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HYDROGEOLOGICAL INVESTIGATIONS IN THE GANGA HINDON INTERBASIN - UPPER GANGA CANAL COMMAND AREA

S RAMASESHAN
DIRECTOR

STUDY GROUP

G C MISHRA
A G CHACHADI

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAVAN
ROORKEE-247667 (UP)
INDIA

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LIST OF SYMBOLS

b'	- thickness of the confining bed
Cv	- coefficient of variance
K	- coefficient of permeability
K'	- vertical permeability of confining bed
m	- thickness of the aquifer
S	- storage coefficient
T	- transmissivity

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SUMMARY

The command of Upper Ganga Canal (UGC) system covers an area of about 24,500 sq.km. located between the rivers Ganga and Yamuna and forms a part of the Gangetic alluvial plain. The area is characterised by tropical climate with mean annual rainfall of the order of 900 mm. The temperature varies between 47 to 2 degree centigrade respectively in summer and winter. The area is characterised by gentle slope towards south and south-east directions. Recent alluvium is the major geological formation occurring in the area.

The aim of the present study is to have an integrated picture about the present hydrogeological conditions in the area, particularly, evaluation of aquifer characteristics through pump test, delineation of recharge and discharge sites of groundwater, depth and fluctuation of water levels, type, nature and extent of water bearing formations, groundwater flow directions, gradients etc.

From the analysis and interpretations of the available data, it is seen that the utilisable groundwater in UGC area occurs mainly in alluvial parts. However, groundwater occurs in Bhabar and Tarai formations but is not extensively used either because of deep water levels or because of high costs of exploitations. Both confined and unconfined conditions prevail. The groundwater regime is recharged mainly through precipitation, seepage from canals and rivers and partly by return flow from irrigation. The gentle gradients of the

water levels indicate highly permeable formations in the area. The water bearing formations mainly consists of sands of varying grain size, quite often mixed with clay and kankar. Clay layers are common and become increasingly predominant towards southern parts of the doab. Study of sand percentage distribution indicates two different depositional trends. The maximum sand percentage is found to occur in the northern parts of the area. Depth to water level varies considerably from place to place with maximum depth in highly permeable Bhabar zone. The artesian conditions exist along the contact zone of Bhabar and Tarai formations. Generally the fluctuation of water level is less than four metres in the major portion of the area. Groundwater mainly flows in the south and south-east directions. River Ganga and Yamuna act as influent rivers in the upstream locations and become effluent in the downstream of the doab. The canal network has significant effect on the groundwater regime in the area. In general two aquifer layers can be delineated one at depth less than 35 m and other at depth greater than 35 m from ground surface. Deeper layers show leaky confined to confined character.

The chemical quality of groundwater is found to be good for drinking and irrigational purposes in most parts of the study area, except in south and south-eastern portions where the salinity is slightly above the upper acceptable limits for drinking and irrigational use.

1.0 INTRODUCTION

The command area of the Upper Ganga Canal (UGC) system is located between the rivers Ganga and Yamuna and forms a part of Gangetic alluvial plain covering an area of 24500 sq. km. The land surface slopes between 160 m to 290 m above m.s.l. (Figure 1). The average rainfall is of the order of 900 mm with tropical climate. The average diurnal temperature varies from 47°C in summer to 2°C in winter seasons.

Geologically, the alluvial deposits are comprised of sand, gravel, silt, clay and nodular concretionary KANKAR, as were laid down in the river channels and wide flood plains. The thickness of the alluvium varies and is more thick in the northern region than in south of the doab. It seems reasonable to believe that the irregularities and undulations in the basement are responsible for its present configuration due to which there is a limited circulation of groundwater downward. Recently as a result of several deep and shallow bore holes by the Oil and Natural Gas Commission(ONGC) in the Gangetic plain, the thickness of alluvium has been determined to be about 1000 metres at Ujhani in U.P. Here the alluvium is underlain by the Vindhyan sediments. At Aligarh the bed rock comprising of Vindhyan shales, has been encountered at a depth of 379 m below ground level. Also in Mathura district the bed rocks of Vindhyan system were encountered at shallow depths of 150-275 metre below ground level.

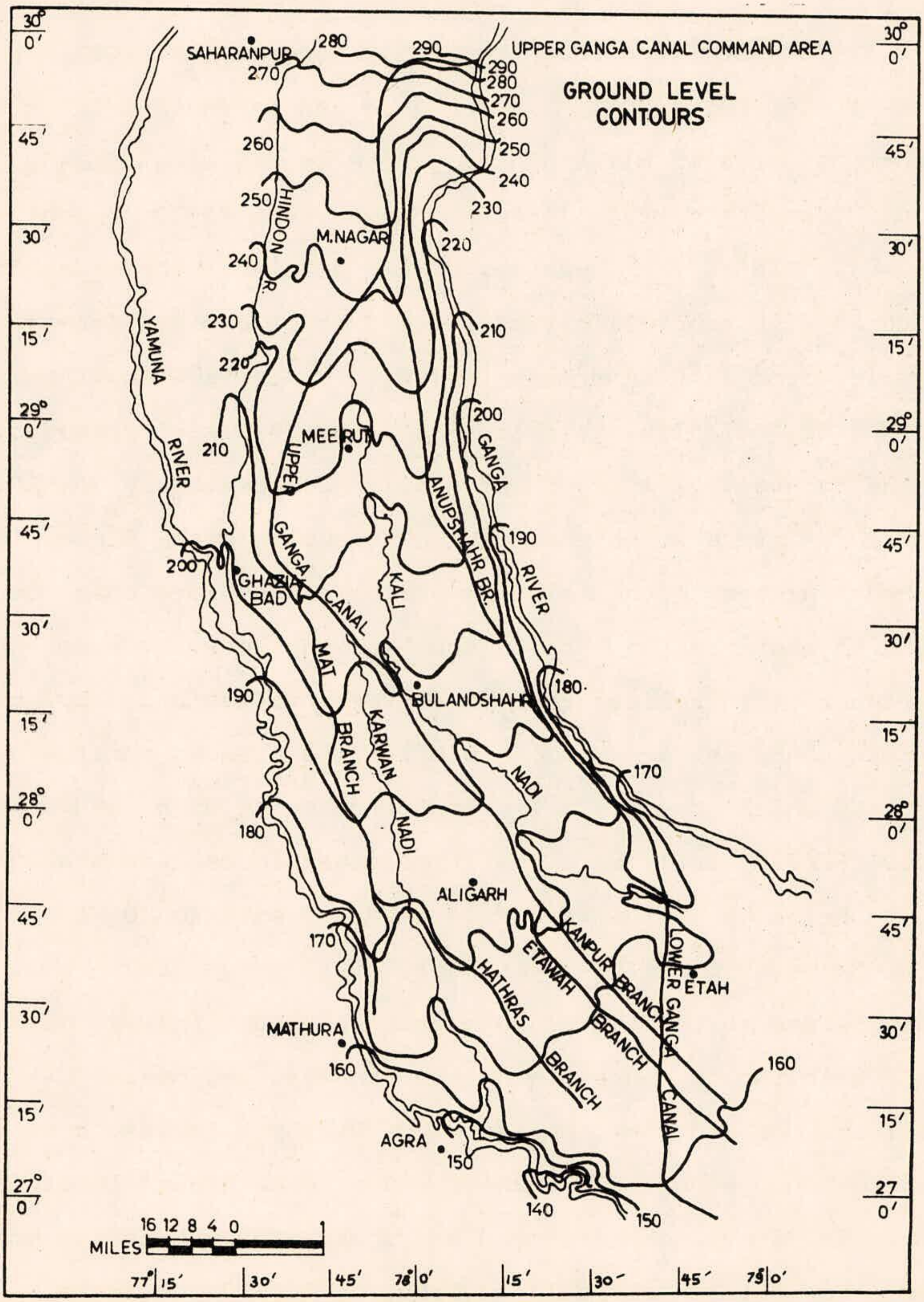

FIGURE 1 - GROUND LEVEL CONTOURS FOR THE UGC COMMAND AREA

In the major parts of the command area the average coefficient of permeability of potential aquifers ranges from 12 to 100 m/day and in parts of Saharanpur, Muzaffarnagar and Meerut districts and north it varies between 15-800 m/day there by indicating highly permeable formations in the upper parts of the command area. The yield has been estimated to be about 150 m^3/hour for most of the tubewells.

The groundwater in the command area occurs both under confined and unconfined conditions. The deeper aquifers are found to occur either in confined or semi-confined conditions, whereas shallow aquifers are generally unconfined. This fact was supported by the analysis of number of pumping tests carried out in the area at different places of the alluvium (Table 1). The depth of water varies between 2 to 20 m below ground level during the premonsoon and between 1.38 m to 17.91 m during post monsoon period (Pathak, 1975) with an average fluctuation of the order of 0.27 m to 2.95 m between April and November.

