INTRODUCTION

Water is one of the most important natural resource on which the survival and progress of mankind depend to a great extent. It is a renewable resource and gets replenished immediately. In view of its wide distribution, low level of contamination, constant temperature and availability in the reach of the consumers in all seasons, ground water development gets first preference for meeting the ever growing demand of water for domestic, agricultural and industrial purposes. The distribution of this resource is highly uneven, of which 97.41 percent of the water on the Earth is contained in the oceans as saline water. The balance of 2.59 percent as fresh water is contained in ice caps and glaciers (1.953%), groundwater (0.614%), lakes (0.008%), soil moisture (0.005%), and in rivers, atmosphere and biota (0.0005%). Thus, only a tiny fraction of 0.014 percent of the Earth's total water in lakes and rivers, and contained in soil moisture, atmosphere and biota is available easily to human beings and other organism (Maurits, 1989).

Surface water is generally easy and economical to harness, but its availability varies with the seasons and its use for irrigation frequently in its wake problems like water logging. On the other hand groundwater is obtainable all the year round and its use in conjunction with surface water holds the sub-soil water level within reasonable limits and the reservoir can be used to store water in times of surplus availability. In the recent years, it is estimated that the principal source of groundwater–rainfall, in the investigated area has decreased considerably due to deforestation and modernisation. The hydraulic relationship between the channel form and related processes is also greatly modified because of ignorantly built embankments, dikes, etc. on rivers, extraction of gravel and sands from river beds, dumping of wastes, etc. made these rivers more erratic in their behaviour especially during the season of peak discharges which results the siltation, flooding, bank erosion, shifting of channels and deteriorating water quality in the study area. Moreover, when a severe drought gripped the area it became imperative to search for the only alternative resource, the groundwater for household and agricultural use from time to time. Under the circumstances the studies have been taken up to solve the groundwater problems on the investigated area as a whole its availability in round the year, its quality for different uses and the proper management of the valuable resources is the need of the day.

HISTORICAL REVIEW

The literature on historical development of origin of artesian wells, springs and groundwater is available in many famous treatises, written by famous workers–Meinzer, Baker, Freeze, Horton, Tolman, Todd etc. (Banerjee, 1980). The importance of groundwater supplies to the tribes of Israel is illustrated in the pages of Bible. Tolman (1937) described the large underground water tunnels or Kanats, in Persia and Egypt dating from 800 BC. Thus from very early times philosophers and earth scientists tried to develop and recognise the source of springs and groundwater.

Though groundwater was exploited from the earliest times there was a lot of misunderstanding regarding its origin, occurrence and movement. The Greek and Roman philosophers put forth several theories about this from time to time. Early Greek philosophers like Homer, Thales and Plato believed that the sea water traveled bellow the mountains and was purified and raised to the surface to appear as springs. Aristotle suggested that air condensed into water inside the mountains and emerged as springs. The German astronomer John Kepler suggested as late as in the 17th century that the earth took in the water of the Ocean like a huge animal digested it and discharged the end products as groundwater and springs. A clear understanding of the hydrologic cycle was achieved by the laterpart of the 17th century. An English astronomer–Edmond Halley, showed that evaporation was sufficient to produce enough water to feed all the springs. The advancement of knowledge to the subject of groundwater mainly took place after the fundamental principles of geology has been established near the end of the 18th century. In fact, the occurrence, movement and distribution of groundwater are all controlled by the geology of the formations through which groundwater moves.

Groundwater hydrology evolved as a definite science in the 19th century.

The French hydraulician Henry Darcy who can be said to the father of geohydrology discovered the laws of groundwater movement. Jules Dupuit and A. Theim developed formulae for flow towards wells. Towards the end of this century Phillip Forchheimer, W. Whittaker, W. Badon Ghyben, C. S. Slitcher, P.Otozky, Alexander Lebedeff applied the potential theory and the Laplace equation to flow water through porous media. Detailed Groundwater investigations in America by U.S. hydrologists began in the last decade of the 19th century. Among them mention may be made of Robert T. Hill, N. H. Darton, T. C. Chamberlin, Allen Hazen and F. H. King and many others initiated the scientific study of groundwater.

