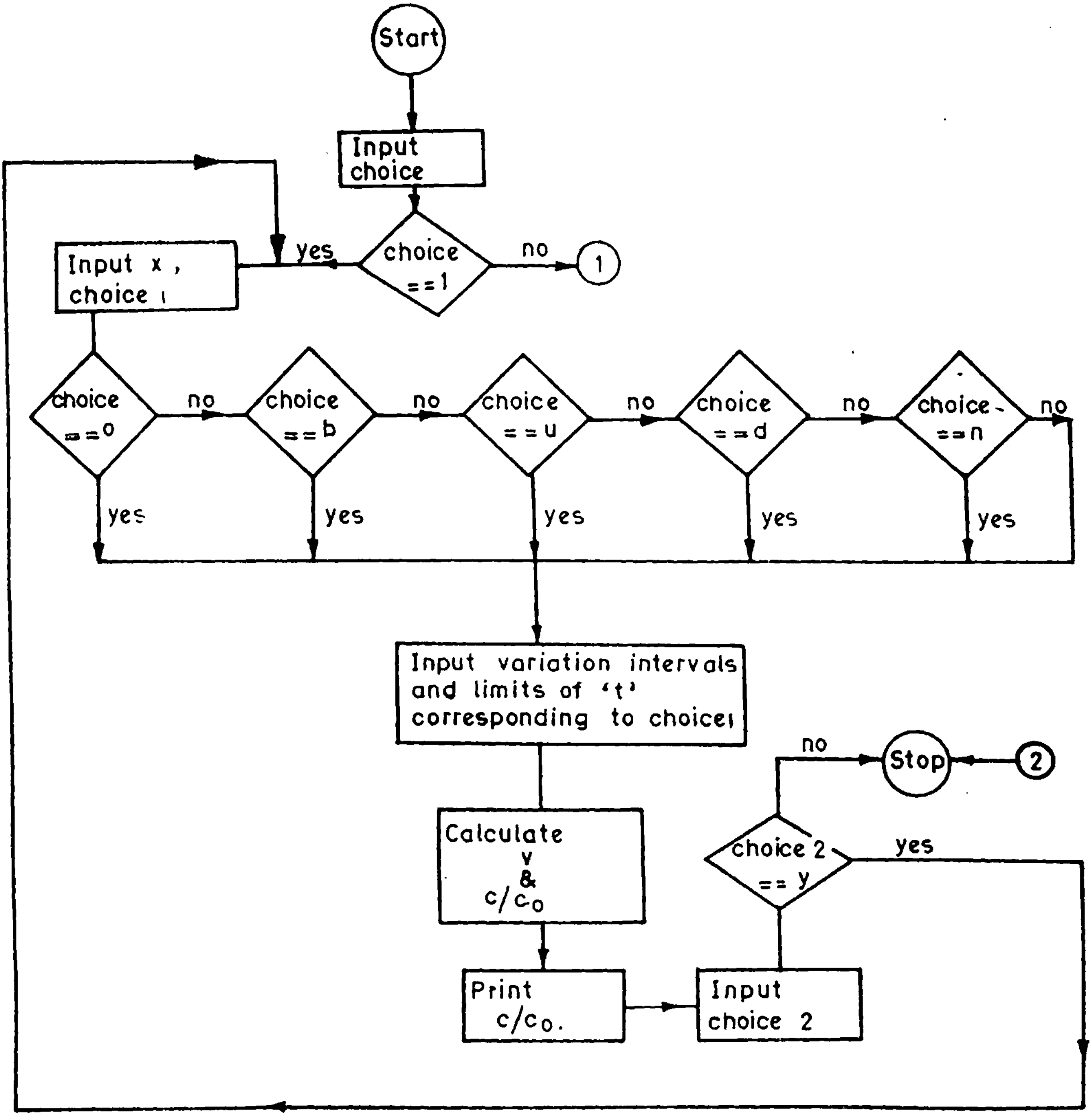

FIG. A1 FLOW CHART OF THE PROGRAM FOR NUMERICAL SOLUTION OF CONTAMINANT TRANSPORT EQUATION FOR CASE I.