The chemical constituents of groundwater in most part of the area of UGC system are within the permissible limits for drinking and agricultural purposes. The chloride concentration is less than 250 ppm. In parts of Saharanpur, Bulandshahar, Aligarh, Agra, Mathura, Etah and Mainpuri districts the concentration of chloride was found to be high, correspondingly the Total Dissolved Solid (TDS) concentrations of more than 1000 ppm (Upper limit for drinking water quality) have been observed in the districts of Mainpuri, Mathura, Etah, Aligarh and Agra. In other parts of the command area

Table 1 - Details of the Results of Aquifer Parameters Estimated Using Pump Test Data in UGC Command Area

Location of test hole/well No.	T m^2/day	S	$\frac{b'}{k'}$ (days)
1	2	3	4
Saharanpur dist.			
Roorkee Group:			
i) Roorkee Military Field Work	2024.34	-	-
ii) Roorkee Univ. Tubewell	1949.83	-	-
iii) Military Engg Services Well	757.58	-	-
iv) CBRI well	1800.79	-	-
v) Landhaura T.W.No. 4	2272.73	3.70×10^{-4}	-
vi) Bhagwanpur T.W.No.29	502.98	-	-
vii) N.I.H.T.W.	1400.00	7.30×10^{-4}	-
Nakur Group:			
T.W.No.6	891.73	9.65×10^{-3}	-
Deoband Group:	454.12	3.90×10^{-3}	359.60
Nagal Group:	640.00	4.00×10^{-3}	-
Bhaneda Ṭanda:	1028.56	7.65×10^{-3}	-
Gangoh Group:	595.00	7.28×10^{-4}	-

1		2	3	4
Muzaffarnagar dist.				
North Lohi Group:				
T.W.No.	20	893.00	5.00×10^{-3}	11.57
	11	981.00	1.40×10^{-2}	3.21
	12	1427.00	2.00×10^{-3}	28.93
	22	1411.00	1.00×10^{-3}	231.48
	17	971.00	4.50×10^{-4}	165.34
	13	888.00	1.00×10^{-3}	578.13
	19	1808.00	1.80×10^{-3}	115.74
	11(a)	536.00	5.00×10^{-3}	-
South Lohi Group:				
T.W.No.	20	936.00	2.00×10^{-3}	23.15
	2	1179.00	1.00×10^{-2}	14.84
	10	1275.00	1.80×10^{-2}	0.42
	7	761.00	1.20×10^{-2}	68.08
	17	1148.00	3.00×10^{-4}	385.80
(Kairana)	3	670.00	2.00×10^{-4}	1157.40
(Kakra)	10	1340.00	4.00×10^{-3}	-
(Daha)	9	1200.00	1.50×10^{-3}	0.017
(M.Nagar)	10(a)	915.00	9.05×10^{-4}	-
Meerut dist.				
Meerut Group:				
T.W.No.	12	1897.00	5.00×10^{-4}	-
Rajpur (Meerut)		1660.00	3.80×10^{-3}	-

1	2	3	4
Bulandshahar dist.			
Jahangirabad			
T.W.No. 75	2676.00	3.11×10^{-2}	-
Danpur :	814.81	8.00×10^{-4}	-
B.B. Nagar:	1207.50	5.70×10^{-4}	-
Lakhauti:	1161.00	2.30×10^{-3}	-
Aligarh dist.			
Hatras:			
T.W.No. 34	541.00	3.35×10^{-3}	-
37	485.00	8.85×10^{-4}	-
Atrauli:			
T.W.No. 37	686.00	5.09×10^{-3}	-
Iglas:	1267.38	9.80×10^{-3}	-
General:			
Etah T.W.No.36	573.00	-	-
Kasganj T.W.No.27	1850.60	-	-
Agra Group:	80.73	4.80×10^{-3}	-

the TDS was found to be below 1000 ppm and hence the ground water is reported to be suitable for drinking and other purposes in these areas. The high concentrations of TDS and chloride in the lower reaches of the command area is obviously due to the increased mineralisation of groundwater in the direction of flow and also due to the local lithological variations in the lower reaches. Bicarbonate concentration in most parts of the study area was found to be less than 500 ppm. But higher concentrations were observed in the districts of Etah, Mathura and Aligarh. Similarly the fluorine content of the groundwater is found to be less than the upper toxic limit for drinking water i.e., 1 ppm.

It should be noted that the detailed water quality analysis and interpretations for major as well as trace elements should be carried out in the districts of Mathura, Aligarh, Agra, Mainpuri, Etah and Bulandshahar in order to assess the suitability of groundwater for irrigation and other purposes, and to detect the exact causes of quality deterioration so as to suggest the steps to improve the groundwater quality for further use in agriculture.

2.0 REVIEW

2.1 Hydrogeology

The Upper Ganga Canal command area forms a part of the Ganga basin which is considered as one of the potential ground water reservoirs of the world. Based on the physiography and hydrogeology, the area can be divided into four sub-groups (Figure 2) viz.,

Alluvial Tract:
- i) Bhabar
- ii) Tarai
- iii) Central Ganga alluvial plain
- iv) Marginal alluvial plain

The alluvial tract is underlain by unconsolidated sediments of Pleistocene to Recent age, and is by far the most important from the point of view of groundwater resources of the area. This tract is made up of four sub-zones as detailed below. (See figure 3 for generalised cross-section along NS direction of the area).

(i) Bhabar : This formation consists of unsorted gravels of various sizes and sands with intercalations of clay. Groundwater occurs under water table conditions. The depth to water level is generally 30 m or more, below ground level. The deep water table conditions are mainly due to the non-availability of the confining layers at shallow depths. The granular materials of this sub-zone are highly permeable but construction

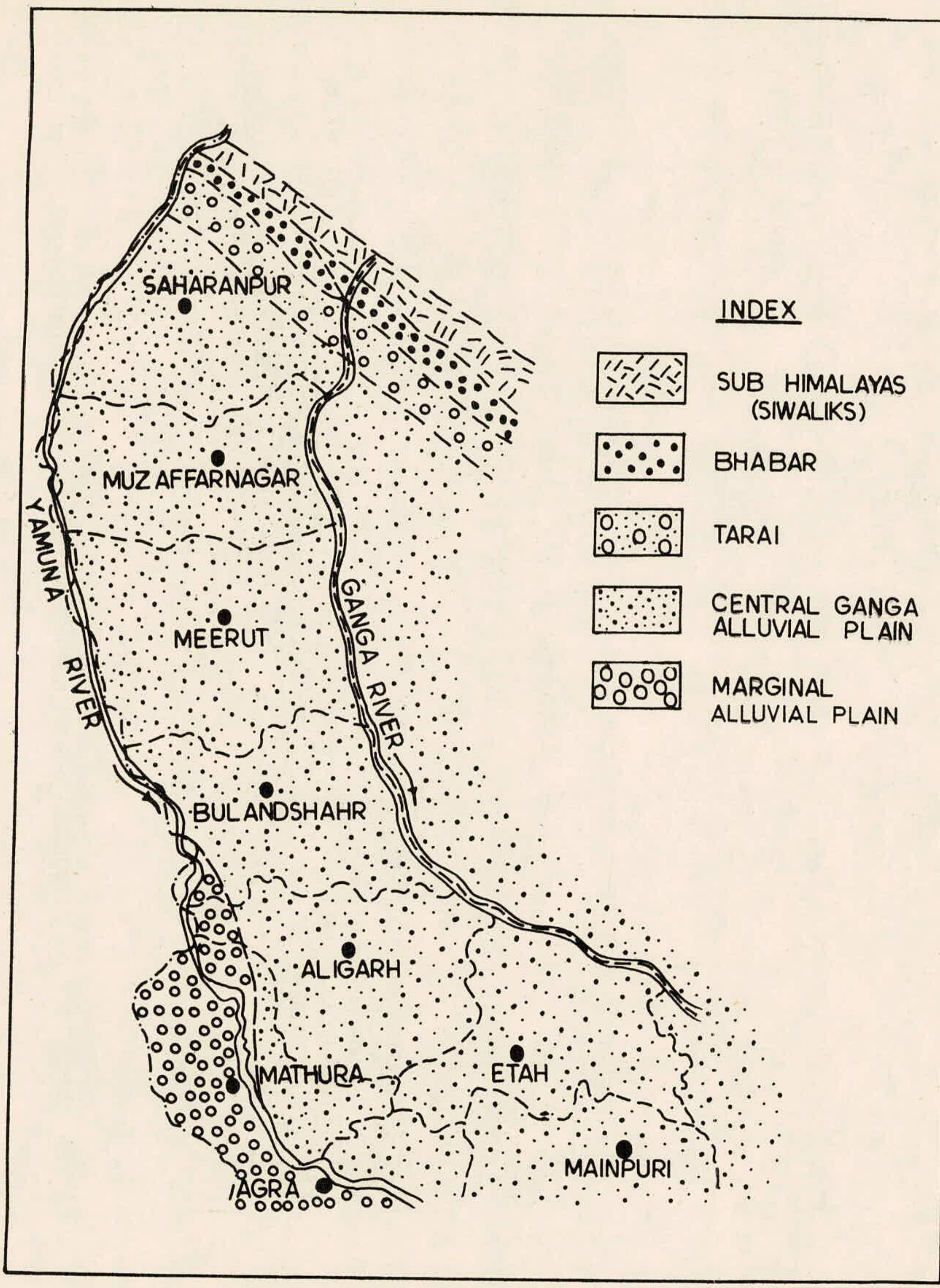

FIGURE 2 - HYDROGEOLOGICAL MAP OF UPPER GANGA CANAL COMMANDAREA (AFTER CGWB)

