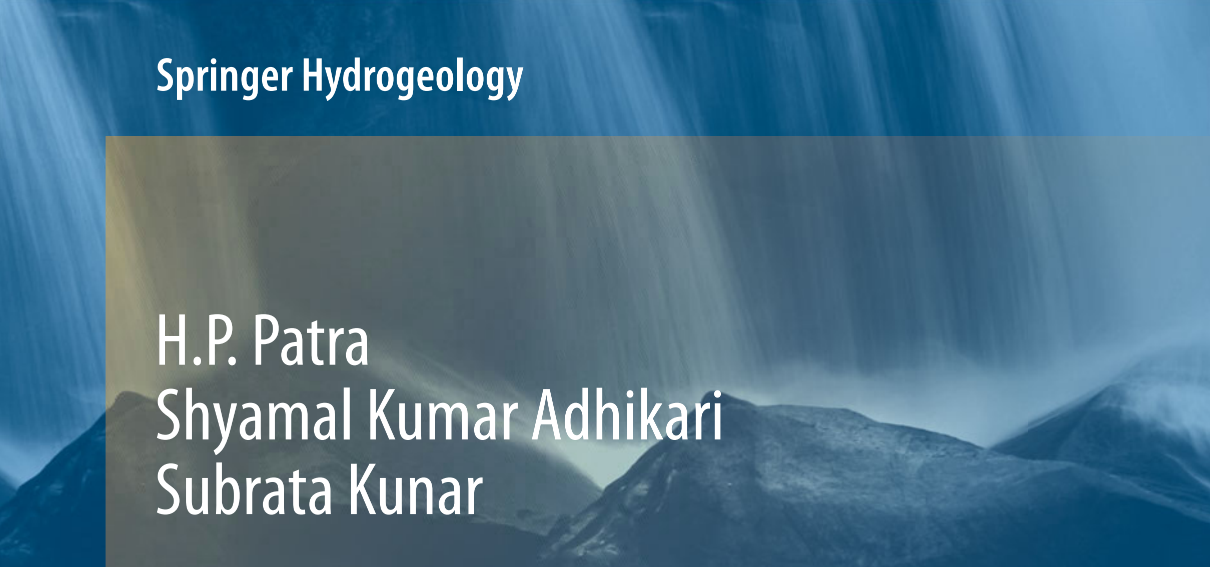

Springer Hydrogeology

H.P. Patra
Shyamal Kumar Adhikari
Subrata Kunar

Groundwater Prospecting and Management

Springer

Springer Hydrogeology

More information about this series at http://www.springer.com/series/10174

H.P. Patra · Shyamal Kumar Adhikari
Subrata Kunar

Groundwater Prospecting and Management

Springer

H.P. Patra
Department of Geology and Geophysics
IIT Kharagpur
Kharagpur, West Bengal
India

Shyamal Kumar Adhikari
Central Ground Water Board
Patna, Bihar
India

Subrata Kunar
RITES Ltd.
Gurgaon, Haryana
India

ISSN 2364-6454 ISSN 2364-6462 (electronic)
Springer Hydrogeology
ISBN 978-981-10-1147-4 ISBN 978-981-10-1148-1 (eBook)
DOI 10.1007/978-981-10-1148-1

Library of Congress Control Number: 2016939105

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer Science+Business Media Singapore Pte Ltd.

Preface

Several books are available in the market on various groundwater development and management issues. The need for a comprehensive book on different practical aspects of groundwater studies has long been felt by geologists, geophysicists, civil and agricultural engineers with an eye to understand the groundwater system and targeting the aquifers under different geologic, terrain and geomorphic conditions.

Use of remote sensing data for a reconnoitre survey for groundwater is almost a routine now. Vertical electrical sounding and seismic refraction surveys in geophysics are used for recommendation of drilling points followed by electrical logging of the boreholes for exact lowering of strainers and subsequent groundwater development. Pumping test after the completion of the well leads to the determination of aquifer parameters and refining assessment of necessary input for design of wells (wells, tube wells and radial collector wells) and yield-drawdown relation. Collection of water samples and its chemical analysis are essential components to understand hydrogeochemistry of groundwater and contamination studies. Further, management of resource, artificial recharge and regulatory legislations are important from the viewpoint of sustained supply of water from aquifers.