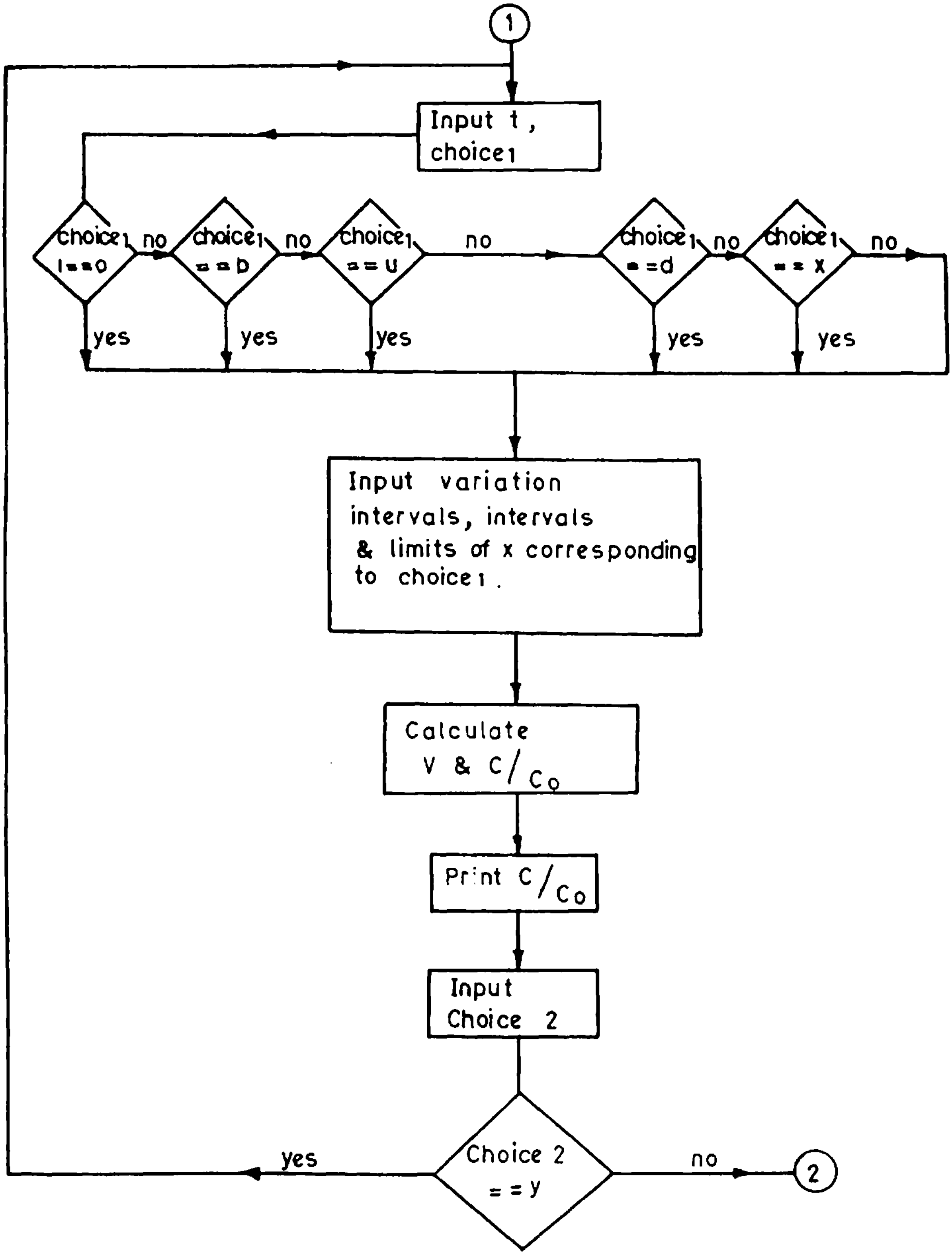

FIG. A1 (Continued)