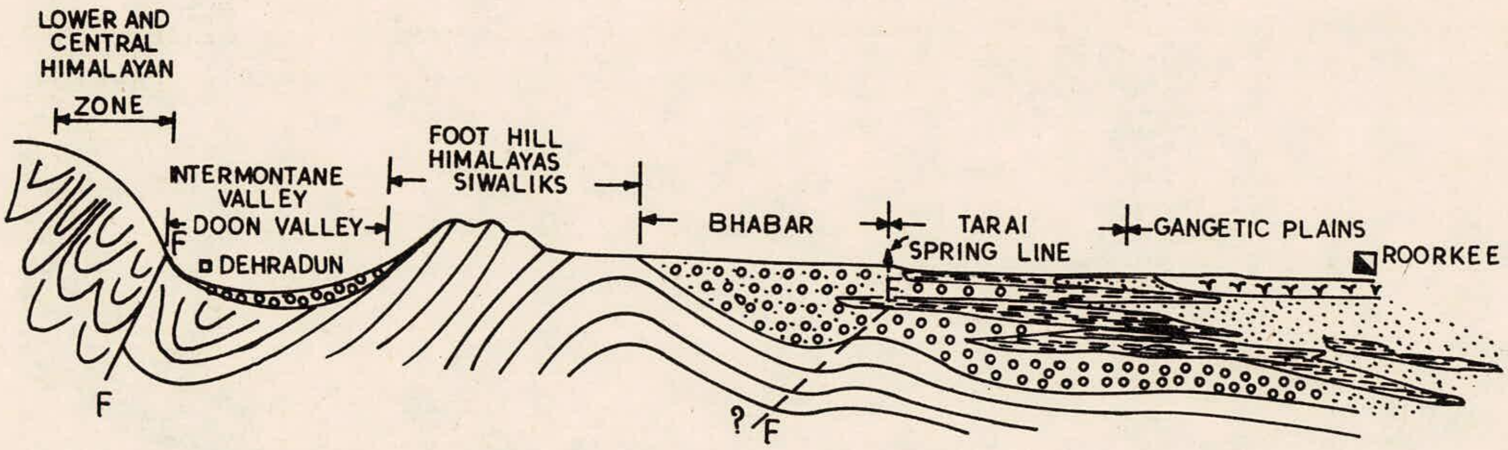

FIGURE 3 - SKETCH MAP SHOWING THE STRUCTURE OF MAJOR GEOLOGICAL FORMATION ALONG ROORKEE-DEHRADUN SECTION

of tubewells in north of this area is difficult because of drilling problems in bouldary formations. The exploratory tubewells by Central Ground Water Board (CGWB) northern region upto a depth of 75 to 152 m have indicated that the saturated granular zone is comprised of boulders, cobbles, pebbles and coarse to fine grained sands upto a depth of 146 m below ground surface. The gravel fraction consists of quartzite, quartz, granite, sandstone and slate. The sand is dominantly composed of quartz. The discharge of the tubewells in this zone varies from 97 to 227 m^3/hour for drawdown between 2.08 m to 9.68 m (Pathak, 1976).

(ii) Tarai : This sub-zone lies to the south of 'Bhabar' (Figure 1) and runs more or less parallel to it. It is composed of clay layers intercalated with beds of coarse sand and gravel. Boulders are rare. This zone is characterised by the occurrence of ground water under confined conditions often with piezometric heads above ground level giving rise to flowing conditions. The CGWB exploratory drill holes upto a depth of 82 to 304 m have indicated that the major aquifer comprises of sands of various grades and fine gravel occurring in the depth range of 25 to 298 m bgl. The piezometric head in flowing wells of this zone vary between 6.63 to 9.20 m above ground level. While in non-flowing wells it ranges between 1.65 to 11.24 m below ground level. The discharge of non-flowing tubewells varies from about 100 to 225 m^3/ hour for drawdown ranging from 2 to 8 m.

Special Features of Bhabar and Tarai Formations

All along the southern slopes of the siwaliks, the plain is bounded by a distinct belt of 8 to 24 kms in width which is known as the Bhabar. In most of the region and except at the south facing abrupt escarpments, the upper Siwalik conglomerates grade into loose Bhabar formations. These are comprised of boulders, cobbles and gravels laid as pedimont deposits, which slope southeards for about 10 to 17 metres per kilometer, in which the groundwater occurs under water table conditions. Although the belt experiences a high rainfall, mean annual rainfall being 1,500 mm to 2,000 mm the water table is generally deep and varies between 6 to 90 metres (30 m generally) below the ground surface. This is due to the high permeability of the formations and the absence or rarity of the confining layers at shallow depths.

Similar to the relationship of the Siwalik to Bhabar and immediately following the Bhabar belt is another belt of low relief with a southward slope of about 0.4 metre per km. which is known as the Tarai belt. It is composed of well defined alternate clay and sand layers of which the latter forms artesian aquifers with heads of 6 to 9 metre above the ground surface. The boundary between the Bhabar and Tarai is marked by the spring line. Towards south, Tarai belt merges into the plains in which the flowing well conditions are practically unknown.

The relative aboundances of various materials in

Tarai to an average depth of nearly 76 metre below ground is given below:

Clay, clay with kankar	- 73%
Fine sand, sandy clay etc	- 7%
Coarse sand, pebbles etc	- 20%

Surface Water Resources of Bhabar and Tarai

Almost 90 percent of the rainfall occurs between June and September. Only a part of this percolates down and replenishes the groundwater regime, and rest of it is carried away as runoff by the network of rivers and rivulets. These rivers while flowing through the highly permeable Bhabar loose considerable amount of water into Bhabar beds and become practically dry during the summer. As these rivers flow further southwards they are joined by several tributaries, derived from diverse springs issuing from the northern margin of Tarai.

In the Bhabar zone, the average slope of the ground is 0.76 to 1.14 metres per km. Most of the precipitation in the zone occurs within a short period of four months. Though these factors would aggravate runoff losses, the very coarse nature of the Bhabar formation minimizes such losses due to percolation into the ground. On the other hand though Tarai has a gentle slope and is covered with luxuriant vegetation, the impervious nature of the soil and other causes do not permit ready absorption of water into the formation. Thus most of the rain water gradually finds its way into the drainage courses. In the thickly vegetated areas of Tarai and Bhabar some amount of water is lost by plant transpiration. There would not be any appreciable loss by direct evaporation, as the area is wooded.

Groundwater Resources of Bhabar and Tarai

The area does not suffer from any scarcity of water. Draught years are rare. Groundwater in the Tarai occurs both under water table and artesian conditions. The water table slopes to the south and confirms to the general topography. The water table which is deep in the Bhabar region becomes shallower towards the Tarai where it is within a few metres below the surface. The Bhabar forms an effective source of recharge to the artesian aquifers in the Tarai region.

The zone of saturation comprises clay, silt, sandy clay, sand, pebbles and boulders. The more permeable beds of sands, pebbles etc., are lenticular in shape and are separated by less pervious beds of clay. The thickness of these beds show considerable lateral variation which is common with fluviatile deposits.

In the Bhabar zone particularly in the upper reaches, the groundwater occurs in the porous and permeable material under unconfined conditions as the material are unassorted and do not possess persistant clay beds to act as aquitard. The aquifer materials in the Tarai are fine grained and comparatively well sorted. The deeper aquifers in the Tarai, in which groundwater occurs under confined conditions are separated by well defined clay beds. Exploratory dilling in this area at south of Piru Mudara has shown that the pressure heads of these aquifers are above the land surface.

Recharge

Recharge to the shallow groundwater in both Tarai and Bbabar formations takes place during the monsoon period. The Bbabar by the virtue of its coarse material readily absorbs the rainwater while finer sediments constituting the Tarai prevent absorption to that extent. Further more in Bhabar the presence of a deep water table provides greater thickness of material to be saturated is limited by the presence of a shallow water table. Other sources of recharge of shallow groundwater in Tarai are presumed to be infiltration from streams, return seepage from irrigation in cultivated tracts, lateral percolation from the Bhabar belt to the north, and leakage of water from the upper most artesian zone.

Discharge

Discharge from the shallow water table aquifer takes place mainly by evaporation and transpiration by certain plants, discharge by springs, consumptions for domestic and irrigational purposes, movements of groundwater along hydraulic gradient towards further south, etc. Evaporation and transpiration of groundwater is more pronounced where the water table occurs within about three metres below ground level. Consumption of shallow groundwater for irrigation and domestic purposes is more in the Tarai where open wells are far more numerous, than in the Bhabar zone. The value of transmissivity varies between 245-1179 m^2/day. The coefficient of permeability (K) varies from 16-22 m/day.

iii) Central Ganga Alluvial Plain

Most part of the Upper Ganga Canal command area comes under this zone. The northern limit of this sub-zone is the southern limit of the 'Tarai' zone. The yamuna river and part of the Ganga, downstream of its confluence with the former, forms the southern limit of Central Ganga Alluvial plain. The alluvium is composed of gravel, sand, silt, clay and kankar. The beds are generally lenticular and there are rapid alternations and gradations between granular and clayey horizons. The near surface groundwater is under unconfined conditions while the deeper portions of the aquifers are under leaky confined and confined conditions. Figures 4 and 5 shows the distribution of aquifer layers in the UGC command area and Hindon river basin respectively.

iv) Marginal Alluvial Plain

This sub-zone is located between the Central Ganga Alluvial plain and the region occupied by the Bundelkhand granite and the Vindhyan rocks (Figure 2). Here the alluvium is composed of silt, clay, kankar and sands of various grades. Groundwater occurs both under confined and unconfined conditions. Exploratory drill holes by CGWB in Susirkalan in Mathura district have shown a prominant and persistant granular zone comprising fine to coarse sand with varying amounts of gravel between depths of 30-170 m in the northern parts of this sub-zone. The sand is commonly red in colour and is generally composed of angular to sub-angular grains of quartz, feldspar and granitic rock fragments and occasionally fragments of Vindhyan rocks. Apart from this there are number of lenses of sand and gravel of limited extent. The clay overburden apparently increases in thickness from Jaipur in Mirzapur district towards west. The depth to water level in tubewells generally range between about 7 m to 26 m below ground level. The discharge of these tubewells varies between 60-240 m^3/hour with drawdown from 3-16 metres. The water quality is poor in this sub-zone.

