EVALUATION AND MANAGEMENT OF WATER RESOURCE FOR A LIMESTONE MINING AREA

S. K. Chaulya

आलेख में भारत के तमिलनाडु राज्य के कोयम्बटूर जिले में अवस्थित एक लाइमस्टोन खनन क्षेत्र के जल संसाधन का आकलन किया गया है। इस क्षेत्र में पृष्ठ जल का मुख्य स्रोत दक्षिण-पश्चिम और उत्तर-पश्चिम मानसून है जो क्रमशः जुलाई-अगस्त और अक्टूबर-नवम्बर माह काल में सक्रिय होता है। कुल वर्षा का लगभग 30% अंश भूजल के रूप में एकत्रित होता है और लगभग 12% पृष्ठ बहाव के रूप में बह जाता है। इस क्षेत्र में जल की कुल उपलब्धता लगभग 52.5 करोड़ घन मीटर है। यह मात्रा क्षेत्र की कुल जल मांग से बहुत कम है। शीत ऋतु में भूजल स्तर भूमि से 13 से 25 मीटर नीचे रहता है जो ग्रीष्म ऋतु में 20 से 30 मीटर हो जाता है। क्षेत्र में उपलब्ध भूजल का 87% उपयोग हेतु विकसित किया जा चुका है। अतः इस क्षेत्र में उपयुक्त भूजल रिचार्ज उपायों को अपनाकर इस भयावह स्थिति का निराकरण करना आवश्यक हो गया है। इस आलेख में क्षेत्र में उपलब्ध रिचार्ज जोन्स की पहचान की गई है और रिचार्ज की उपयुक्त विधि बताई गई है। आलेख में क्षेत्र का वर्णन और जल संसाधन की वर्तमान स्थिति का भी उल्लेख किया गया है।

INTRODUCTION

This paper describes a case study carried out for evaluation, planning and management of water resources within a limestone mining area. The Walayar limestone mine covers an area of 65.18 hectares (ha) in Mavuthampatty village of Thondamuthur block at Coimbatore district of Tamilnadu in southern India (Figure 1). At present, the bottom bench of the open pit has reached upto the groundwater level of the area. As per the future demand of the limestone, the open pit mine has to be deepened below groundwater level of the area. Therefore, exploitation of limestone in this open pit mine will influence the surface and groundwater resources in and around the mine. Thondamuthur block has been considered as influencing zone of this mining area for water resource accounting study. As this region is facing an acute water shortage, proper management and conservation of the water resource is required in and around the mine. The assessment of surface and groundwater resources is necessary to know the availability with respect to the demand in and around the mine considering influencing parameters for the area (Coates, 1981; Graniel and others, 1999; Karaguzel and others, 1999). Based on the study results, a management and conservation strategy is formulated for Thondamuthur block i.e. the study area.

METHODOLOGY

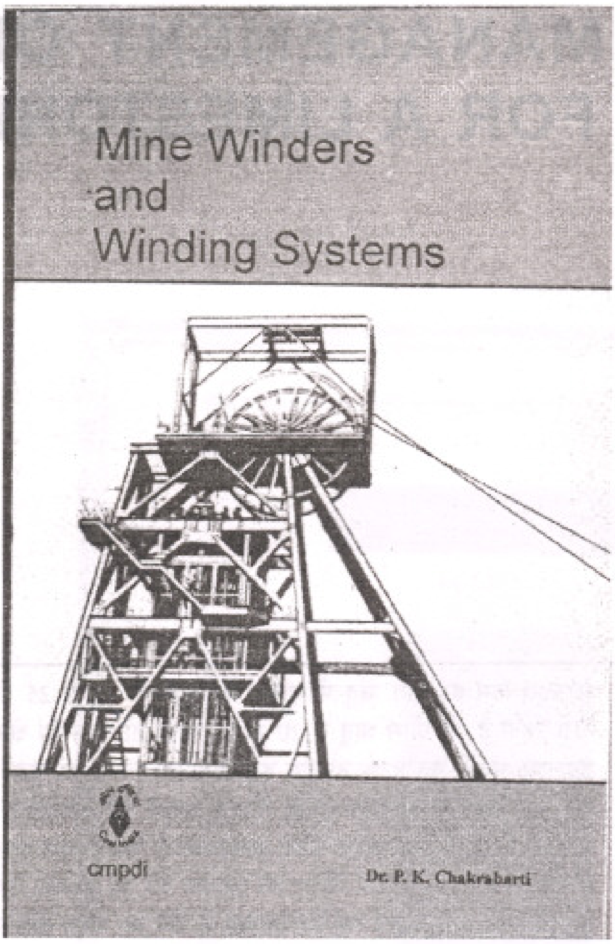
Methodologies adapted to this study include:

- Collection of data characterising drainage patterns, recharge zones, rainfall, ground and surface water resources, water balance status and other details of the study area.

- Analysis of rainfall patterns and intensity to evaluate runoff characteristics. Collection of long-term groundwater levels for correlation of rainfall with groundwater level fluctuations and analysis of pre- and post-monsoon groundwater level fluctuations (Adamovski and Homory, 1983; Weeks and Boughton, 1987 and Soliman *et al.*, 1997).

- Analysis of geological structure and strategraphic sequences from borehole data and geological cross sections of the mine as per the methodology described by

Central Mining Research Institute, Barwa Road, Dhanbad – 826 001 (India)



Underground mining shall continue to occupy a very significant place in the overall coal production - both in India & worldwide. Therefore, designing of mine winders and their electrical driver, which are selected for the lifetime of an underground coal mine, shall remain vital to practising design engineers, stu- dents of mining machinery, mechanical & electrical engineers.

This book on **Mine Winders and Winding System** would serve as a guide and check for correct planning and selection of right equipment - the issues not found in conventional text books. Formulae, tables, graphs & other quantitative informations have been included in this vital publication of CMPDI.

And so much in just Rs. 150/-

Rush a DD
drawn in favour of CMPDI to
HOD (Publications), CMPDI,
Kanke Road, Ranchi- 834 008
for getting your personal copy.