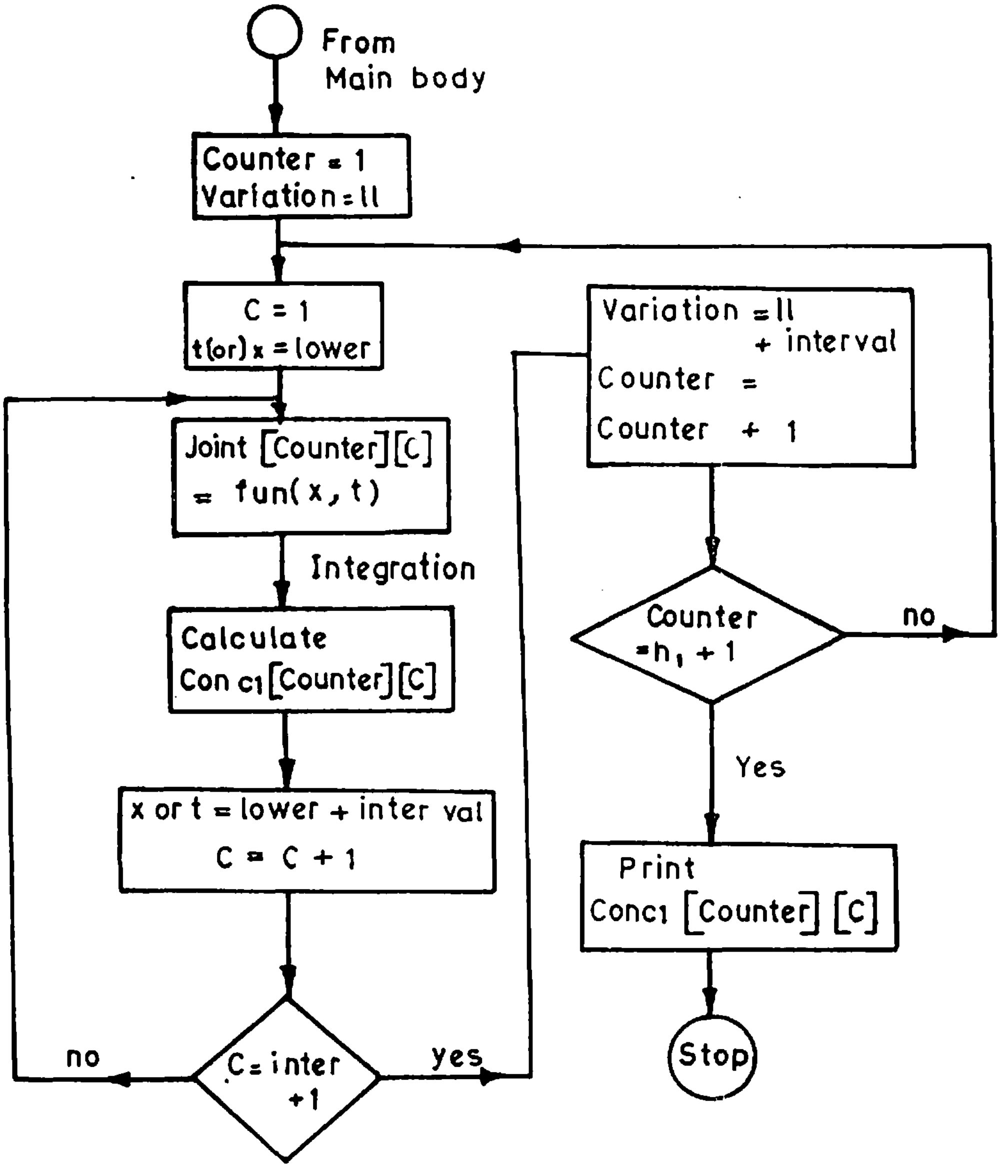

FIG. A2 ELABORATE FLOW CHART FOR TABULATING V & C/C_0 VALUES FOR CASE - I FOR EITHER DEPTH OR TIME TO BE CONSTANT.