2.2 Aquifer Characteristics

The hydrogeological characteristics of the deeper aquifers in the Indo-Gangetic alluvium has been a matter of controversy. Taylor (1959) while describing the ground water provinces of India has mentioned that in the axial belt, the deeper aquifers are under confined, although the flowing well conditions are very rare. Chaturvedi and Pathak (1965), on the basis of pump test data from Muzaffarnagar-Meerut region have shown that the tubewells in this area tap water from water table aquifers. These conclusions were based on the large values of storage coefficient reported by the authors. Later Chaturvedi and Pathak while analysing data from Aligarh-Mathura, districts, which are also located in the axial belt and are to the south of Meerut-Muzaffarnagar area have shown that the deeper aquifers in the region are under leaky-confined conditions. They concluded that there are varying geohydrological conditions in different parts of U.P.

Raghava Rao (1965) had carried out the analysis of pump-test data from Roorkee-Saharanpur area which lies about 20 miles to the north of Muzaffarnagar and he concluded that the deeper aquifers in Roorkee-Saharanpur area show an average value of storage coefficient of the order of 3.70×10^{-4} (Table 2) thereby indicating that the deeper aquifers in the area are under confined conditions.

Singhal and Gupta (1966) have analysed pump test data from wells in Muzaffarnagar area. They have concluded that the deeper aquifers in the area are under leaky-confined conditions. Gupta (1968) from his study in Muzaffarnagar-Meerut area concluded that the deeper aquifers are under confined condition as the values of storage coefficient are found to be low. However, it does not mean that the overlying clay formations have complete sealing effect. It is found that as pumping from the deeper aquifer continues, water from the overlying water table aquifer leaks to the deeper aquifers. The percentage of leakage increases with increase in time of pumping (Table 3) and thus these aquifer behave as leaky-confined during pumping. In Muzaffarnagar-Meerut area two

Table 2 - Comparative Statements of the Formation Constants of Alluvial Deposits in UGC Command Area

S.No.	Location of pump test site	Depth of aquifer tested (m)	T m^2/day	S	Hydrological situation	Remarks
1.	Roorkee	121.92	503-2297	$3.7x10^{-4}$ -	Confined below 30 m	After Raghava Rao 1965
2.	NIH Tubewell	150.00	1000-2100	$7.3x10^{-4}$ -	Confined to semi-confined	After Chachadi, 1982
3.	Muzaffarnagar	60.96	2136-4645	$9.3x10^{-2}$ - $2.0x10^{-1}$	Water table conditions	After Chaturvedi and Pathak, 1965
4.	Atrauli	91.44	621-4657	$1.7x10^{-2}$-$1.4x10^{-1}$	Water table conditions	ETC Tech. Bulletin
5.	Aligarh and Mathura	91.44	558-1987	$1.4x10^{-4}$-$2.5x10^{-2}$	Leaky confined and confined	ETC Tech. Bulletin
6.	Jalesar	76.20	372-1242	$6.0x10^{-4}$-$9.0x10^{-3}$	Confined	ETC Tech.Bull.
7.	Agra	137.16	43-1179	- -	Confined	ETC.Tech.Bull.
8.	Muzaffarnagar	137.16	58-2495	$1.0x10^{-4}$ -	Confined to leaky confined	After Gupta 1968

Table 3 - Percentage Leakage Through Confining Layers with Time at Various Locations in UGC Command Area During Pumping Tests

S.No.	Location	Time (min)	Leakage (%)
1.	Daha Group (Dist. Meerut)	50	00.5
		100	04.0
		200	06.3
2.	Hathras Group (Dist. Aligarh)	10	23.0
		50	53.0
		100	58.0
		200	64.0
		240	65.0
3.	Jahangirabad Group (Dist.Bulandshahar)	45	01.6
		90	04.0
		135	07.0
		180	12.0
4.	Hathras Group (Dist.Aligarh)	100	15.0
		150	21.0
		200	26.0
		240	27.0
5.	Atrauli Group(Dist.Aligarh)	20	25.0
		60	47.0
		90	51.0
		120	52.0
		180	52.0
6.	Gangan Group(Dist. Moradabad)	50	19.0
		100	28.0
		150	32.0
		200	33.0
		225	34.0
7.	Barailly Group (Dist. Barailly)	20	10.0
		200	43.0
		600	48.0
		2160	54.0
8.	Hindon - Kali Doab(Dist. Muzaffarnagar)	80	02.1
		180	15.7
		360	24.5
		720	31.7
		1440	37.7
		1800	39.6

types of aquifers have been delineated i.e. the shallow aquifer lying within 24 m from ground surface and deeper aquifer of 30-91 m thick lying in the zone 30 to 91 m below ground surface. The deeper aquifer is not composed of a single aquifer but of a number of aquifers interconnected with each other. The above two hydraulic units are separated by a thick clay layer intermixed with silt and kankar which behaves as an aquitard. The well logs of numerous boreholes sunk in the Ganga alluvium clearly indicate that it is composed of alternating beds of varying grain sizes, deposited at a slight inclination away from the Himalaya, the material getting gradually finer with increasing distance from the foothills. The upper part of the alluvial talus, or the 'Bhabar Zone' at the foot-hills of Himalayas is composed of coarse gravels resembling the alluvial fans. It lies in a heavy rainfall belt and is characterised by unusually high infiltration rates, as a result of which almost all of the rainfall is absorbed undergound. Further, a large number of streams emerging from the Himalayas of the Siwalik foothills also loose considerable volume of water by seepage into the coarse gravel of 'Bhabar Zone'. Most of the water then absorbed reappears immediately to the south as springs, forming the marshes of the 'Tarai zone' where the water table comes upto the ground. Then assuming that the sand beds of the Ganga alluvium outcrop in the 'Bhabar Zone' it would serve as an efficient intake area, and water under artesian pressure would be obtained by tapping these strata further down in the plains. It is, however, doubtful that if the strata would extend laterally to such a great distance in view of the rapidly changing physical conditions under which the alluvium was deposited.

Chandra and Saksena (1975) have reported that: i) the ground water in the UGC Command area occurs under water-table conditions, and ii) the aquifer is unconfined and interconnected for all practical purposes. The specific yield value worked out through pump test and other means is of the order of 13 percent justifying that the aquifer is unconfined.

The strata exhibits variations both laterally and vertically. In general, coarse sand beds either alone or in association with consolidated sand, gravel, or pebble beds occur at relatively greater depths below the ground whereas clay beds either alone or in association with fine sands or kankar, predominate at shallower depths. The sands are mainly composed of quartz, feldspar, muscovite and biotite. The consolidated sand beds have often been loosely termed as 'sand stone' in the drillers log. The gravels met with, have sometimes size as large as 0.051 m in diameter. They are chiefly composed of dark quartzite and are locally known as 'bajri'. Conglomerate beds of unsorted gravels are often met with at greater depths but their thickness is generally small. A single piece of kankar may exceed 0.076 m in diameter and one third of a metre in length. In Meerut a tube well is sunk to an average depth of about 91 m below ground level. In general, an aggregate thickness of about 30 m of good water bearing strata comprising well assorted sand of gravel are obtained per well. These are generally designated as beds of 'clean sand' or 'clean gravel' in the driller's log on account of an almost complete absence of finer materials. Under exceptionally favourable conditions, the 30 m of water bearing strata may be obtained from within the first 60 m of the well drilled and that too from only one or two beds.

There is hardly any well marked tendency towards either a progressive increase or decrease in the occurrence of fine or coarse sediments either horizontally or vertically. The structure of the alluvium is thus very chaotic, lenses and stringes of water bearing materials occur rather irregularly, giving way abruptly to relatively impervious clays. This is obviously, due to the rapidly changing physical conditions under which the alluvium was deposited. Hence well sorted sediments occur rather rarely and even most of the so called coarse beds contain a fair amount of fine sand and even some clayey matter, which lower the water bearing qualities. Then, the alluvium at least up to the depth of an average tube well (100 m) may be viewed as a complex unit of sand and clay. The average specific yield and permeability in the zone of fluctuation of water table as determined by laboratory methods in UGC Command area are 20.81 percent and 15.66 m/day respectively (Table 4).

2.3 District-wise Briefing of Hydrogeological Conditions

The hydrogeological conditions existing in different districts of Upper Ganga Canal Command Area are described in brief as below:

Table 4 - Specific Yield and Permeability Values for Different Districts in UGC Command area as Determined by Laboratory Methods

S.No.	Districts	No. of Samples	Specific yield average (%)	Depth bgl (m)	Permeability average (m/day)
1.	Saharanpur	23	19.4	2-10	16.10
2.	Meerut	24	21.49	upto 23	32.43
3	Muzaffarnagar	06	20.67	-	18.16
4.	Gaziabad	16	21.65	3-24	7.16
5.	Bulandshahar	20	20.76	2-14	9.71
6.	Aligarh	-	-	-	15.20
7.	Bijnor	-	-	-	10.60
		Mean	20.81		15.66

2.3.1 Saharanpur District

The major hydrogeological units coming in this district are Bhabar, Tarai and part of Central Ganga Alluvial plain towards the southern edge. The groundwater in these formations occurs under confined, semi-confined and unconfined conditions. In the Bhabar belt in the northern part of the district the water table conditions prevail and the static water level is found at greater depths (more than 30 m b.g.l.) because of the bouldary formation constituting the major part of the aquifer system. The specific capacity, transmissivity and permeability of these formation are found to be about 242 lpm/m, 342.6 m^2/day, and 15.4 m/day respectively (Pathak, 1978). In the low lying Tarai formation the groundwater occurs mainly under confined and flowing conditions. The exploratory drillings have indicated the transmissivity and permeability of the order of 338 m^2/day and 17.09 m/day respectively.