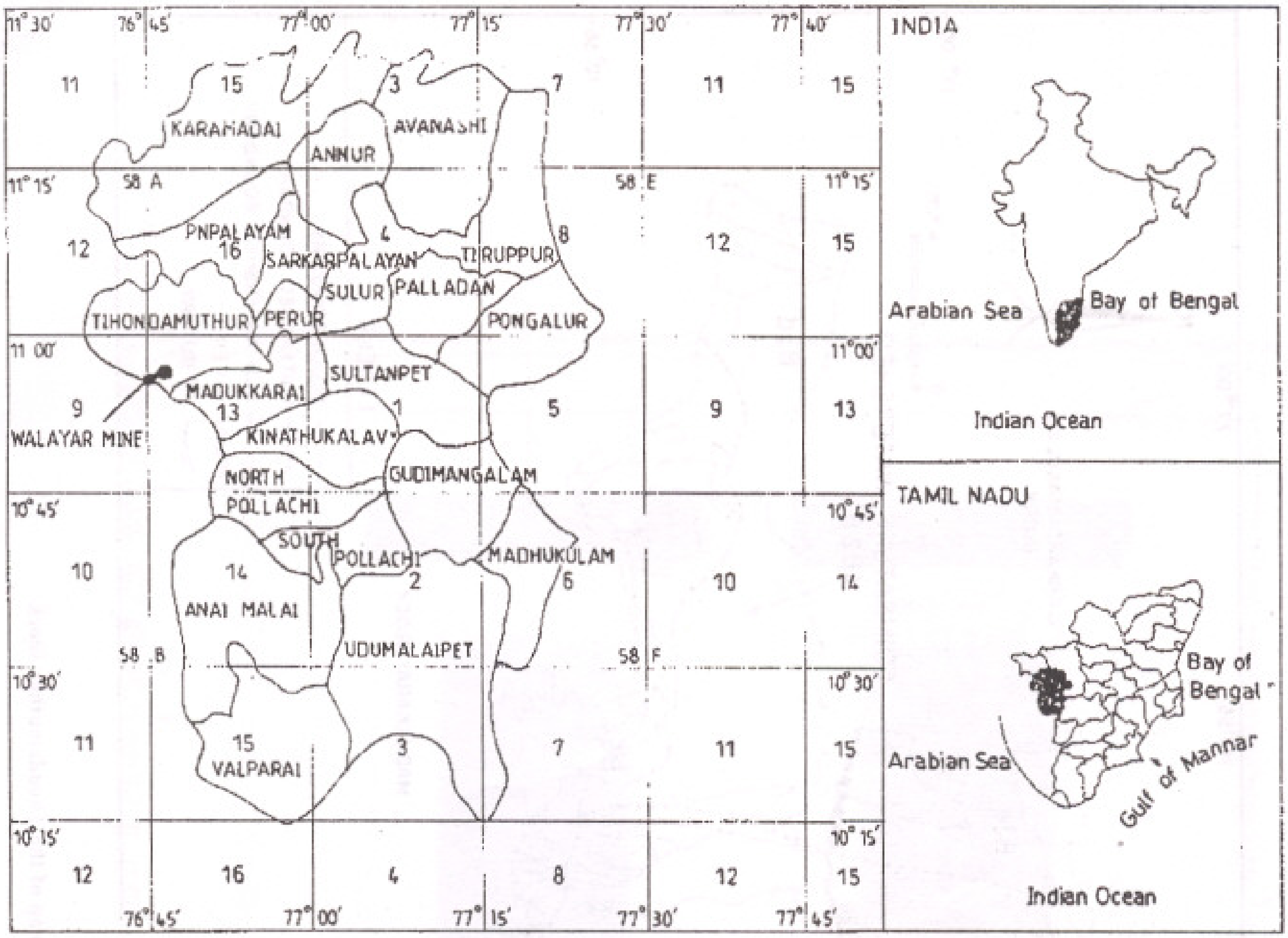


Fig. 1 : Location map of the Thondamuthur block

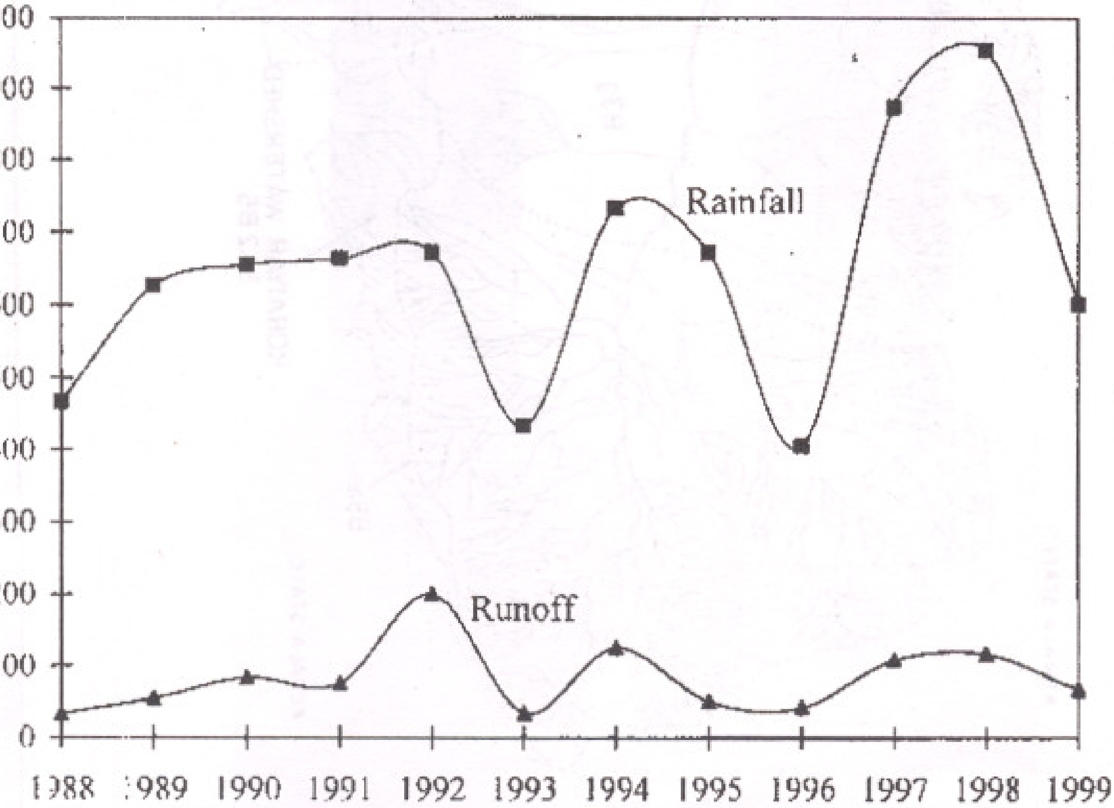


Fig. 2 : Annual rainfall/runoff hydrograph for the study area

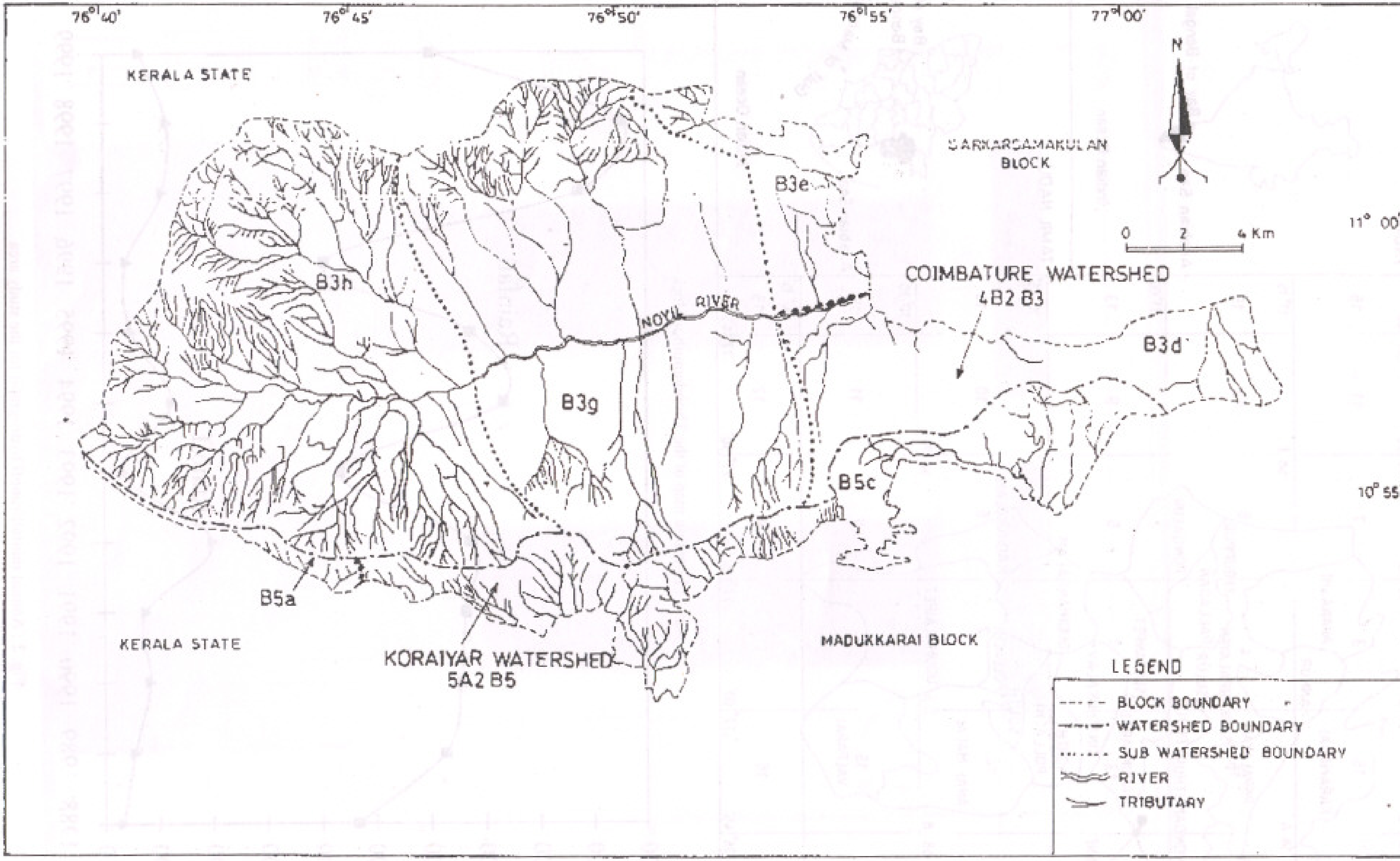


Fig. 3 : Drainage and watershed map of the Thondamuthur block

Karaguzal *et al.* (1999), Chaulya *et al.* (2000) and Chakraborty and others (2001).

- Determination of aquifer parameters by pumping test and groundwater analysis to estimate the availability of groundwater and pump capacity requirements following Rao and Rao (1985), Drawson and Istok, (1992), Kresic (1997), Singh *et al.* (1999), Bell and Maud (2000) and Umar and Ahmad (2001).

- Calculation of water resource potential of the area based on rainfall, runoff, evaporation, infiltration, drainage, landuse, soil characteristics, geology, geomorphology, terrain features, slope, lineament density, etc. following Bradon (1986), Lyle (1987), Marsily (1986), Karanth (1990), Tolman (1993), Abu-Taleb (1999) and Feng *et al.* (2000).

- Study of water balance based on analysis of water resource availability and demand in the area following Brawner (1986), Basu and Basu (1999), Berger (2000) and Reddy *et al.* (2000).

- Analysis of physico-chemical properties of groundwater as per the standard method of analysis to evaluate it's potability (Down and Stocks, 1977; Dominico and Schwart, 1990; AWWA, 1992; Lee *et al.*, 2001)

- Finally, formulation of water management strategy based on technical and economic feasibility, and the recharge potential of the area following the experience of various case studies (ASCE, 1972; Aral, 1995; Abu-Taleb, 1999; El Ouali *et al.*, 1999; Graniel *et al.*, 1999; Yang *et al.*, 1999; Farah *et al.*, 2000; Reddy *et al.*, 2000).

LOCATION

Thondamuthur block is located in southern side of Coimbatore district. This block is bounded by Kerala state in the west, Perur block in the east Madukkarai in the south and Coimbatore (or) P.N. Palayam block in the north. The location map of Thondamuthur block is shown in Figure 1. It falls within the co-ordinates of longitude: 76° '40' 00? – 77° 02' 00? E and latitude: 10° 56' 00? – 11° 03' 00? N of Survey of India toposheet numbers 58B/13, 58B/16, 58F/1. It has a geographical area of around 480 km^2.

RAINFALL