APPENDIX : A2

****

COMPUTER PROGRAMME FOR CORRELATION ANALYSIS

****

```
C
C     THIS PROGRAM CALCULATES THE CORRELATION COEFFICIENT BETWEEN ALL
C
C     POSSIBLE PAIRS OF VARIABLES  AND CONSTANTS `A' & `B' OF THEIR
C
C     LINEAR RELATIONS ONLY FOR THOSE WHICH HAVE HIGH VALUE OF `r'.
C
      REAL DATA(35,14) , R(14,14) , COUNTER , C , D , EF , E2 , F2
      REAL M2 , MN , RELATION(100,3) , SUM1 , SUM2 , AVEXI , AVEXJ
      REAL TAB(35 , 51) , F , G , E
      INTEGER  Q,NAME(28) , S , NAME1(100,5) , COUNT , I , J , K
      INTEGER A , T , L , B
C
C     READING THE DATA FROM  THE INPUT FILE NAMED "INPUT.DAT"
C
      OPEN (2,FILE = "INPUT.DAT" ,ACCESS ='READ',STATUS='UNKOWN')


      READ(2,10) (NAME(I) , I = 1 , 28)
   10 FORMAT(14(2A4,1X))

      DO 20 J = 1 , 35
      READ(2,30) (DATA(J,K) , K = 1 , 14)
   30 FORMAT( 14(F8.2,1X) )
   20 CONTINUE

C
C     PROCESS FOR CALCULATION OF CORRELATION COEFFICIENT
C

      COUNT = 1

      DO 70 I = 1 , 13
      S = I + 1
            DO 80 J = S , 14
            MN = 0.0
            M2 = 0.0
            EF = 0.0
            E2 = 0.0
            F2 = 0.0
```

```
      COUNTER = 0.0
      SUM1 =  0.0
      SUM2 = 0.0
      SUMA = 0.0
      SUMB = 0.0
          DO 90 K = 1 , 35
          IF (DATA(K,I) .LE. 0.00) GO TO 90
          IF (DATA(K,J) .LE. 0.00) GO TO 90
          COUNTER = COUNTER + 1.0
          SUMA = SUMA + DATA(K,I)
          SUMB = SUMB + DATA(K,J)
          SUM1 = SUM1 + (1.0/DATA(K,I))
          SUM2 = SUM2 + (1.0/DATA(K,J))
 90       CONTINUE
      AVEXA = SUMA / COUNTER
      AVEXB = SUMB / COUNTER
      AVEXI = SUM1 / COUNTER
      AVEXJ = SUM2 / COUNTER
          DO 400 A = 1 , 35
          IF (DATA(A,I) .LE. 0.00) GO TO 400
          IF (DATA(A,J) .LE. 0.00) GO TO 400
          C = (1.0/DATA(A,I)) - AVEXI
          D = (1.0/DATA(A,J)) - AVEXJ
          E = (DATA(A,I) - AVEXA)
          F = (DATA(A,J) - AVEXB)
          EF = EF + (E * F)
          E2 = E2 + (E * E)
          F2 = F2 + (F * F)
          MN = MN + (C * D)
          M2 = M2 + (C * * 2)
400       CONTINUE
      R(I , J) = EF / (SQRT(E2 * F2))
      R(J , I) = R(I , J)
      R1 = ABS(R(I,J))
      IF (R1  .LE. 0.500) GO TO 80
      RELATION (COUNT , 1) = R(I , J)
      RELATION(COUNT , 3 ) = MN / M2
      RELATION (COUNT , 2) = AVEXJ - (RELATION(COUNT,3) * AVEXI)
      NAME1(COUNT , 1) = NAME(2*I-1)
      NAME1(COUNT , 2) = NAME(2*I)
      NAME1(COUNT , 3) = '    '
      NAME1(COUNT , 4) = NAME(2*J-1)
      NAME1(COUNT , 5) = NAME(2*J)
      L = 1
      DO 111 T = 1 , 35
      IF (DATA(T , I) .LE. 0.0) GO TO 111
      IF (DATA(T , J) .LE. 0.0) GO TO 111
      B = 3 * COUNT
      TAB(L , B - 2) = DATA(T , I)
      TAB(L , B) = DATA(T , J)