2.3.2 Meerut district

This district is completely covered by Central Ganga Alluvial plain. The groundwater occurs under confined as well as unconfined conditions. The pump test analysis conducted in the area indicated that most of the deeper aquifers are under semi-confined to confined conditions whereas shallow aquifers are unconfined to semi-confined. The historical record indicate that the water level exists at less than 15 metres below ground level. The transmissivity varies from 1100 m^2/day to 9399 m^2/day in general, thereby indicating the high yielding aquifers.

2.3.3 Muzaffarnagar district

This district is also traversed by Central Ganga Alluvial formations and the groundwater occurs under both semi-confined and unconfined conditions. Mostly the deeper layers are semi-confined. The static water level lies within at about 20 m below ground surface. The transmissivity and storage coefficient of the aquifer vary from 58-4645 m^2/day and 0.2-10^{-4} respectively.

2.3.4 Bulandshahar district

This district is mainly traversed by Central Ganga Alluvial plain and in most parts the groundwater occurs under confined to semi-confined conditions. Depth to water level is less than 15 m below ground level. The transmissivity, storage coefficient and permeability vary from 795-2676 m^2/day, 3.0 x 10^{-2} - 5.7 x 10^{-4} and 27-50 m/day respectively.

2.3.5 Aligarh district

Central Ganga Alluvial plain is the only formation which traverses the whole district. The groundwater in general occurs under confined and semi-confined conditions. At places shallow aquifers are under unconfined conditions. The depth to water is in general less than 12 m below ground surface. The drilling operations have shown Vindhyan sandstones as bed rock formations. The transmissivity and storage coefficient of the water bearing strata vary from 541-1987 m^2/day and 2.5 x 10^{-2} - 1.4 x 10^{-4} respectively. The hydraulic conductivity (K) varies between 34-80 m/day.

2.3.6 Agra district

The major lithounits of this district are Marginal Alluvium and Central Ganga Alluvium. Both confined and unconfined aquifer systems are prevalent in the area. The water level is generally deep and the permeability of the water bearing formation varies from 6 to 53 m/day. The transmissivity value ranges from 140 m^2/day to 1288 m^2/day.

2.3.7 Mainpuri district

This district is covered by Central Ganga Alluvial plain. Unconfined as well as confined conditions are common. The depth to groundwater is generally less than 10 metres below ground level. The quality of water is questionable.

2.3.8 Etah district

Part of Central Ganga Alluvium is the major lithounit in this district. Both confined and unconfined aquifer system exists. Because of the presence of thick clay layers the deeper aquifers are generally under confined conditions. The depth to groundwater is less than 10 m below ground level in general. The exploratory drilling indicated the transmissivity and permeability of the order of 700 m^2/day and 31 m/day respectively.

2.4 Chemical Quality of Groundwater in UGC Command Area

In major parts of the Upper Ganga Canal Command Area the overall quality of groundwater in the deeper aquifers have been found to be good and have less than 250 ppm of chloride content. However, brackish to saline water exists in the south-western parts, viz., in the districts in Agra, Mathura and Mainpuri with chloride concentration ranging from 250 ppm to more than 1500 ppm. The maximum chloride concentration of 1900 ppm has been reported to be present in water sample collected from Bharatpur in Agra district. The presence of such saline pockets coupled with the unproductive nature of aquifers, possess a great problem in this part of the UGC Command Area. The waters are generally non-incrusting and non-corrosive to well screens. But in some of the areas the waters are either incrusting, corrosive or both. About half of the incrusting water are likely to cause soft type of incrustations which may be removed by giving proper treatment to such wells. It is advisable to try such treatments on wells whose discharge is seen falling gradually. This will lengthen to some extent, the life of incrusted well.

2.5 Study of Sand Percentage Distribution at Different Depths in the UGC Command Area

The detailed study of the lithologs at various bore hole sites in the command area has indicated that the major part of the strata consists of sands of varying grain size intercalated with varying thickness of clay layers at places mixed with silt, kankar and other concretionary materials (Figures 4 and 5). The aquifers in UGC Command Area are distributed in two different layers. (Model Study UGC, National Institute of Hydrology, 1982). The first aquifer in top layer extending upto 34.5 m below ground level has been identified and the second aquifer is located at more than 35 m below ground level. An intervening aquitard is present between these two layers.