Rainfall in the area mostly takes place during July-August and October-November coinciding with south-west and north-east monsoons. The most rainfall accompanies north-east monsoons. The average annual rainfall during the twelve-year period (1988-1999) is 590 mm. The relation between annual rainfall and runoff is presented in Figure 2. The rate of pan evaporation observed during the months of January and February is 3.0 mm, which is the lowest, and the highest is 7.9 mm in the month of June.

DRAINAGE

The area is within the Coimbatore (4B2B3) and Koraiyar (5A2B5) watersheds, and the Noyil River drains its central part (Figure 3).

GEOLOGY AND GEOMORPHOLOGY

The bedrock in the area is Archean crystalline rock. The rock types include charnockite and gneiss. The block has landforms covered by western ghat structural hills, pediments (buried pediments shallow and deep) and valley fills. Hydrogeomorphological map of the block is presented in Figure 4.

MAJOR SOIL TYPES

The hydrological soil group 'C' with a slow rate of infiltration and moderate runoff covers about 60% of the area. The rest of the area is covered by hydrological soil group 'B' with moderate infiltration and runoff. Sub-watershed-wise distribution of hydrological soil groups are shown in Table 1.

SLOPE

Only 11% of the block area has very gentle slope (1-2%). The remaining portion of the area varies between moderate slope (5-10%) and very steep slope (>35%). Very steep slope cover about 13.6% of the study area. Sub-watershed-wise average slopes are listed in Table 2.

LAND USE

Agricultural lands cover about 48% of the area and about 38% is covered by forest land. Settlements cover about 5% of area. Sub-watershed-wise land use areas are listed in Table 3.

SURFACE WATER RESOURCE

The major source of surface water in the region is south-west and north-east monsoon during July-August and October-November, respectively. Percentage of seasonal runoff depends upon various factors in addition to precipitation including topography, land use, soil, slope, physiography, drainage and hydrogeomorphology of the area. Similarly, harnessable surface water of the area depends on surface structures and storage facilities including the above- mentioned factors. The sub-watershed-wise actual runoff and harnessable surface water are estimated in Table 4. The total harnessable surface water for the area is around 524 million cubic metre (MCM). This quantity is not sufficient for the demand in the region.