Accordingly, Chap. 1 of the book provides introductory aspects of groundwater geology and geophysics followed by remote sensing application in Chap. 2. Chapter 3 extends a brief outline of the concepts, definitions and formulae for use in later chapters (Chap. 6) in determination of aquifer parameters and calculation of yield. Geophysical prospecting methods for groundwater survey are dealt with in Chap. 4, dealing with principles, interpretation and applications of the most useful and relevant techniques. Chapter 5 deals with geophysical well logging techniques and their applications in water wells including some case studies. Chapter 6 gives the procedure to conduct pumping test, interpretation of pumping test data for computation of aquifer parameters, yield and for design of radial collector well followed by an actual ease study. Groundwater quality and contamination aspects are discussed in Chap. 7; Chap. 8 deals with groundwater management, its sustainability and regulation.

Although this book is meant for students, in general, professionals involved in groundwater, engineering geology and environmental science will find it quite useful.

While attempting to incorporate varied topics on each of which books can be written, the present volume renders all aspects of groundwater investigations and management under one cover. In doing so, there may be errors of omission on the part of the author, and therefore, constructive comments and suggestion for improving the value and the utility of the work will be highly appreciated. I am thankful to co-authors S. Kunar, Member, CGWB, and Dr. S.K. Adhikari Scientist, CGWB, for contributing various case studies for different hydrogeological conditions along with present scenario of groundwater legislation and management in India. I am indebted to Prof. Amitabha Chakraborty, Prof. Shankar Kumar Nath and all other members of the staff of the Department of Geology and Geophysics for their interest and support needed for the work.

It is a pleasure to thank the Director of the Institute and Head of the Department of Geology and Geophysics, Indian Institute of Technology Kharagpur for their kind cooperation for the project work. The DST Project (Sanction No. 100/IFD/3374/98-99 dated 11.01.1999) under USERS scheme has been totally funded by the Department of Science and Technology (DST), Government of India, for which the author is extremely grateful.

Kharagpur, India H.P. Patra
Patna, India Shyamal Kumar Adhikari
Gurgaon, India Subrata Kunar
March 2016

Contents

1 Introduction 1
- 1.1 Surface Water and Groundwater 1
- 1.2 Groundwater Geology 2
- 1.3 Groundwater Geophysics 2
- 1.4 Groundwater Exploration 2
- 1.5 Groundwater Development 3
- 1.6 Aquifer Parameters 3
- 1.7 Groundwater Quality and Contamination 4
  - 1.7.1 Groundwater Quality 4
  - 1.7.2 Groundwater Contamination 4
- 1.8 Groundwater Management and Legislation 4
- References 5

2 Remote Sensing in Groundwater Studies 7
- 2.1 General Considerations 7
- 2.2 Remote Sensing 10
- 2.3 Remote Sensing Technique 10
- 2.4 Satellite Image 12
  - 2.4.1 Data 12
  - 2.4.2 Resolution 13
- 2.5 Image Processing 14
  - 2.5.1 Image Interpretation 14
  - 2.5.2 Image Enhancement 15
  - 2.5.3 Image Classification and Generation of Thematic Maps 17
  - 2.5.4 Case Study 18
- 2.6 Applications 20
  - 2.6.1 Surface Water Harvesting 20
  - 2.6.2 Groundwater Exploration 20

2.6.3 Monitoring of Freshwater Submarine Springs 23
2.6.4 Water Table Depths for Aquifers in Deserts 23
2.6.5 Lineaments from IRS LiSS H Satellite Data 24
2.7 Other Geological Applications 26
2.7.1 Geomorphology 26
2.7.2 Geological Mapping 26
2.8 Geographic Information System (GIS) 28
2.8.1 Basic Components of GIS 29
2.9 Application of GIS in Groundwater 30
2.9.1 Groundwater in a Soft Rock Area Through GIS: A Case Study 31
2.10 Integration of Multigeodata for Hard Rock Area: A Case Study 36
2.10.1 Classification 37
2.10.2 Depth to Bed Rock Contour 37
2.10.3 Dar Zarrouk Parameters 39
2.10.4 Vadose Zone Contour 42
References 44