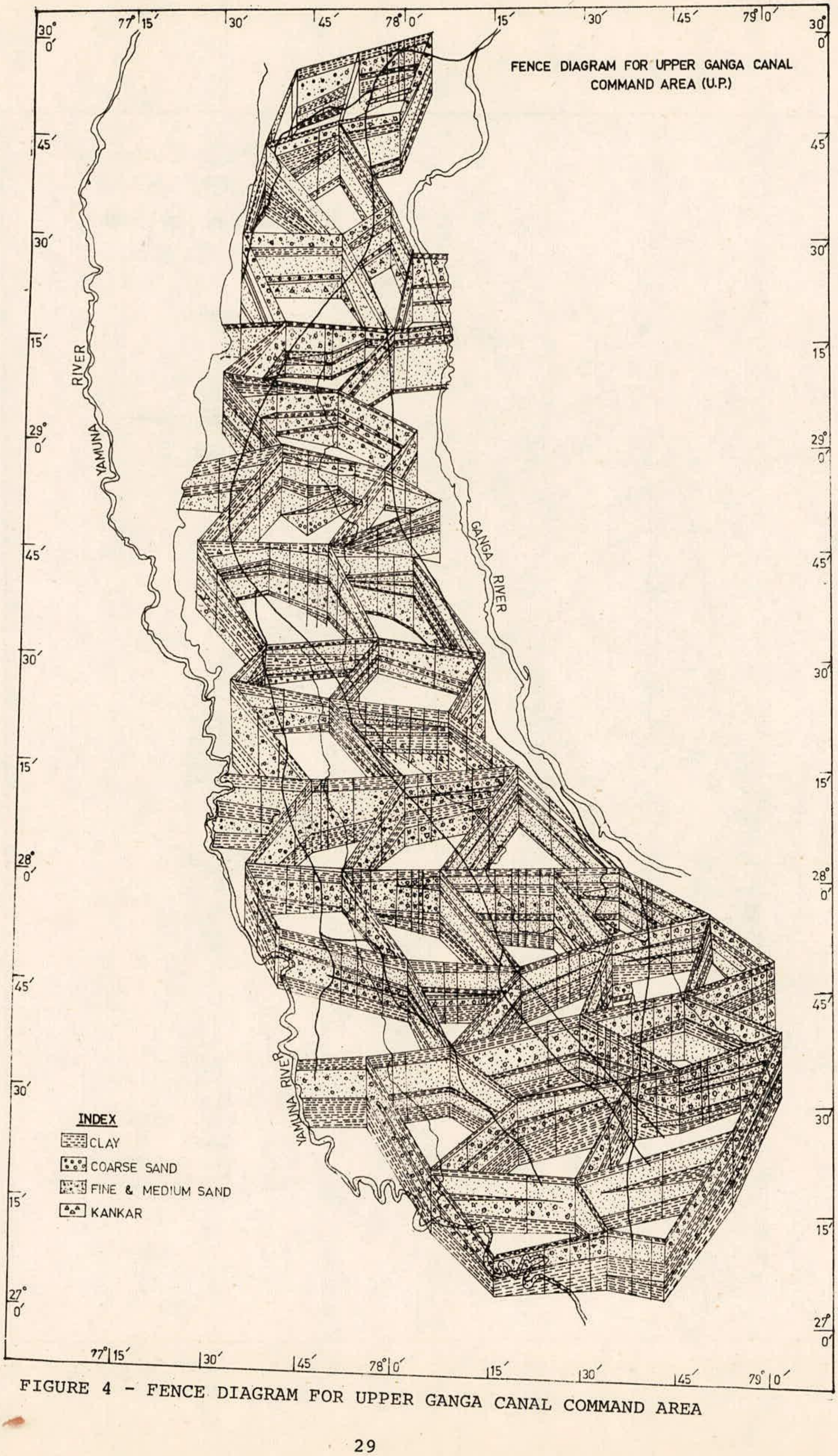

FIGURE 4 - FENCE DIAGRAM FOR UPPER GANGA CANAL COMMAND AREA

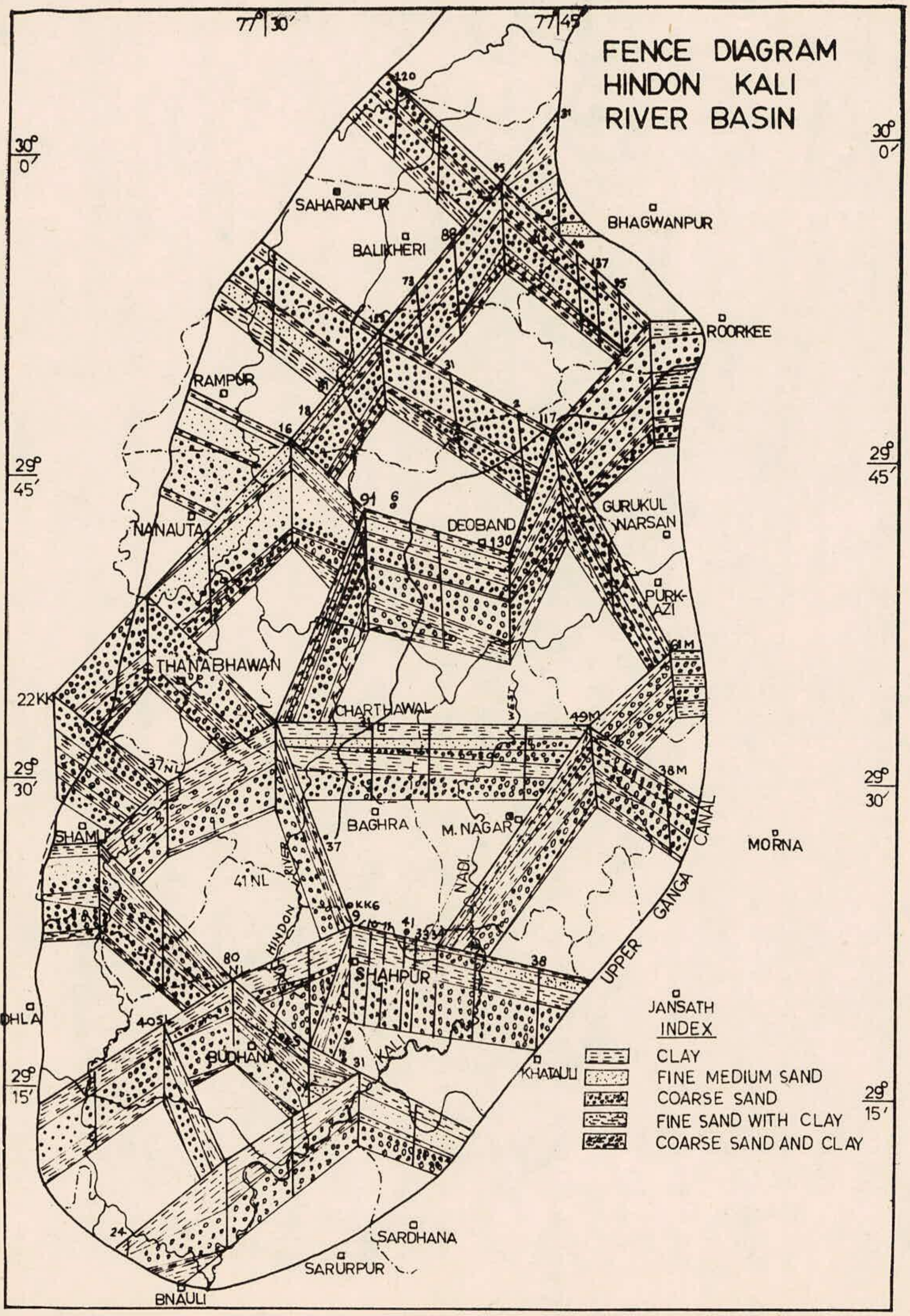

FIGURE 5 - FENCE DIAGRAM FOR HINDON - KALI RIVER BASIN

Based on the lithologs, the percentage of aquifer material for each layer has been found and the average values of maximum and minimum percentage distributions are given in Table 5.

Table 5 - Percentage Sand Distribution in Command Area of UGC

Variable	Maximum (%)	Location	Minimum (%)	Location
Percentage of sand in the upper aquifer	74.90	Muzaffar-nagar Group	28.4	Gaziabad group
Percentage of sand in the lower aquifer	83.10	Jansat Group	35.50	Hathras group
Commulative percentage of sand in the both aquifers	78.40	Jansat group	42.60	Hathras group

From the study of the contours of sand distribution (Figure 6) in the lower layer, it is seen that the percentage of aquifer material decreases towards the downstream side of the Ganga-Yamuna river system. Thus there is a progressive increase in the non-aquifer material (clay, silt, kankar, etc.) towards the lower reaches of the doab which is purely a depositional phenomena. This is also clear from the study of the

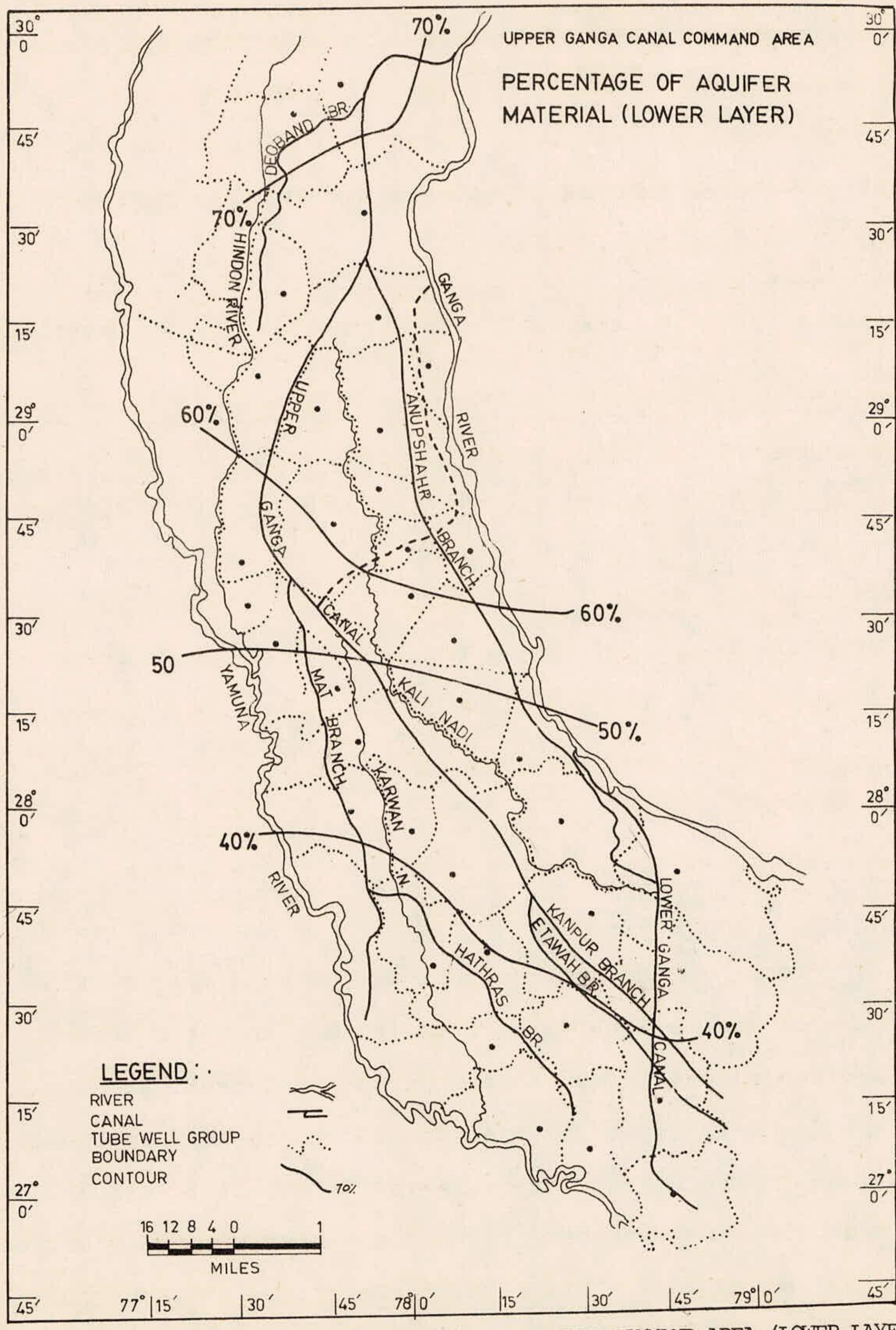

FIGURE 6 - PERCENTAGE OF AQUIFER MATERIAL IN UGC COMMAND AREA (LOWER LAYER)

fence diagram (Figure 4). A maximum aquifer material of about 83 percent is found in Muzaffarnagar district where as a minimum of about 28 percent of aquifer material is found in Gaziabad district. The decrease in the percentage of aquifer material towards the downstream direction of the rivers Ganga and Yamuna, indicates the depositional trend from north to south.

On the other hand the study of the contour map of sand percentage for the upper layer (Figure 7) indicates that the depositional trend is not the same as that of the lower layer. The percentage of aquifer material in this upper layer increases progressively from west to east, that is from river Yamuna towards the river Ganga. It is also seen from the map that the contour line of 60 percent sand is running in the middle part of the study area almost parallel to the Ganga and Yamuna river courses. This increase in the percentage aquifer material from river Yamuna towards Ganga indicates that the depositional trend for the upper layer was from east to west which in turn shows that the river Ganga probably took an active part in the deposition of the upper aquifer material whereas both the rivers Ganga and Yamuna might be equally active in depositing the lower layer of the aquifer found in UGC command area.

The variation of the grain size of the aquifer material has been reported by various workers. From these studies it can be concluded that there is a general decrease in the grain size of sand with depth, in the depth zone of 34-110 m below ground.