Table 1 : Distribution of hydrological soil groups

Watershed Code	Sub-watershed Code	Hydrological soil groups (Area in km²)		Total Area (km²)
		B	C	
4B2B3	B3d	9.63	42.85	52.48
	B3e	6.23	19.62	25.85
	B3g	50.74	118.92	169.66
	B3h	70.46	90.83	161.29
5A2B5	B5a	0.49	4.42	4.91
	B5c	38.05	27.34	65.35
Total		175.60	303.98	479.58

Table 2 : Sub-watershed wise average slope

Watershed code	Sub-watershed Code	Area (km²)	Slope (%)
4B2B3	B3d	52.48	(1-2)
	B3e	25.85	(5-10)
	B3g	169.66	(5-10)
	B3h	161.29	(5-10)
5A2B5	B5a	4.91	(10-15)
	B5c	65.39	(>35)
Total		479.58	

GROUNDWATER RESOURCE

Occurrence of Groundwater

Groundwater occurs in the porous and granular weathered mantle as well as in bed-rock joints, fissures and fractures at shallow depths below the weathered mantle. It also occurs in the narrow and deep seated fracture zones developed due to tectonic deformations in unweathered crystalline rocks.

Since these fracture zones are interconnected with the weathered mantle through vertical linear fractures (lineaments), groundwater occurs generally under phreatic conditions in the area. On the basis of depth of occurrence, the potential aquifers in the project area can be classified as shallow and deep aquifers.

Shallow Aquifers

The shallow aquifers in the area occur within a depth of 30 m below the surface level. Thickness of weathered zone ranges from 10 to 40 m and depth of bedrock ranges from 50 to 55 m. Shallow aquifers are essentially composed of disintegrated rock material as well as partly decomposed but highly jointed and fractured crystalline rocks occurring just below the weathered mantle. The nature and thickness of the aquifer vary considerably from place to place and within short distances, depending on the mineralogical composition and structural characteristics of the parent rocks as well as the topographic and drainage conditions of the area.

Hence, the yield potential of the shallow aquifer is highly variable ranging from less than 0.5 lps to as much as 6.5 lps. Apart from the above-mentioned factors, local recharge conditions also influence the shallow aquifers and the yield of wells located near the recharge zones is generally high. The aquifers are tapped by hand-dug wells for domestic and irrigation purposes in the area.

Deep Aquifers

The deep-seated fracture zones developed due to post crystalline tectonic deformation form the deep aquifers in

Table 3 : Sub-watershed-wise land use (km^2)

Category	Sub-watershed code						Total
	4B2B3d	4B2B3e	4B2B3g	4B2B3h	5A2B5a	5A2B5c	
Built up land							
1.1 Settlement	9.62	4.73	4.65	0.97	-	6.37	26.34
1.2 Industrial area	-	-	-	-	-	-	-
1.3 Air strip	-	-	-	-	-	-	-
Agricultural Land							
2.1 Crop land	19.44	4.39	89.20	13.03	-	9.05	135.11
2.1a Fallow harvest	-	-	-	-	-	-	-
2.2b Dry crop land	-	-	-	-	-	-	-
2.2 Plantation	13.47	10.82	29.60	41.47	-	0.02	95.38
Forest Land							
3.1 Dense Forest	-	-	-	19.95	-	-	19.95
3.2 Open Forest	-	-	-	-	-	-	-
3.3 Degraded Forest	0.93	3.49	36.86	75.55	4.90	37.32	159.05
3.4 Grass Land	-	-	-	-	-	-	-
3.5 Forest Plantation	-	-	0.32	1.91	-	-	2.23
3.6 Mangrove Forest	-	-	-	-	-	-	-
Waste Land							
4.1 Scrub Land	-	-	-	-	-	-	-
4.2 Salt Affected Land	-	-	-	-	-	-	-
4.3 Gullied Land	-	-	-	-	-	-	-
4.4 Water Logged / Swampy	-	-	-	-	-	-	-
4.5 Sandy Area	4.80	0.51	50.7	6.00	-	8.66	25.04
4.6 Barren Land	-	-	-	-	-	-	-
4.7 Steep Slope	-	-	-	-	-	-	-
4.8 Rock Outcrop	-	-	-	-	-	-	-
Water Bodies							
5.1 River Stream	0.24	0.01	1.08	-	-	0.40	1.73
5.2 Reservoir/Tank	3.29	0.17	0.21	0.34	-	0.02	4.03
5.3 Rock Outcrop	0.07	-	2.17	1.91	0.01	3.37	7.53
Others							
6.1 Problem Soil	0.62	1.73	0.50	0.16	-	0.18	3.19
6.2 Industrial Waste	-	-	-	-	-	-	-
6.3 Salt Pan	-	-	-	-	-	-	-
6.4 Reclaimed Land	-	-	-	-	-	-	-
6.5 Tidal	-	-	-	-	-	-	-
6.6 Sand Features with Vegetation	-	-	-	-	-	-	-
Total	52.48	25.85	169.66	161.29	4.91	65.39	479.58

Key: - no land under the category

the area. These fracture zones extend down to a depth of 200 m or even more. The deep-seated fractured rocks occur in the form of vertical to sub-vertical linear zones of restricted width as well as horizontal to sub-horizontal fractured zones of varying thicknesses alternately with massive plinths. The horizontal fracture zones are more productive than the vertical fractures. The deep aquifers are tapped extensively in the area by bored wells ranging in depth from 100 m to as much as 250 m for domestic as well as irrigation purposes. Wherever the existing hand-dug wells have gone dry, bored wells are drilled close to them and water is pumped out either by submersible pumps or by air compressors.

Seasonal Change in Groundwater Levels

During the winter season groundwater level ranges between 13 and 25 m from ground surface whereas, during summer season groundwater level varied from 20 to 30 m. The deepest water level is generally noticed in the month of May every year. The rise in water level due to monsoon recharge varies from less than 1 m to as much as 10 m depending upon the location of the well, and the amount and intensity of rainfall during the monsoon.

However, during the course of field visits in January-February and April-May, 2000 it has been observed that most of the irrigation hand-dug wells are either dry or contain very little water, indicating that there was no appreciable rise in water levels during the north-east monsoon of 1999. This anomaly in the water levels between the observation wells and the irrigation hand-dug wells, which are surrounded by bored wells are quite noticeable.

This may be due to the fact that the water levels in the irrigation wells never reach static water level conditions as the aquifer remains depleted in and around the wells due to continuous pumping by the bore wells for irrigation throughout the year. Moreover, the bored irrigation wells are located in clusters and within very short distances from each other causing mutual interference i.e. draw down effects. The net result is the depletion of the aquifer and formation of permanent depressions in the water table in and around such bored irrigation wells.

Pumping Tests

Pumping tests are the most accurate, reliable and commonly used method to evaluate the hydraulic parameters of an aquifer, the efficiency of a well and optimum pumping rates (Kresic, 1997). The methodology of a pumping test is dependent on its application (Drawson and Istok, 1992). A 24-hour well pumping test in a confined aquifer has been conducted to determine its hydrogeological parameters with exploratory drilling in the area. The results of the pumping tests carried out at two bore wells are given in Table 5. The lithological logs of exploratory boreholes in the area indicate the varying thicknesses and discharge capacities shown in Table 6 for selected lithologic units.

Groundwater Recharge

Rainfall is the major source of groundwater recharge in the area. Some amount of recharge takes place during the pre-monsoon showers as well as during the south-west monsoon season. However, the bulk of recharge to groundwater is contributed by the north-east monsoon which brings the rainfall to the area during October, November and December months. It has been estimated that groundwater recharge in the area ranges from 30 to 33% of the annual rainfall in the area. It has also been estimated that the run-off from the area is quite low, hardly exceeding 11% of the seasonal rainfall.