      G = RELATION(COUNT,3)+(RELATION(COUNT,2)*DATA(T,I))
      TAB(L , B - 1) = DATA(T , I) / G
```

```
                L = L + 1



  111           CONTINUE
                COUNT = COUNT + 1
   80           CONTINUE
   70     CONTINUE

          COUNT = COUNT - 1
          DO 21  I = 1 , 14
          R(I , I) = 1.0
   21     CONTINUE
C
C
C         PROCESSING THE OUTPUT
C
C

          OPEN (3,FILE = "OUTPUT.DAT" ,ACCESS ='WRITE',STATUS='UNKOWN')

C
C         OUTPUT OF CORRELATION MATRIX
C
          WRITE(3 , 100)
  100     FORMAT(1H ,'TABLE.1.',5X,'CORRELATION COEFFICIENT r AMONG VARIOUS
     1    \PARAMETERS OF GROUND WATER')
          Q='-'
          WRITE(3 , 120)(Q,I=1,135)
  120     FORMAT(X,135A)

          WRITE(3 , 130) (NAME(2*I-1),NAME(2*I),I = 1,14)
  130     FORMAT(1X,'Paramt.   ',X,14(2A4,1X))

          WRITE(3 , 121)(Q,I=1,135)
  121     FORMAT(1X,135A)

          DO 160 J = 1  , 14
          WRITE(3 , 170) NAME(2*J-1),NAME(2*J),( R(J  , K),K=1,14)
  170     FORMAT(1X,2A4,14(1X,F5.3,3X))
  160     CONTINUE

          WRITE(3 , 122)(Q,I=1,135)
  122     FORMAT(1X,135A)
C
C
C         PROCESSING CONSTANTS 'A' & 'B'
C
C
          WRITE(3 , 230)
  230     FORMAT(1X,'TABLE.2',5X,'LEAST SQARE FITTING OF THE RELATION x/y
```

```
     1 \= A + Bx  AMONG VARIOUS PARAMETERS')

      WRITE(3 , 250)(Q,I=1,51)
  250 FORMAT(1X,51A)

      WRITE(3 , 260)

  260 FORMAT(2X,'x',11X,'y',9X,'r*',8X,'B',10X,'A')

      WRITE(3 , 251)(Q,I=1,51)
  251 FORMAT(1X,51A)

      DO 270 I = 1 , COUNT
      WRITE(3 , 280)NAME1(I ,1),NAME1(I ,2),NAME1(I ,3),NAME1(I ,4),N
     1 AME1(I ,5),RELATION(I,1),RELATION(I, 2),RELATION(I,3)
  280 FORMAT(1X,5A4,2X,F5.3,2(2X,F9.4))
  270 CONTINUE

      WRITE(3 , 252)(Q,I=1,51)
  252 FORMAT(1X,51A)

      WRITE(3 , 340)
  340 FORMAT(2X,'*r : Correlation coefficient between x and y')

      WRITE(3 , 253)(Q,I=1,51)
  253 FORMAT(1X,51A)

C
C     PROCESSING PREDICTED & OBSERVED VALUES OF 'y' AS A FUNCTION OF 'x'
C     ONLY FOR 'r' > 0.5
C

      DO 305 I = 1 , COUNT

      WRITE(3 , 306)I,NAME1(I,4),NAME1(I,5),NAME1(I,1),NAME1(I,2)
  306 FORMAT(1X,'TABLE',I2,' Predicted & Observed values of ',2A4,'as
     1 a function of ',2A4)

      WRITE(3 , 302)RELATION(I , 1)
  302 FORMAT(25X,'(r = ',F5.3,')')

      WRITE(3 , 301)(Q,J=1,40)
  301 FORMAT(1X,40A)

      WRITE(3,308)NAME1(I,1),NAME1(I,2),NAME1(1,4),NAME1(I,5)
  308 FORMAT(1X,2A4,18X,2A4)

      WRITE(3,309)
  309 FORMAT(18x,'Predicted',3X,'Observed')

      WRITE(3 , 303)(Q,J=1,40)
  303 FORMAT(1X,40A)
```

```
      B = 3 * I
      DO 310 J = 1 , 35
      WRITE(3,307)TAB(J,B-2),TAB(J,B-1),TAB(J,B)
307   FORMAT(1X,F7.2,10X,F7.2,5X,F7.2)
310   CONTINUE

305   CONTINUE

STOP
      END
```