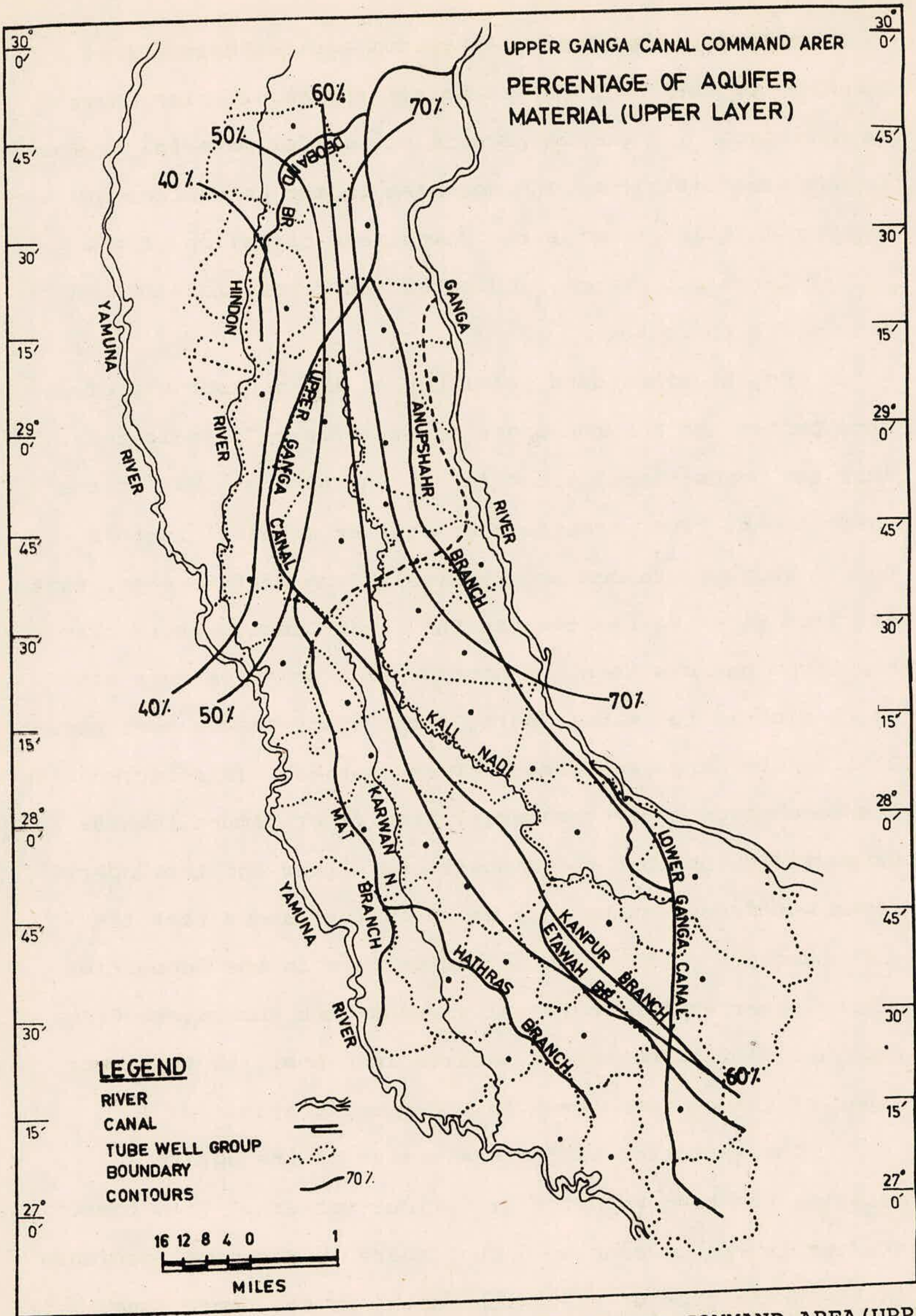

FIGURE 7-PERCENTAGE AQUIFER MATERIAL IN UGC COMMAND AREA (UPPER LAYER)

The overall picture of sand percentage distribution in the area indicates that, in general, the percentage of aquifer sand decreases towards south and south-west in the upper and lower aquifers. This decrease in the water bearing material down south has a bearing on the production of the wells. The increase in the percentage of non-aquifer material downstream may be one of the causes of the deterioration of the groundwater quality in the lower reaches of the Ganga-Yamuna doab (viz., in the districts of Mainpuri, Mathura, Agra and Etah.

2.5.1 Study of aquifer sand distribution in different groups

District Saharanpur

Group: Deoband - The percentage of aquifer material in both layers is generally more than 50 and the distribution is uniform. The standard deviation of sand percentage distribution varies from 14.3 to 18. The coefficient of variance is found to be 0.217-0.3.

Roorkee - The variations are more or less similar to the adjacent Deoband group of wells, but relatively the coefficient of variance is more in this group of wells thereby suggesting a variable thickness of aquifer in the area.

District Muzaffarnagar

Group: Muzaffarnagar - Both layers show higher percentage of aquifer material (generally 80) and the relative coefficient of variation is less than that of the Deoband and Roorkee groups. This in turn suggests the lesser variation in the aquifer material in this group.

Kakra - The percentage of sand is more than 70 in the lower aquifer. The coefficient of variance is more in the upper layer than that in the lower layer.

Jansath - The percentage of sand is generally same for both the aquifers at different locations. The sand distribution in both the aquifers has lower values of coefficient of variance (Cv = 0.2).

District Meerut

Group: North Bhatipur - The percentage of aquifer material is generally same in both the layers and vary less in the lower layer than in the upper layer.

District Gaziabad

Group: Gaziabad - The percentage of aquifer material is generally more than 50 in the lower layer and the distribution is uniform as compared to the upper layer where the aquifer material is less than 40 percent.

Hapur - In these group of wells the percentage sand is about 70 in both the aquifer layers and there is no significant variation from place to place. These group of wells show more or less uniform aquifer thickness.

District Aligarh

Group: Aligarh - In this group the percentage of aquifer material is more than 50 in general in the upper layer and shows less variation from place to place. In the lower aquifer layer the sand percent is less than 40 and the distributuon show higher variations from place to place.

Iglas - Shows same character as that of Aligarh group except that the coefficient of variation in the lower layer is relatively more than Aligarh group.

Atrauli - In this group both lower and upper layers shows uniformity in aquifer material content and its variation in space.

Hathras - Here the aquifer in the upper layer shows lesser variation in space as compared to the lower layer and the percentage of aquifer material is more in the upper layer (50) whereas in the lower layer it is generally less than 40 percent.

Sikandra Rao - Here both layers show more or less uniform variations and uniformity in their aquifer material percentages.

District Etah

Group: Jalesar - The variation of aquifer material in both the layers is not significant and the aquifer material is less than 40 percent.

Etah - The water bearing material is more or less uniform in both the layers and is generally more than 40 percent with less variation. Similar observations are found in groups Aliganj, Kasganj and Marhara.

District Agra

Group: Agra - The aquifer material percentage is more in the upper layer than in the lower on (50-60 in upper layer and less than 40 in lower layer) and the variability is also more in both the layers. Similar observations are found in Firozabad and Itmadpur groups.

3.0 CONCLUSIONS AND RECOMMENDATIONS

3.1 From the study of fence diagram, cross-sections and isopach maps of Ganga-Yamuna doab it is seen that the water bearing formations become scarce as one moves from hills towards south-east in the doab. In some places in the districts Bulandshahar, Aligarh, Etah, Mainpuri, Farrukhabad and Etawah, the water bearing formation may fall below 30 percent. On the other hand in the northern areas water bearing formation is quite high, sometimes exceeding 90 percent of the total strata drilled.

3.2 From the strata charts it is seen that the texture of the formation becomes finer as one moves south-east of the Siwalik hills. Gravel and coarse sand are scarcely found in Etah, Mainpuri and Farrukhabad districts.

3.3 The study of the fence diagrams and cross-sections also show that the aquifers have lenses of clay almost everywhere in the doab. However, in the north-western areas namely Meerut, Muzaffarnagar, Saharanpur, the aquifers are under unconfined condition. Whereas in south-eastern areas namely Farrukhabad, Mainpuri, Etawah, Etah, Aligarh, Bulandshahar the aquifers are confined and semi-confined on a local scale.

3.4 Generally the top surface in the doab constitutes of a clay stratum because of which the recharge due to rainfall is not substantial. However, in certain areas in Muzaffarnagar, Meerut, Farrukhabad and Mainpuri sandy stratum comes up right to the top surface as such these are the possible areas of rainfall recharge.

3.5 The analysis of the lithologs indicate that in certain parts of the UGC area there is fairly good likeliness in strata charts of neighbouring wells and abrupt variations are seldom seen. The scope of predetermining the strata in such an area with the help of strata charts of neighbouring wells is therefore, possible.

3.6 The quality of the groundwater in the UGC area is in general,suitable for irrigation however, there are certain areas where the waters are moderate and hence just satisfactory for the purpose. Saline water areas are located mostly in districts of Agra, Mathura, Mainpur, Jaunpur, Ghaziapur, and Allahabad.

3.7 The waters are generally non-incrusting and non-corrosive to well screens, except in certain parts of the study area.

3.8 About half of the incrusting waters are likely to cause soft type of incrustations which may suitably be removed by giving proper treatment to the wells. It is advisable to try such treatments on wells whose discharge is seen falling gradually. This will lengthen to some extent, the life of the incrusting wells.

3.9 Most of the groundwater in the area are alkaline with the exception of about 4 percent wells whose waters are acidic and hence highly corrosive to well screens.

3.10 While installing new wells in the area where possibilities of incrustations, corrosion are seen to exist, due care should be taken to exclude such strata.

3.11 On a larger scale the aquifer system may conform to a single aquifer system which is under unconfined condition in the Bhabar and confined condition in Tarai zone. However, different opinions exist regarding the nature of the aquifer. The ground water model studies carried out by the National Institute of Hydrology, assume existence of a two layer system in UGC area. The nature of the aquifer i.e. whether it is only a single aquifer or a multiaquifer system can only be ascertained after studying the behaviour of the aquifer system with the help of multilevel piezometers.

3.12 The study of the water table/piezometric contour maps (figures 8 and 9) shows that the general flow of water is along south-eastern direction. It is also clear from the maps that the canal network has modified the groundwater flow regime. Canals act as an influent bodies and also the river Ganga is influent in the upper region and becomes effluent downstream.