Chemical Quality of Groundwater

Water quality is one of the important aspects for the groundwater recharge studies. The electrical conductivity (EC) of the groundwater is the essential parameter in recharge of groundwater. The various parameters considered are EC, Nitrate (NO_3), Iron (Fe) and Fluoride (F). The chemical quality of groundwater is generally potable. High Fe content exceeding the permissible limit of 0.3 mg/l (as per Indian Standard, IS: 10500) has been reported at a few localities in the area. The general ranges of chemical constituents are given in Table 7.

Groundwater Development

Groundwater being the only water source for domestic, irrigation and industrial use in the area, it is extensively exploited by means of wells. Large areas cultivated with crops like sugar-cane, turmeric, coconut and banana are irrigated by groundwater. Large scale use of groundwater for irrigation has led to the lowering of water levels in wells resulting in drying up of hand-dug wells which are 35 to 40 m deep. Where the dug wells have been forced to yield enough water for irrigation, the farmers have drilled vertical as well as horizontal bores inside them to augment in yield. But it is found that these wells also dry up within a few years of construction. With the advent of fast drilling down the hole (DTH) rig, people have resorted to drilling wells and install air compressors or submersible pumps to lift the groundwater. The average depth of bored irrigation wells was about 80 m in 1972 and has progressively increased over the years and at present more than 200 m well-depths are common.

Increased withdrawal of groundwater for irrigation has adversely affected the domestic water supply and it has become necessary to go for deep bored-wells with power pumps to maintain rural water supply systems in almost all

Table 4 : Estimates of harnessable surface water resource for sub-watershed areas

Water-shed Code	Subwater-shed Code	Subwater-shed Area (km^2)	Seasonal rainfall (mm)	Seasonal runoff (mm)	% of runoff	Harnessable surface water (MCM)
4B2B3	B3d	52.48	326.200	19.177	5.87	10.06
	B3e	25.85	1006.323	134.160	13.22	34.68
	B3g	169.66	382.600	51.426	13.44	87.24
	B3h	161.29	1180.172	227.052	19.23	366.21
5A2B5	B5a	4.91	382.600	38.501	10.06	1.90
	B5c	65.39	382.600	37.079	9.70	24.24
	Total					524.33

Table 5 : Aquifer parameters of two exploratory wells located near the mining lease

Parameters	Location	
	Madukkarai	Sundarapuram
Depth drilled (m)	51.81	290.16
Length of casing (m)	1.0	6.73
Rock type	Crystalline limestone & biotite geniss	Crystalline biotite geniss & crystalline limestone
Static water level (m)	15.44	9.7
Discharge during drilling (lps)	0.75	4.35
Duration of pumping (min.)	3000	300
Discharge (lps)	8.33	1.16
Drawdown (m)	0.46	5.6
Specific capacity (lpm/m)	17.28	0.032
Transmissivity (m^2/d)	1146.5	1.367
Storativity	2.84×10^{-2}	-----
Total available drawdown (m)	2.78	-----
Safe pumping rate in (lps/d)	80.3	-----
Condition of the aquifer	Unconfined aquifer with delayed gravity drainage	Unconfined aquifer with delayed drainage

Table 6 : Characteristic of different lithology

Lithology	Thickness (m)	Discharge (lps)
Soil	1.52	1.19
Limestone massive	27.43	4.98
Limestone fractured	9.14	6.25
Limestone fractured with quartz veins	13.71	6.88

Table 7 : Water quality details

Location	EC (micromhos/cm)	NO_3 (mg/l)	Fe (mg/l)	F (mg/l)
Irruttupallam	2482	48	0.7	0.2
Kanthagoundenchavadi	4680	14.2	0.7	0.2

Table 8 : Status of groundwater development in the study area

Item	Value
Groundwater recharge (ha m)	3043
Utilizable groundwater recharge (ha m)	2587
Net groundwater draft (ha m)	69506
Balance groundwater available for development (ha m)	10527
Stage of groundwater development (percentage)	87

the villages in the area.

However, no statistics are available for the number of bored-irrigation wells constructed by the farmers in the area. It is a common sight to find three or four bored-wells within an acre of land under irrigation and a few cultivators own more than one hundred bored-wells to irrigate 6 to 8 ha of land.

The status of groundwater development for the area is given in Table 8. From this table, it can be seen that the stage of groundwater development for area has already been around 87%, and falls under "Dark" category. The "Dark" category means where the development of groundwater is more than 85% of available groundwater resource. The above situation has to be mitigated by immediate initiation of suitable measures for groundwater recharge.

GROUNDWATER RECHARGE

Artificial Recharge Possibilities

In view of the very favourable hydrogeological conditions, the natural recharge of groundwater from rainfall is more than 30%, which is quite high for a hard rock area. Moreover, the runoff is hardly 11% of the rainfall and that too is almost completely stored in the surface water bodies, such as tanks and ponds. Hence, there is no surface water source available within the area to augment the ground resource by artificial recharge. Water has to be brought from outside the area to artificially recharge the aquifers for the augmentation of the groundwater potential of the area to meet the future demands.

Suitability of Aquifers for Artificial Recharge

The nature of the aquifers in the project area can be described as a medium made up of irregular plinths of massive rocks separated from one another by intensively fractured and highly permeable rock materials on the sides, and weakly fractured and moderately permeable rock materials at the top and bottom of the massive plinths. The transmissivity along the horizontal fractures are much lower than the vertical fractures, giving rise to strong anisotropy character to the fractured rock aquifers of the area. Coupled with low horizontal permeability, the very low hydraulic gradient (less than 3.48 m per kilometre) has made the fractured rock aquifers a highly suitable medium to retain the artificially recharged water for considerable time. Highly permeable vertical fractures allow deep percolation of the recharging waters into the aquifers for attaining full saturation (Maidment, 1993; Strack, 1998).

Methodology for Artificial Recharge

Various methods are available for artificial recharge of aquifers and are being practiced world-wide (Linsley *et al.*, 1975; Freeze and Cherry, 1979; Kashef, 1987; Fetter, 1994; Todd, 1995; Soliman *et al.*, 1997). They include water spreading, contour bunding, contour trenching and construction of check dams, percolation ponds, recharge well, etc. (Soliman *et al.*, 1997). The method suitable for a particular situation is dependent on the hydrological and topographic conditions of the area and the purpose for which the artificial recharge of aquifers is resorted to (El Quali *et al.*, 1999; Farah *et al.*, 2000). For example, if the natural recharge to the aquifer from the rainfall is low and