3 Groundwater Geology and Geological Prospecting 47
3.1 Introduction 47
3.2 Hydrologic Cycle 48
3.3 Groundwater in Different Types of Rocks 48
3.3.1 Sedimentary Rocks 48
3.3.2 Igneous and Metamorphic Rocks 49
3.3.3 Carbonate Rocks 49
3.3.4 Volcanic Rocks 49
3.4 Types of Aquifers 49
3.5 Basic Equation on Determination of Aquifer Parameters 50
3.5.1 Steady-State Flow Conditions in an Unconfined Aquifer 50
3.5.2 Unsteady Conditions in Confined and Unconfined Aquifers 50
3.5.3 Cooper–Jacob Method of Determination of T′ and S′ 51
3.6 Water Wells 51
References 51

4 Geophysical Prospecting for Groundwater 53
4.1 General Considerations 53
4.2 Geophysical Methods 54
4.2.1 Choice of Geophysical Methods 58
4.2.2 Surface Geophysical Methods for Fractured Aquifers 59
4.3 Electrical Resistivity Methods 60

4.4 Current Flow in a Homogeneous Earth . . . 63
4.5 Resistivity Measurement . . . 65
4.5.1 Resistivity and Apparent Resistivity . . . 68
4.5.2 Anisotropy in Rocks . . . 68
4.6 Current Flow in a Horizontally Stratified Earth . . . 70
4.7 Schlumberger Apparent Resistivity-Type Curves . . . 71
4.7.1 Two-Layer Curves . . . 71
4.7.2 Three-Layer Curves . . . 71
4.7.3 Four-Layer Curves . . . 72
4.7.4 Asymptotic Values of Schlumberger Curves . . . 73
4.8 Principle of Reduction . . . 78
4.9 Schlumberger Curve Matching with Ebert Charts . . . 80
4.9.1 Ebert Chart Method . . . 82
4.9.2 Interpretation of a Four-layer HK-type Curve . . . 83
4.9.3 Interpretation of a Multilayer HKQ-type Curve . . . 84
4.10 Inversion of Resistivity Data . . . 85
4.11 Resistivity Sounding Case Study . . . 86
4.11.1 Geology of the Area . . . 86
4.11.2 Geosounding Studies and Results . . . 86
4.12 Seismic Measurement . . . 89
4.12.1 Characteristics of Seismic Refraction Method . . . 92
4.12.2 Field Procedures and Instrumentation . . . 94
4.12.3 Corrections to a Datum . . . 97
4.12.4 Interpretation of Refraction Data . . . 98
4.13 Sequential Inversion of Seismic Refraction and Geoelectric Data . . . 100
4.13.1 General Consideration . . . 100
4.13.2 Sequential Inversion . . . 101
4.14 Other Surface Geophysical Methods for Groundwater . . . 102
4.14.1 Electromagnetic Methods . . . 102
4.14.2 Time Domain (Transient) Electromagnetic Method . . . 103
4.14.3 Airborne Electromagnetic Method . . . 107
4.14.4 Electrical Resistivity Tomography . . . 109
4.14.5 Gravity and Magnetic Methods . . . 114
4.15 Some Additional Case Studies . . . 114
4.15.1 Case Studies in Hard Rock Area . . . 114
4.15.2 Case Study from Alluvial Area: Ramkrishna Mission Complex, Narendrapur (West Bengal) . . . 121
4.15.3 Case Studies at Island Coast Little Andaman Island After Tsunami and Earth Quake Calamities . . . 123
References . . . 132

5 Borehole Geology and Well Logging . . . 135
5.1 General Considerations . . . 135
5.2 Geological and Geophysical Log . . . 136

5.3 Logging in Groundwater Development 136
5.3.1 Groundwater Development 137
5.4 Logging in Water Wells 137
5.4.1 SP Logging. 137
5.4.2 Point Resistance Logging 140
5.4.3 Resistivity Logging (Normal and Lateral) 140
5.4.4 Natural Gamma Ray Logging 141
5.4.5 Neutron Log 142
5.4.6 Sonic Log. 142
5.4.7 Gamma–Gamma Ray or Density Log 142
5.4.8 Calliper Log 143
5.4.9 Temperature Log 143
5.5 Case Studies 144
5.5.1 A Case Study in the Lateritic Terrain 144
5.5.2 A Case Study from Coastal Areas of Orissa 146
5.5.3 Resistivity Survey and Correlation of Electrical Logs in Arsenic-Infested Areas of N-24 Parganas (West Bengal) 147
5.5.4 A Case Study in Madhubani Area (Resistivity and Logging) 152
References 157