****

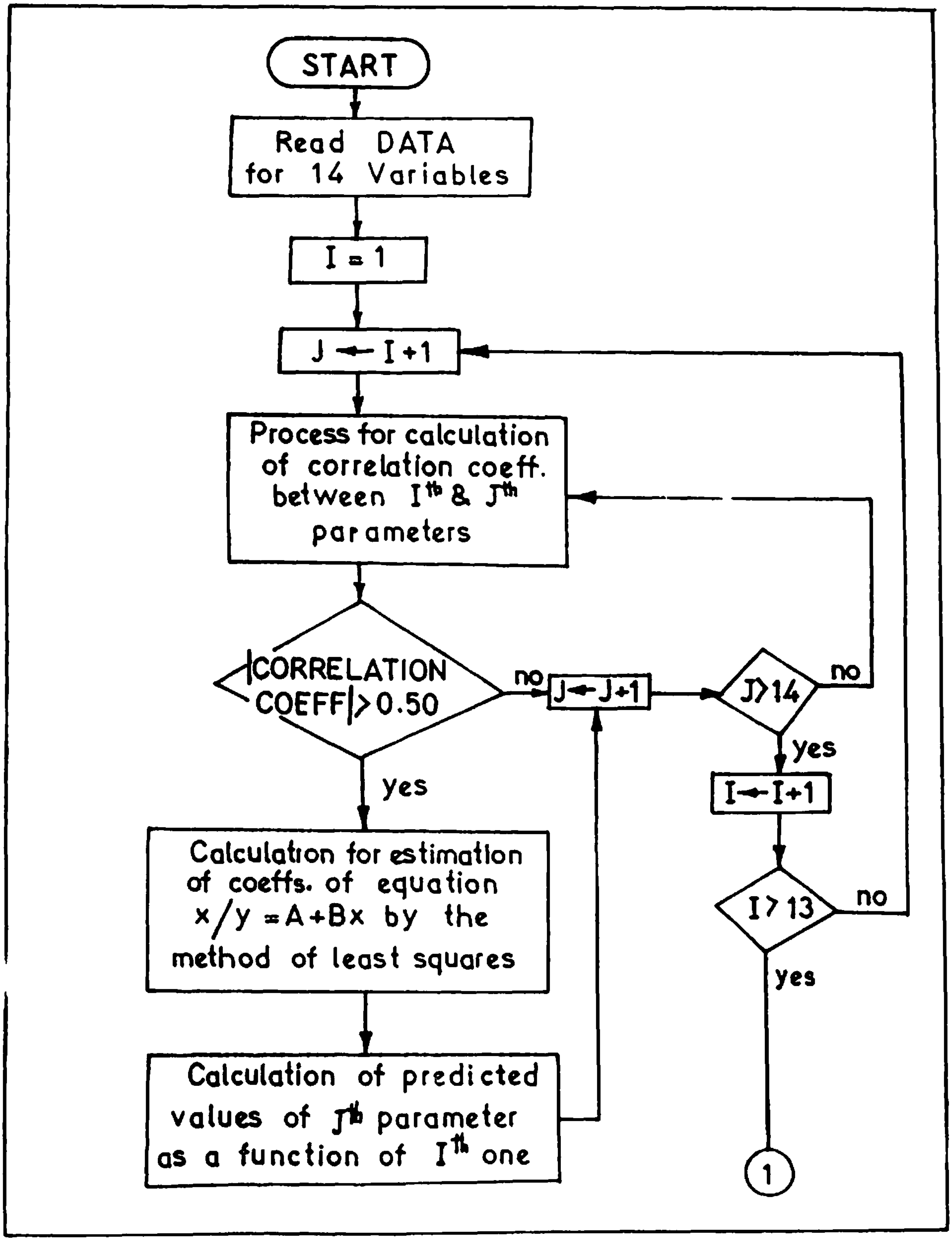

FIG. A 3 FLOW CHART FOR CORRELATION ANALYSIS

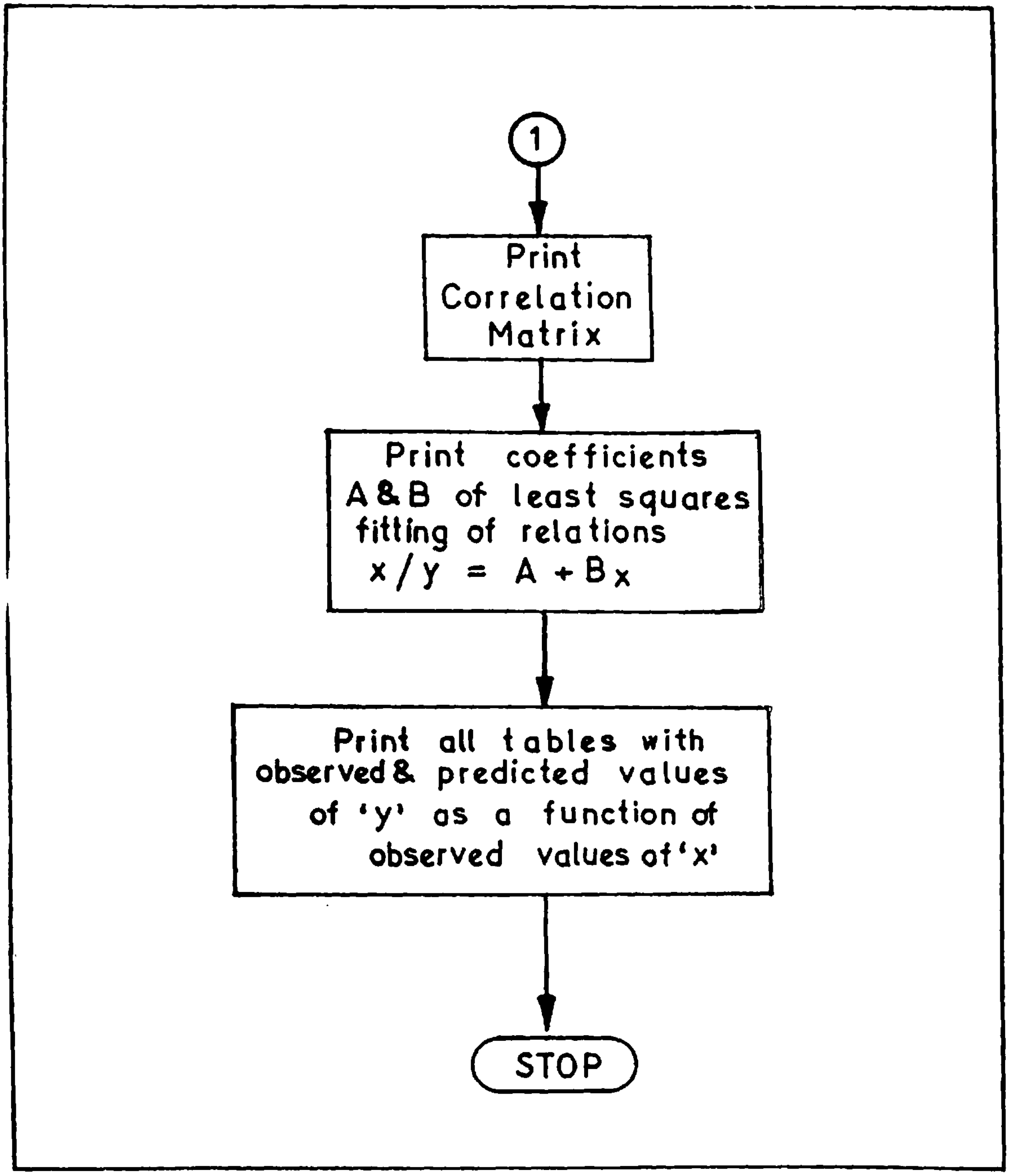

FIG. A3 (Continued)

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VITAE

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PONDICHERRY UNIVERSITY

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Director

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CPCB/1/92
23/3/92

To,

Dr S.K. Singh
Department of Civil Engineerig
Birla Institute of Technology & Science
Pilani
Rajasthan

Dear Dr Singh,

I have been asked by a New Delhi publisher to compile and edit for them a volume on the quality of Indian groundwaters. May I request you to kindly permit me to include your following paper, coauthored with Dr Vivek Anand, as a chapter :

Study of Groundwater Quality in Jhunjhunu District (Rajasthan).

J. Inst. Public. Eng. (1) 47-57 (1991).

May I have your kind permission? The copyright would remain with your goodself but kindly ensure that the paper you permit me to reproduce should not already have been published in another book nor should it be permitted for use by others till this book comes out.

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I will be greatly helped if you may kindly send the typed manuscript of your paper with tracings of the figures. Even more welcomce would be the text - revised and updated if you so desire - on a floppy composed in any of these packages : Wordstar (Version 4), PC Write (Version 2.4), or Chi Writer (version 3.1), with dotmatrix print-out and tracings.

A line of acceptance from you would be a moral booster.

With warm regards.

Yuors sincerely,

(S.A. Abbasi)