Table 9 : Summary of the identified recharge zones in the study area

Name of the Panchayat	Village name	Type of Well	Zonation/Source ID No.	Recommendations
Devarayapuram	Devarayapuram	OW	High-1	–
	Devarayapuram	OW	Moderate-2	–
	Kondaiyampalayam	OW	High-3	DS
	Boolagoundenpudur	OW	Moderate-4	–
	Veelerugampalayam	BW	Moderate-5	–
	Devarayapuram	BW	Moderate-6	CD
	Parameswarampalayam	BW	Moderate-7	–
Madampatti	Madampatti	BW	Moderate-8	–
	Madampatti	BW	Moderate-9	CD
	Seelappagoundenpudur	OW	Moderate-10	CD
	Seelappagoundenpudur	BW	Moderate-11	–
Madavarayapuram	Irruttupallam	OW	High-12	CD
	Irruttupallam	OW	Moderate-13	–
	Thamppulipalayam	BW	High-14	–
	Thamppulipalayam	BW	High-15	PP
	Thamppulipalayam	OW	Moderate-16	–
	Nallurpatti	BW	High-17	PP
	Irruttupallam	BW	High-18	–
Narasipuram	Narasipuram	OW	High-19	–
	Narasipuram	BW	High-20	–
Perurchettipalayam	Arumuga goundenur	BW	Less-21	DS
	Pachapalayam	OW	Less-22	–
	Pachapalayam	BW	Moderate-23	DS
	Perurchettipalayam	OW	Moderate-24	–
	Perurchettipalayam	OW	Moderate-25	–
	Perurchettipalayam	BW	Moderate-26	–
	Kurinchi Nagar	BW	Moderate-27	–
	Arumuga goundenur	BW	Less-28	CD
	Pachapalayam	BW	Moderate-29	–
	Indra colony	BW	Moderate-30	–
Thennamanllur	Puththur	OW	Moderate-31	CD
	Santhigoundampalayam	OW	Less-32	–
	Thennamanullur	OW	Moderate-33	–
	Puththur	BW	Less-34	–
Theethipalayam	Kalampalayam	OW	Moderate-35	–
	Kalampalayam	OW	Moderate-36	–
	Theethipalayam	OW	Less-37	CD
	Theethipalayam	BW	Less-38	–
	Theethipalayam	BW	Less-39	–
	kalampalayam	BW	Less-40	CD
Vallimalaipattinam	Viraliyur	BW	High-41	CD
	Viralipattinam	BW	High-42	–
	Varaliyur	BW	High-43	CD

Key: BW - Bore well, OW - Open well, CD - Check dam, DS - Desilting of tank, PP - Percolation pond