The 20th century has been painstaking refinements in the methods of field investigation and interpretation of data collected, laboratory methods of investigation of hydrologic characteristics of water-bearing materials and the developments of methods of making groundwater inventory. Due to an increase in the activity in hydrologic investigations in recent years in different countries of the world, several national and international organisations have been established to coordinate the research regarding this and related subjects. The International Association of Scientific Hydrology has been conducting significant work in this direction. The U. S. Geological Survey and Groundwater Hydrology Section and American Geophysical Union have been active in developing and investigating groundwater. At present various hydraulic and hydrologic laboratories in different countries of the world, adopted groundwater studies as one of the most important branches of research. Many Europeans have participated with publications of either specialized or comprehensive works.

The development of water resources seems to have started first in India by means of open wells for irrigation and drinking water were in common use as early as in the Mahabharata period about 6,000 years ago. In the ruins of Mohan-jo-daro and Harappa dating back some 5,000 years, public and private baths have been discovered with ceramic pipes for water supply and brick conduits under the streets for drainage. Several ancient tanks are still in use of irrigation in India. Recent researches have shown that Punjab was the first in India to have any human habitation. The first civilization to rise in India was the Indus Valley

Civilization of which Punjab constituted a major territorial unit. In this context, Russian Scientists–have demonstrated that bread wheat originated from Punjab between Hindu Kush and Himalayas. Irrigation was practiced during this time by various means like dug wells, tanks and canals in different periods of the history– which was before 2000 BC prior to even the Aryan Culture and the dug wells were experienced of a large diameter having a depth not exceed 50 meters. In India, the first tubewells were sunk in 1935 in Uttar Pradesh and since then groundwater has progressed by leaps and bounds.

The first attempt to obtain artesian water in West Bengal was made in Calcutta in 1904 and the first deep boring was approximately 147 m located at Fort William, Calcutta in 1938. Medlicott (1881) expressed the probability of existence of artesian conditions in the plains of Upper India by assuming the presence of continuous "Bhabar" like deposits of coarse sand, gravel and shingle under the alluvial clay overlying immediately the bed rocks beneath the sediments. But Oldham (1884) was not convinced and differed this argument and bored two artesian wells at Port Canning (79m) and Chandernagore (73m) on experimental basis. With the establishment of the Geological Survey of India (GSI) in 1851, investigation on groundwater problems became a part of its various activities. During the early part of its existence, the investigations were primarily directed at local specific water supply problems of which tempo was rather slow before forties of this centuries. But the systematic geohydrological survey of the country was perhaps most actively felt during the 2nd World War because of its important strategic position in the world. With the attainment of Independence in 1947, the national Government laid importance on the assessment of water resources of the country. Concurrently with the large scale river valley development programmes, the need for assessing groundwater resources was also acutely felt in different parts of this state (Chatterjee, 1967). But the intensive geohydrological investigations started since 1953 when the Government of India, in collaboration with Technical cooperation Mission of U. S. A., undertook extensive test drilling for exploring groundwater resources of the country and to delineate the area suitable for groundwater development for agriculture and other uses (Banerjee, 1969).

The status of the study area underwent drastic changes with the discovery of Darjeeling around 1829 (Banerjee, 1980) whose bracing climate and strategic location drew strong fascination from the Britishers. The hardrocks of the area were not considered at all suitable for groundwater exploration till the year 1975. Because the highly pervious nature of deposits in the "Terai" area, the recharging water percolates down rapidly and the water table, therefore occurs comparatively lower down ranging from 2.5 to 4.0 m b.g.l. Intensive geohydrological investigations were started from 1959 in the study area (Banerjee, 1967) by G.S.I. and later the efforts for exploring groundwater resources through exploratory drilling were taken up by the West Bengal Public Health Engineering Department (PHED) of Siliguri Sub-division since 1978, which was followed by a number of Central & State Government Organisations and installation of tubewells were taken up on a growing scale since early nineties at a depth ranges from 78 m to 310 m below ground level (b.g.l).

In Asiatic countries, as far as groundwater study is concerned, India became too prominent. The recent increase in the study of developing groundwater resources in different parts of the country is due to the increasing emphasis being laid on the agricultural development of the country. At present in India, a number of hydraulic and hydrologic laboratories and research centers have taken groundwater investigation as one of the most important branches of study. Among these, the names may be mentioned of Central Water and Power Research Station (CWPRS), Poona; Central Ground Water Board (CGWB), Haryana; Geological Survey of India (GSI), Calcutta; Centre for Study of Man & Environment (CSMEC), Calcutta; and Groundwater Division, Irrigation Research Institute, Roorkee, reputed and well recognised one by all.