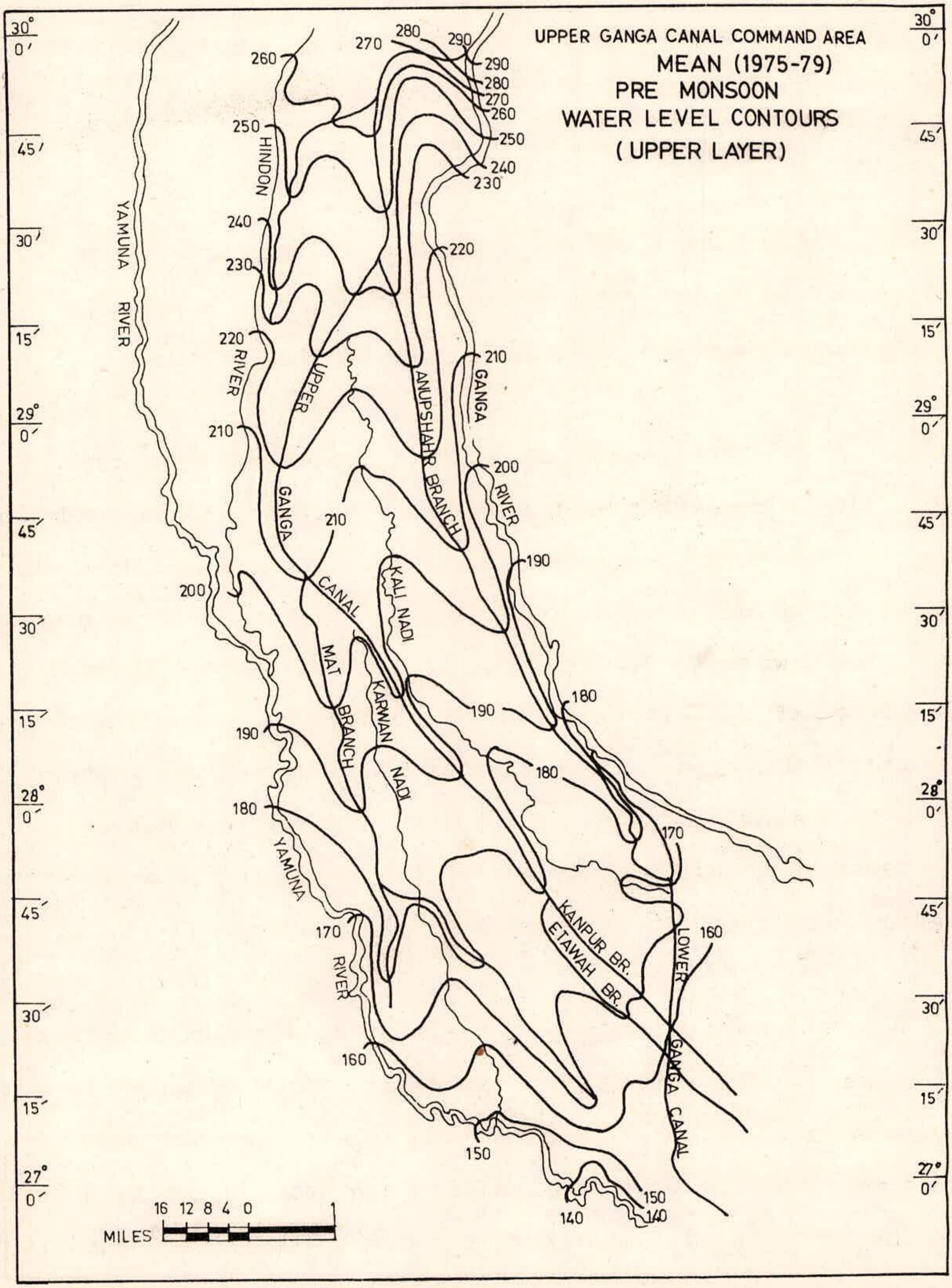

FIGURE 8 - MEAN(1975-79) PRE-MONSOON WATER LEVEL CONTOURS FOR UGC COMMAND AREA (UPPER LAYER)

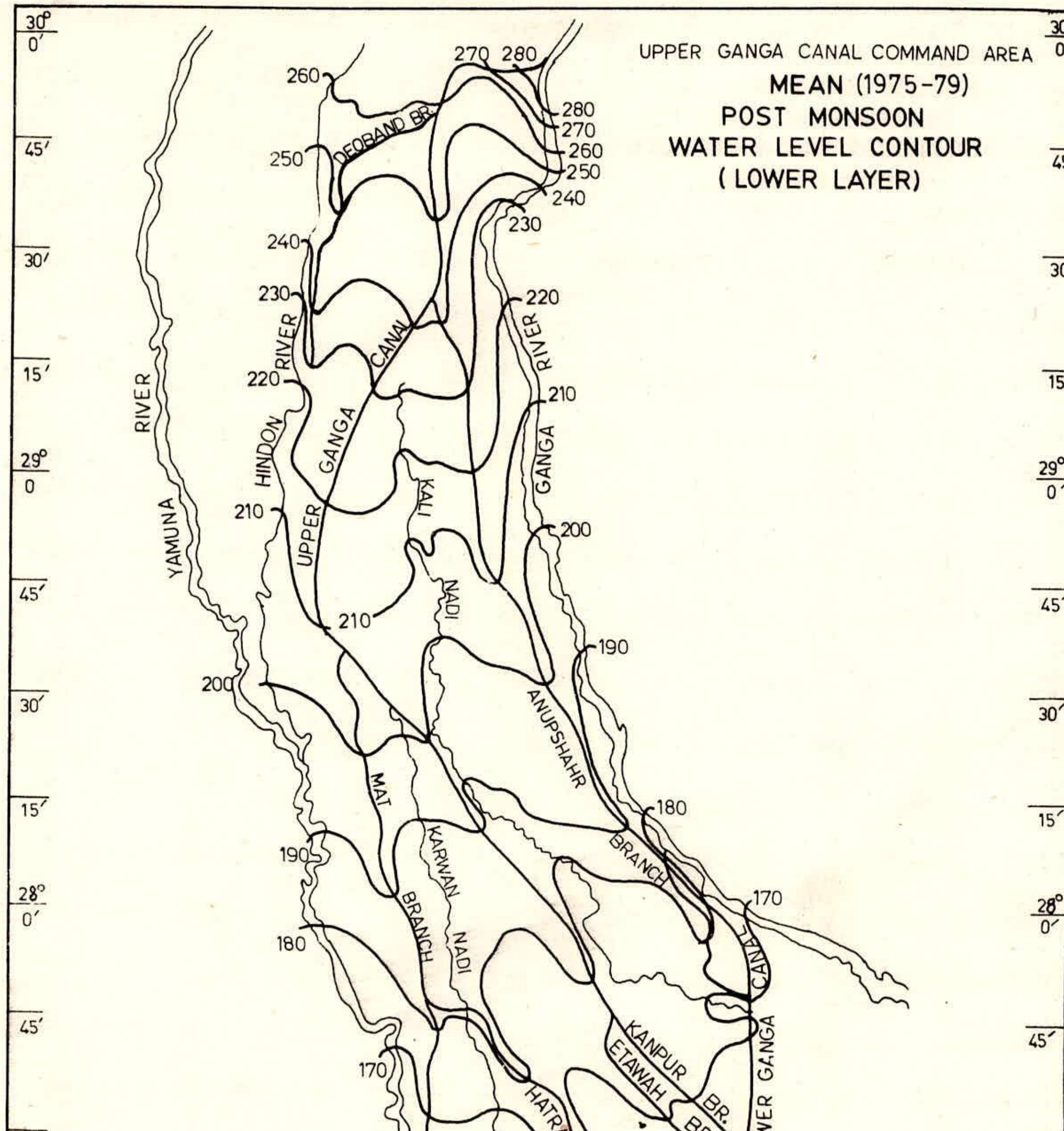

FIGURE 9 - MEAN (1975-79) POST-MONSOON WATER LEVEL CONTOURS FOR UGC COMMAND AREA (LOWER LAYER)

Similarly river Yamuna is also effluent in the lower portion of the Ganga-Yamuna doab and hence river Ganga and Yamuna are replenished by groundwater regime at downstream in the doab. The gradient of the groundwater flow in general, is very gentle thereby indicating the high permeability of the aquifers. The groundwater table and piezometric level contour maps do not show any marked changes in their configuration and hence the recharge from canals and other sources are possibly influencing both the layers. The flow line analysis indicate that the major recharge to the groundwater regime takes place from northern parts where highly permeable 'Bhabar zone' is located. The other source of recharge is through canal seepage in the area apart from rainfall recharge, and return flow from irrigation.

3.13 In the lower layer the coefficient of variance of aquifer material increases towards south as the percentage of the aquifer material decreases in the same direction. However, the relative coefficient of variation is more in the western margin along Yamuna river course than on the eastern margin of the UGC command. Hence in the upper regions of UGC the lower aquifer has uniform character i.e. the variations from place to place are not significant. The following well groups are found to show these characteristics: Deoband group; Muzaffarnagar group; Kakra group; Jansath group; Meerut group; North and south Bhatipur groups; Upehra and Kithar groups; and Hapur group.

All the above well groups show coefficient of variance less than 0.25 and in remaining groups the variation is higher than this, and it progressively increases towards south and west, thereby indicating the larger variations in the aquifer material in the command area in these directions.

3.14 In the upper layer the following well groups show coefficient of variance less than 0.25: Muzaffarnagar group; Jansath group; North and South Bhatipur groups; and Upehra group. Rest of the well groups show high coefficient of variance (greater than 0.25). Therefore these comparisons indicate that the upper layer is varying from place to place in its thickness.

On an average both layers show larger variations in their aquifer material content towards south and south-east directions in the doab and also the percentage aquifer material decreases in these directions.

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