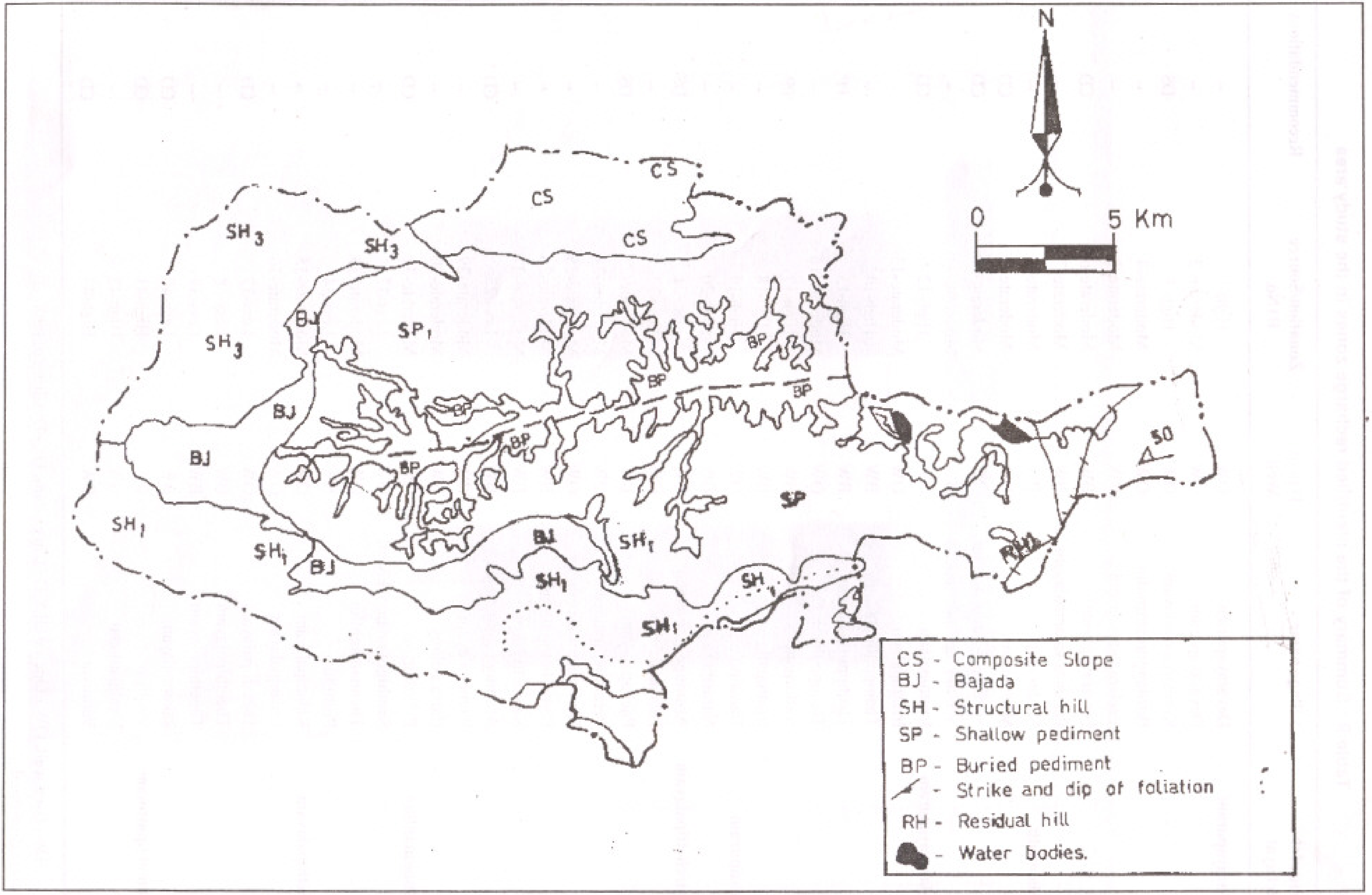


Fig. 4 : Hydrogeomorphological map of the study area

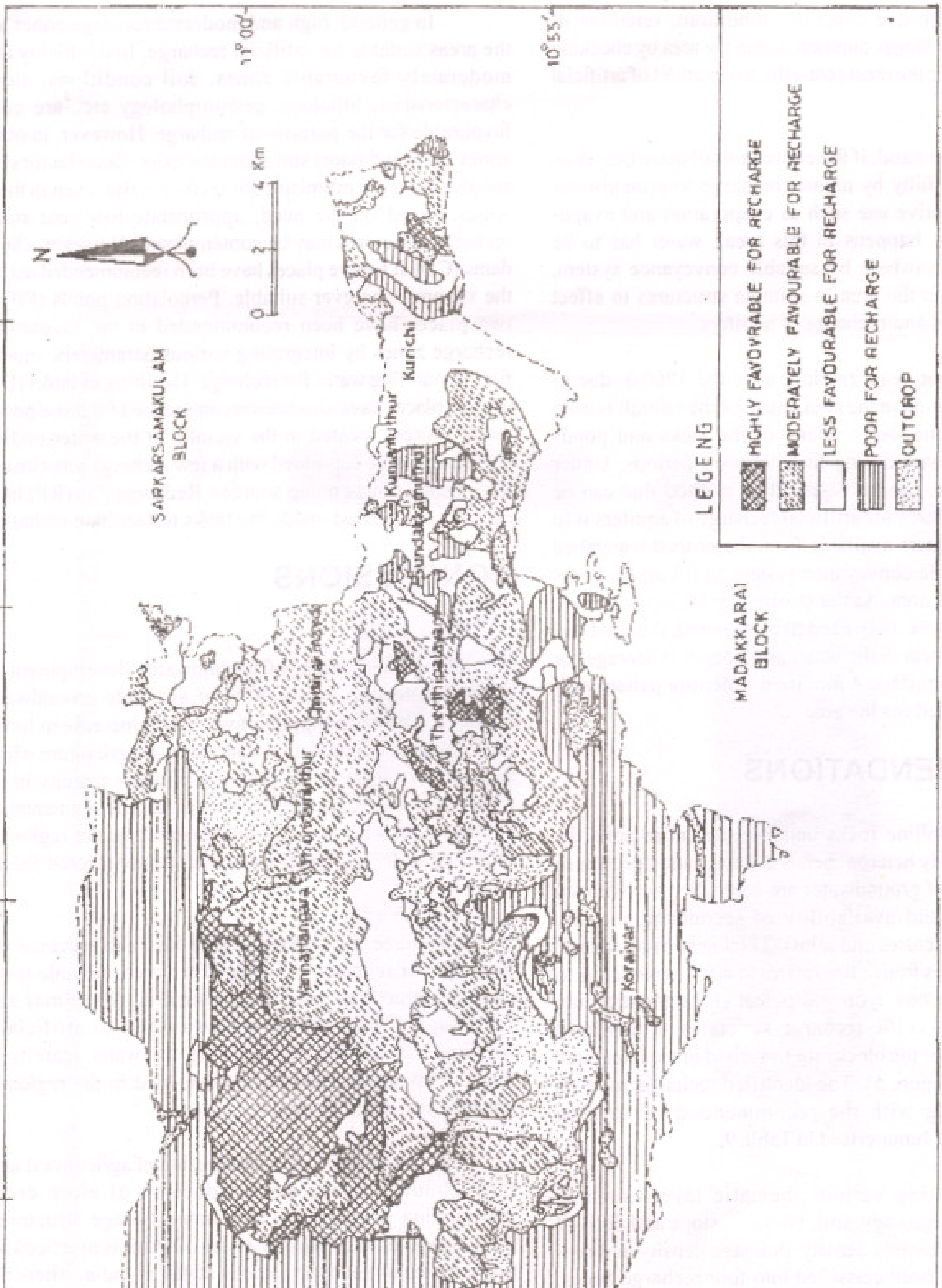


Fig. 5 : Zonation map of the Thondamuthur block

the runoff is high due to terrain conditions, retention of surface water for longer duration within the area by checking the run-off will be the most cost-effective method of artificial recharge.

On the other hand, if the entire rainfall occurring in an area is used up fully by natural recharge to groundwater and by consumptive use such as evaporation and evapo-transpiration (as happens in this area), water has to be brought from elsewhere by suitable conveyance system, and stored within the area in suitable structures to effect deep percolation and recharge of aquifers.

In the recent years (mainly after the 1960s), due to intensive cultivation in the area, much of the rainfall is used up directly by the fields. Many of the tanks and ponds remain empty even during the monsoon periods. Under this scenario, the most cost-effective method that can be employed in the area for artificial recharge of aquifers is to bring surplus waters available from the nearest watershed through a suitable conveyance system to fill up the tanks and ponds in the area. As the existing tanks and ponds are in prolonged disuse, they need to be repaired, dredged and modernised to receive the water and keep it in storage for recharging the aquifers. A modified water use pattern may also be considered for the area.

RECOMMENDATIONS

Since crystalline rocks underlie the entire area, the aquifers are highly heterogeneous in nature and occurrence and movement of groundwater are controlled by intensity of weathering and availability of secondary porosity developed by fractures and joints. Thickness of weathered zone, which varies from a few metres to 40 m, is moderate to high. Taking various hydrogeological characteristics into consideration, specific recharge structures, which have been identified for the block, are furnished in the integrated zonation map (Figure 5). The identified recharge zones in the block along with the recommended recharging methodology are summerised in Table 9.

By integrating various thematic layers such as geomorphology, geology, soil, land use, slope and derived maps such as lineament density, drainage density and run-off; the area has been classified into four recharge zones: (i) High (highly favourable), (ii) Moderate (moderately favourable), (iii) Less (less favourable) and (iv) Poor (not favourable) zones which are indicated in Table 9.

The fractures, faults/shears or joints that are delineated by lineaments observable on satellite images are shown on the integrated zonation maps. These lineament zones are the highly favourable areas for recharge and for sitting well locations. Detailed geophysical surveys including electromagnetic surveys and electrical resistivity surveys may be conducted to better locate these zones in the field.

In general, high and moderate recharge zones are the areas suitable for artificial recharge. In the highly and moderately favourable zones, soil conditions, slope characteristics, lithology, geomorphology etc., are quite favourable for the purpose of recharge. However, in other zones, (less and poor) soil characteristics, slope factor etc., are also not quite promising for recharge. But, even in these zones, based on the need, appropriate low cost small recharge structures may be contemplated. However, check dams (CD) at twelve places have been recommended across the streams wherever suitable. Percolation ponds (PP) at two places have been recommended in the favourable recharge zones by integrating various parameters, mostly for impounding water for recharge. Desilting of tanks (DS) at three places have also been recommended for those power pump sources located in the vicinity of the water bodies. Desilting can be combined with a few recharge pits close to the existing power pump sources. Recharge pits (RP) have been recommended inside the tanks to facilitate recharge.

CONCLUSIONS

The present stage of groundwater development or utilization for the area is 87% of available groundwater resource. The consumption of water will increase in future due to growth of population, industry and agriculture which will further aggravate the problem of water scarcity in the region. Therefore, an effective water resource augmentation strategy has to be properly implemented in the region. A modified water use pattern may also be considered for the area.

To reduce the surface runoff loss and enhance the groundwater recharge capacity of the area, suitable water retaining structures should be constructed. Water may also be brought from outside the watershed to artificially recharge the aquifers for reducing the water scarcity in future. Few canals have to be developed in the region to enhance the water resource.

This would also help in cultivation of agricultural land throughout the area and production of more crops surrounding these canals and water storage structures. Similar type of inter-basin transfer of water is practiced for artificial recharge in the various states of India, where the result is quiet encouraging.

ACKNOWLEDGEMENTS

Author is grateful to Dr. M.K. Chakraborty, Dr. M. Ahmad, Dr. R.S. Singh and Mr. A.K. Chowdhury, Scientists, CMRI, Dhanbad for necessary help in conducting the study and preparing the manuscript. The help and data provided by Central Groundwater Board, Chennai; Anna University, Chennai; Tamilnadu Water Supply and Drainage Board, Coimbatore; Public Works Division (Groundwater), Coimbatore; Agricultural University, Coimbatore; Indian

Bureau of Mines, Nagpur; and others, is sincerely acknowledged. Author is also thankful to M/s Associated Cement Company, Madukkarai for sponsoring this research work. Finally, the necessary help and facilities extended by the management of Walayar limestone mine during the field study are gratefully acknowledged.