STUDY AREA

The Terai area of Darjeeling district, area under investigation is situated in the northern part of West Bengal, India. According to recent census, the Darjeeling is better spelled as Darjiling (Census, 1981). It covers mostly the thick alluvium and partly the piedmont plain of Mechi-Mahananda interfluive which is

LOCATION MAP

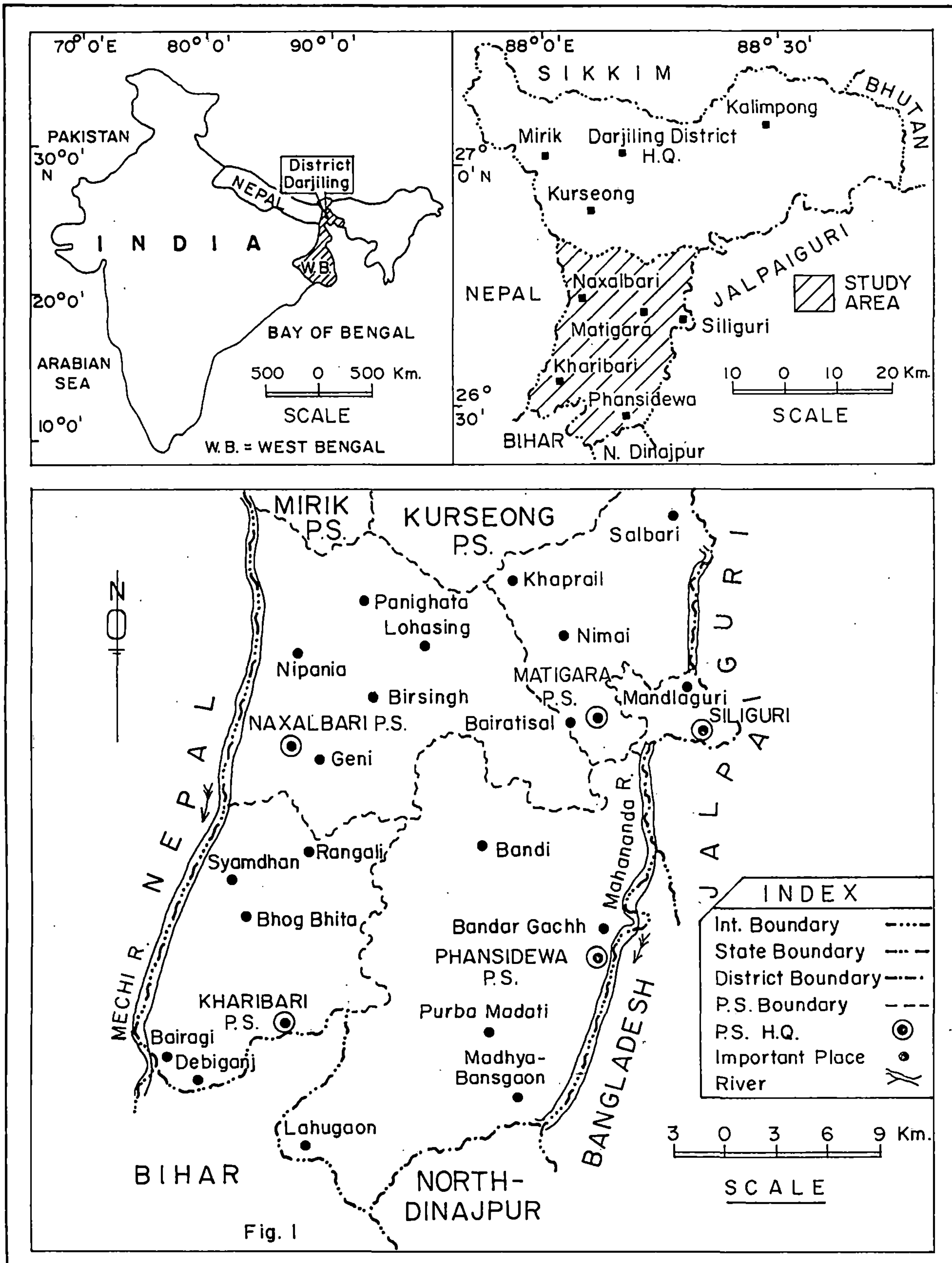

Fig. 1

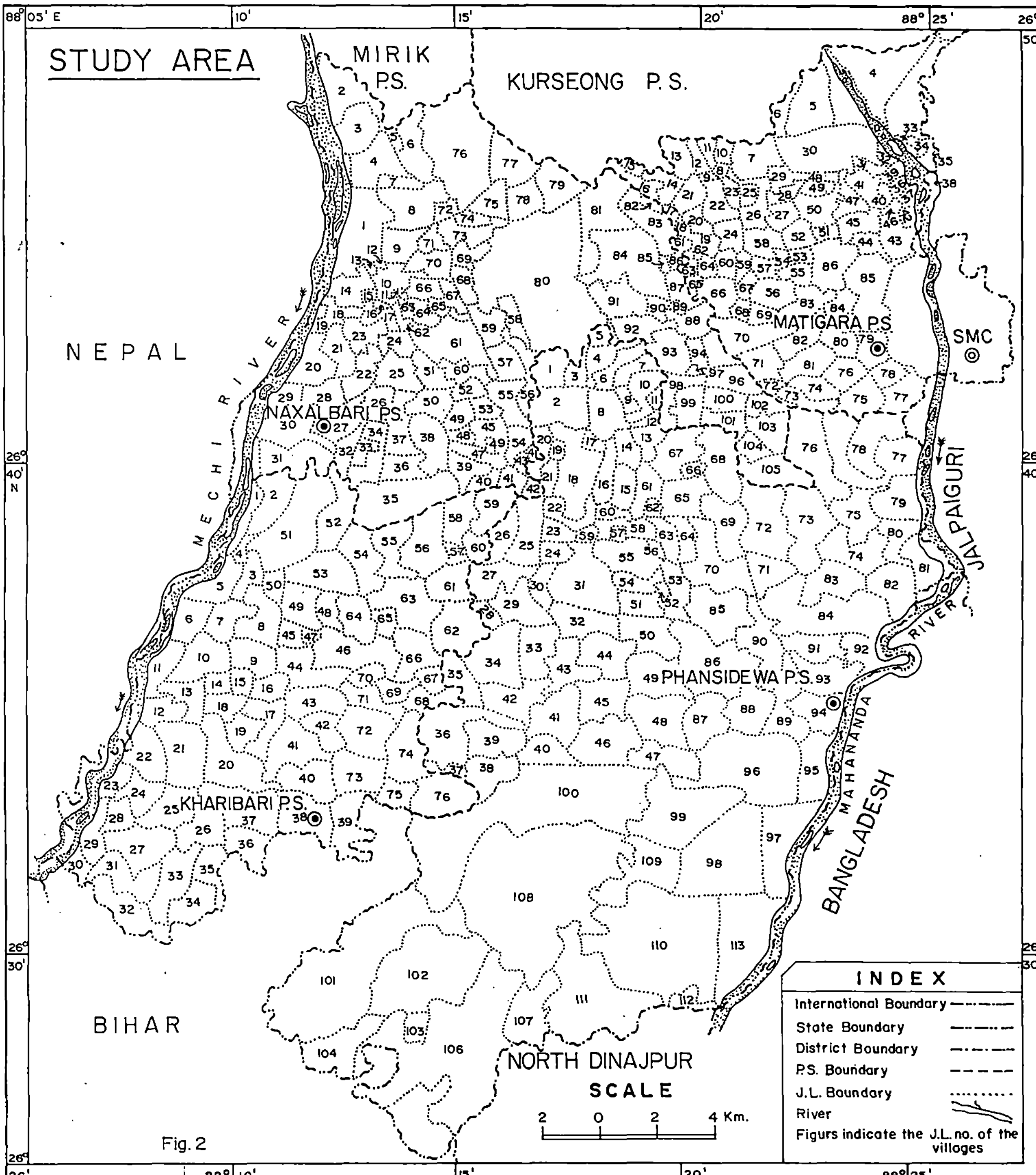
STUDY AREA
MIRIK P.S.
KURSEONG P.S.
NEPAL
MECHI RIVER
NAXALBARI P.S.
MATIGARA P.S.
SMC
JALPAIGURI
RIVER
PHANSIDEWA P.S.
MAHANANDA
BANGLADESH
KHARIBARI P.S.
BIHAR
NORTH DINAJPUR
SCALE
2 0 2 4 Km.
INDEX
International Boundary
State Boundary
District Boundary
P.S. Boundary
J.L. Boundary
River
Figurs indicate the J.L. no. of the villages
88° 05' E
10'
15'
20'
88° 25'
26° 50'
26° 40' N
26° 30'
26° 26'