REFERENCES

Abu-Taleb, M.F.: 1999, 'The use of infiltration field tests for groundwater artificial recharge', Environmental Geology 37(1/2), 64-71.

Adamovski, K. and Hamory, T.: 1983, 'A stochastic system of model of groundwater level fluctuations', Journal of Hydrology 62, 129-141.

ASCE (American Society of Civil Engineers): 1972, 'Manual on Groundwater Management', ASCE Mann (40).

AWWA (American Water Works Association): 1992, Standard Method for the Examination of Water and Waste Water, (A.E. Greenbag; C.S. Lenore and A.D. Eatten eds.), Washington DC 20005.

Aral, M.M.: 1995, Advances in Groundwater Pollution Control and Remediation, Kluwer Academic Publishers, The Netherlands.

Basu, G.C. and Basu, S.K.: 1999, 'An approach for estimation of hydrological water budget for its significant role in water resources management', Indian Journal of Engineers 28(182), 39-43.

Bell, F.G. and Maud, R.R.: 2000, 'A groundwater survey of the greater Durben area environs, Netal, South Africa', Environmental Geology 39(8), 925-936.

Berger, K.: 2000, 'Validation of the hydraulic evaluation of landfill performance (HELP) model for simulating the water balance cover systems', Environmental Geology 39(11), 1261-1274.

Bradon, T.W. (ed.): 1986, 'Groundwater: Occurrence, Development and Protection, Water Practice Manuals', The Institution of Water Engineers and Scientists, London, 615p.

Brawner, C.O.: 1986, 'Groundwater and coal mining', Mining Science and Technology 3, 187-198.

Chakraborty, M.K., Chaulya, S.K., Ahmad, M., Singh, K.K.K., Singh, R.S., Tewary, B.K. and Gupta, P.K.: 2000, 'Hydrogeological conditions around an opencast mine', Minetech 22(1), 41-53.

Chaulya, S.K., Chakraborty, M.K., Ahmad, M., Singh, K.K.K., Singh, R.S., Tewary, B.K. and Gupta, P.K.: 2000, 'Water resource accounting for an iron-ore mining area in India', Environmental Geology 39(10), 1155-1162.

Coates, D.R.: 1981, Environmental Geology, John Wiley & Sons, New York.

Dominico, P.A. and Schwart, F.W.: 1990, Physical and Chemical Hydrogeology, John Wiley & Sons, New York, 824p.

Down, C.G. and Stocks, L.: 1977, Environmental Impact of Mining, Applied Science Publishers, London, 131p.

Drawson, K. and Istok, J.: 1992, Aquifer Testing, Design and Analysis, Lewis Publishers, Boca Raton, Florida, 280p.

El Ouali, A., Mudry, J., Maria, J., Chauve, P., Elyamine, N. and Marzouk, M.: 1999, 'Present recharge of an aquifer in a semi-arid region: an example from the Turoniam limestone of the Errachidia basin, Morocco', Environmental Geology 38(2), 171-176.

Farah, E.A., Mustafa, E.M.A. and Kumai, H.: 2000, 'Sources of groundwater recharge at the confluence of the Niles, Sudan', Environmental Geology 39(6), 667-672.

Feng, Q, Cheng, G.D. and Masao, M.R.: 2000, 'Trends of water resource development and utilisation in arid north-west China', Environmental Geology 39(8), 831-838.

Fetter, C.W.: 1994, Applied Hydrogeology, Macmillan, New York, 691p.

Freeze, R.A. and Cherry, J.A.: 1979, Groundwater, Pentice-Hall, Englewood Cliffs, N.J., 604p.

Graniel, C.E., Morris, L.B. and Carrielo-Rivera, J.J.: 1999, 'Effects of urbanisation on groundwater resource of Merida, Yacatan, Mexico', Environmental Geology 37(4), 303-312.

Karaguzel, R., Scholr, R. and Ebel, B.: 1999, 'Hydrogeological investigation of Antalya basin concerning the future domestic water needs of Antalya city (Turkey)', Environmental Geology 38(2), 159-167.

Karanth, K.R.: 1990, Groundwater Assessment, Development and Management, Tata McGraw-Hill Publishing Company Ltd., New Delhi.

Kashef, A.A.I.: 1987, Groundwater Engineering, McGraw-Hill, Singapore, 512p.

Kresic, N.: 1997, Hydrology and Groundwater Modelling, Lewis Publishers, New York, 461p.

Lee, C.H., Lee, H.K. and Lee, J.C.: 2001, 'Hydrogeochemistry of mine, surface and groundwater from the Sanggok mine Creek in the Upper Chungju Lake, Republic of Korea', Environmental Geology 40(4/5), 482-494.

Linsley, R.K., Kohler, M.A. and Pauhlus, J.L.H.: 1975, Hydrology for Engineers, McGraw-Hill, New York, 482p.

Lyle, E.S. Jr.: 1987, Surface Mine Reclamation Manual, Elsevier, New York, 268p.

Maidment, D.R. (editor-in-chief): 1993, Handbook of Hydrology, McGraw-Hill, New York.

Marsily, de, G.: 1986, Quantitative Hydrogeology: Groundwater Hydrology for Engineers, Academic Press, Orlando, 441p.

Rao, R.V.R. and Rao, V.V.: 1985, 'Integrated surveys for groundwater', in B.B.S. Singhal (ed.), Proceedings of the

International Workshop on Rural Hydrology and Hydraulics in Fissured Basement Zones, 15-24 March, 1984, Department of Earth Science, University of Roorkee, India, pp.95-103.

Reddy, M.R., Raju, N.J., Reddy, Y.V. and Reddy, T.V.K.: 2000, 'Water resources development and management in the Cuddapah district, India', Environmental Geology 39(3-4), 342-352.

Singh, V.S., Krishnan, V., Sharma, M.R.K., Gupta, C.P. and Dhar, R.L.: 1999, 'Hydrogeology of limited aquifer in a granitic terrain', Environmental Geology 32(1/2), 90-95.

Soliman, M.M., LaMoreaux, P.E., Memon, B.A., Assaad, F.A. and LaMoreaux, J.W.: 1997, Environemntal Hydrogeology, Lewis Publishers, New York, 386p.

Strack, O.D.L.: 1998, Groundwater Mechanics, Pentice-Hall, Englewood Cliff, N.J., 732p.

Todd, D.K.: 1995, Groundwater Hydrology, John Wiley & Sons, Singapore, 535p.

Tolman, C.F.: 1993, Groundwater, John Wiley & Sons, New York, 530p.

Umar, A. and Ahmad, M.S.: 2001, 'Hydrogeological and hydrogeochemical frameworking of regional aquifer system in Kali-Ganga sub-basin, India', Environmental Geology 40(4/5), 602-611.

Weeks, W.D. and Boughton, W.C.: 1987, 'Test of ARMA model forms for rainfall-runoff modelling', Journal of Hydrology 91, 29-47.

Yang, Y., Lerner, D.N., Barrett, M.A. and Tellam, J.H.: 1999, 'Quantification of groundwater recharge in the city of Nottingham, U.K.,' Environmental Geology 3(3), 183-198.