Fig. 2

referred to as chicken neck (Fig.-1). It lies between 26°26'N and 26°50'N latitude and 88°05'E and 88°27'E longitude and is represented by parts of the Survey of India (SOI) toposheet No. 78B/1, 78B/2, 78B/3, 78B/5, 78B/6 and 78B/9 on the scale of 1: 50,000. On its north and north-eastern side lie respectively, the state of Sikkim and the territories of Bhutanese Kingdom. On its western side lies the territory of Nepal. On its east and south-eastern side lie, respectively, the district of Jalpaiguri and Bangladesh territories. On its southern side lies partly the district of North Dinajpur and partly the state of Bihar. The study area on average 35 kms in length (north-south) and 24 kms in breadth (east-west). It is approximately "rhomboid" in shape, enclosing an area of about 833 km^2. The area of investigation is divided into four administrative blocks–Matigara, Naxalbari, Kharibari and Phansidewa and Siliguri Municipal Corporation (SMC) of which covers 379 villages all over the area (Fig.-2). The locality index is given in the Appendix-I. The areas under review are well connected by roads and railways. Most of the interior villages are connected either by metalled or unmetalled motorable roads.

PURPOSE AND SCOPE OF THE STUDY

The study attempts an inter-disciplinary approach falling within the field of Hydrogeology, Geomorphology and Environmental geology. A comprehensive investigation was taken up with a view to repressing the occurrence of groundwater, depth and forms of water level, seasonal fluctuations in water levels, the quality of water available from shallow and deeper aquifer zones and to study the feasibility of further exploitation in the area.

Besides these, long term studies on the surface water resources, their nature and stability, precipitation spread, frequency and intensity, surface evaporation, run-off and discharge, together with studies on infiltration, percolation and groundwater recharge on a regional scale must also be coordinated with the data available from drilling and testing records to facilitate a complete interpretation of the same for forming the basis of the regional groundwater potential evaluation. Attempts also have been made to speak about statistical optimization for cost effective drilling depth for shallow bore wells in the study area. This may also be beneficial to the planning, development and management of watersheds and interfluves and above all, provide man with a better place to live in.

PREVIOUS WORK

Geological investigation in Darjiling and the adjoining areas began in the middle of the last century. Hooker (1854) traced the regional domal picture of the geniuses and observed the overlying sedimentary bedding. The region has, however, attracted the attention of earlier famous geologists from time to time but a very few published records on the groundwater geology of the study area are available. The first systematic groundwater investigations in this area was undertaken by Banerjee (1969) of the GSI in 1958-59 four exploratory bore holes were drilled at Salbari and Padajole under the India-USA Operational Agreement for the assessment of groundwater potentialities and qualify for irrigation and related purposes. A geophysical survey was carried out by Stanvoc Oil Company in 1982 located at Male of the district employing earth resistivity and refraction seismic method but no comprehensive report has been published so far.

A number of short-term investigations have been carried out during the last three decades for tackling the problem of water supply at different sectors in the study area. Among them Roy, A. K. (1974), Jana & Dutta (1996), Jana & Haque (1999) are recognisable. In the recent years, Public Health Engineering Department and Central Water Commission (CWC) and other research institutions of the district have drilled more than 20 nos. of exploratory bore holes in the study area upto 20m depth from b.g.l under the iron elimination plant programme and most of the deep tubewells are working very good without any technical problem arises and the quality of water is standard for all types of uses.

OBJECTIVES

The field work for the groundwater investigations was made continuously for two consecutive seasons–1997 and 1998. Best efforts were made to approach all the possible spots to visualise the geological setup and record the important hydrological parameters of the area into two phases. In the first phase the nature of the shallow groundwater body was studied by inventorying more than 1200 open dug wells and the second phase of the investigation commenced with the drilling of the exploratory bore holes. The major objectives of the research work will be as follows: -

- To observe the physical features of the study area for better understanding of the sub-surface water resources.
- To collect the lithological logs and geological information to determine the thickness, extent and the behaviour of the principal aquifers of the area.
- To study the fluvial dynamics of the major rivers with respect to their channel forms and related processes.
- To make assessment of groundwater potentialities by conducting proper hydraulic characteristics of aquifers.
- To identify the water table fluctuations and their implications for equity and sustainability.
- To identify the detailed inventory of existing tubewells and dug wells for the determination of the extent to which ground water in the area could be used for different purposes and their proper balance.
- To collect the water samples from different sites in the area for proper geo-chemical assessment.
- To make assessment of the existing quantum of annual utilization of groundwater for irrigation, domestic, livestock and industrial uses—their related problems and remedial measures.
- To suggest developmental, conservational and management strategies for the restoration of the geo-ecological stability of this strategically important tract of the country.

METHODOLOGY

For an appraisal of the groundwater resources of the study area depending upon the above mentioned objectives the following types of hydrological and geological information, methods and appliances are needed:

a) **Basic Data Collection** :

i) Different types of maps from SOI, GSI, CWC, PHED & CGWB were used for the preparation of the base map of the study area.

ii) Data has been collected from satellite imagery geocoded (IRS-IC LISS III of bands 2, 3 & 4 of scale 1:50,000) date Jan 26, 1999.

iii) Review of literature from different libraries in India & Bangladesh.

iv) Data has been collected regarding physical aspect, climatological, population and ecological data from secondary sources.

b) **Field Observations** :

i) Study sites in the piedmont and alluvial plains of the study area based on geological, hydrological and remote sensing techniques had been identified and data had been collected for analysis.

ii) Flow of groundwater and level were measured by seasonal observations from the field and for the consecutive years.

iii) Soils and water samples from the different sites were collected from the field at different seasons.

c) Laboratory Works :

i) Different chemical and physical properties of the soil and water samples were measured from a number of research laboratories.

d) Table Works :

i) Different types of maps and diagrams were prepared based on field data, result from analysis of the soil and water samples and other information from the different sources.

LIMITATIONS OF THE STUDY

Needless to say those limitations had been many and handicaps numerous. Drilling and testing methods left much to be desired and naturally lacunae crept into the panel of data that baffled the scholars while processing and interpretation of the same were taken up. Lack of equipment for individual aquifer testing proved a serious handicap in the assessment of the aquifer potentialities while the restriction on the number of brothels did not permit the drilling of the maximum of observation wells to find out the extent and continuity of the hydrogeological characters of the aquifers penetrated boreholes.

Moreover, the entire programme for the present work involves intensive fieldwork near the border areas of Nepal and Bangladesh territories. The two countries are separated from study area, respectively by the Mechi River in the West and Mahananda River in the east. Surveying the rivers at these border points will not be easy, as it is difficult to procure the permission for survey at these reaches. Along with the fluvial processes, other geomorphic processes also have molded the landforms. Major parts of the landforms in the area are fluvial origin. Hence, more emphasis has been given to such landforms. Moreover, the major rivers have their origins in the hills, which extend beyond the study area. Thus, the channel behaviour depends, to some extent, upon the conditions prevailing in the upper part of the respective basin. Whatever the reasons, the study area is under the threat of deteriorating hydrogeological conditions of the rivers. Since no detailed and intensive work of this kind has been done in this area, the review and references work will become difficult. However, the researcher has to take endeavor for all possible measures to procure relevant information during the course of such fieldwork.

DATA COLLECTION AND COMPILATION

The data on each well include formation log, depth drilled and depth of a finished well, granular zones tested individually or cumulatively, cumulative discharge, drawdown, static water level, coefficient of different parameters, quality of water from each individual zone and its utility for several uses. The distances at which the wells do not interfere when operated simultaneously are known as optimum distances and these are determined for dug, dug-cum-bore or tubewells. The wells are therefore, to be tested for discharge and drawdown. It may be mentioned that data on the existing tubewells in the State's different organisations have rarely been kept or maintained accurately. Complete data, when compiled accurately for individual area and basin facilitate in compiling individual or cumulative piezometric and quality maps for the confined aquifers. The information will help both the groundwater geologists and stratigraphers to arrive at a more satisfactory basis of geologic correlation.

DESIGN OF THE THESIS

The thesis has been designed in the following format :