6 Aquifer Parameters, Pumping Test and the Yield 159
6.1 General Considerations. 159
6.2 Estimation of Permeability, Transmissibility and Storativity (Storage Coefficient). 160
6.3 Pumping Test Analysis and Recovery Test 160
6.3.1 Cooper–Jacobs Straight-Line Method 160
6.3.2 Modified Theis Method 161
6.3.3 Hantush Inflection Point Method 161
6.3.4 Transmissibility from Recovery Test Data. 162
6.3.5 Step-Drawdown Pumping Test 163
6.4 Estimation of Aquifer Properties from Surface Geoelectric Data 164
6.4.1 Theoretical Background 164
6.4.2 Geosounding Measurements: A Case Study. 166
6.5 Pump Test and Design of Radial Collector Well: A Case Study 171
6.5.1 Introduction 171
6.5.2 Geology of the Study Area 171
6.5.3 Aquifer Parameters for Well Design. 172
6.5.4 Determination of Safe Yield of Collector Well 174
6.5.5 Characterization of Aquifer Material. 178

6.6 Design of Collector Well 178
6.6.1 Design on the Basis of 16-h Pumping 180
References 181

7 Groundwater Quality and Contamination 183
7.1 Introduction 183
7.2 Dissolved Salts and Salinity 184
7.3 Groundwater Utilization 184
7.3.1 Groundwater for Drinking (Domestic and Municipal) 185
7.3.2 Groundwater for Irrigation (Agriculture) 185
7.3.3 Groundwater for Industry 186
7.3.4 Groundwater for Protection of Environment 186
7.4 Groundwater Quality and Control 186
7.5 Sources of Groundwater Contamination 187
7.5.1 Municipal and Domestic Sources 187
7.5.2 Agricultural Sources 188
7.5.3 Industrial Sources 188
7.6 Remedial Measures 188
7.7 Arsenic Contamination and a Case Study 189
7.7.1 Arsenic Contamination in Groundwater 189
7.7.2 A Case Study 189
References 195

8 Groundwater Legislation and Management 197
8.1 Introduction 197
8.2 Legal Aspects of Groundwater 198
8.3 Groundwater Legislation 198
8.3.1 Global Scenario in Legislation 199
8.3.2 Indian Scenario in Legislation, Regulation and Control 200
8.4 The Present Scenario 208
8.5 Groundwater Pollution Control in India 209
8.5.1 Contamination Problems 209
8.6 Groundwater Development and Management 210
8.6.1 Groundwater Resource Development 211
8.7 Groundwater Resource Management 212
8.7.1 Groundwater Supply Management 212
8.7.2 Groundwater Demand Management 213
8.8 Groundwater Management Scenario in India 214
8.8.1 Groundwater Development in India 214
8.8.2 Improvement of Groundwater Development Constraints 218
8.8.3 Groundwater Development Strategies 218
References 219

About the Authors

Prof. H.P. Patra graduated with Honours and Distinction in Physics from Bihar University in 1958 and completed Master of Technology degree in exploration geophysics in 1961 and Ph.D. degree in Geophysics from the Indian Institute of Technology Kharagpur in the year 1968. He had been directly engaged in teaching, research and field surveys in electrical and electromagnetic methods of prospecting applied to groundwater from 1961 to 1997. He is the author of several international books from Elsevier, Amsterdam, and Balkema, Amsterdam. These are (i) Direct Current Geo-electric Sounding: Principles and Interpretation, 1968; (ii) Geo-electric Sounding-2: Time–varying Geo-electric sounding, 1980; and (iii) Schlumberger Geo-electric Sounding in Ground Water: Principles, Interpretation and Application, 1999. Dr. Patra retired as Professor of Geophysics and as Head of the Department of Geology and Geophysics, IIT Kharagpur in June 1997.

Dr. Shyamal Kumar Adhikari completed Masters in exploration geophysics from IIT Kharagpur during 1985 and Ph.D. in 2001 from Indian School of Mines, Dhanbad, India. He is serving Central Ground Water Board (CGWB) as geophysicist for more than 28 years having colossal experience in the field of surface and borehole geophysical data acquisition, processing and interpretation by using latest state-of-the-art equipment and software in the field of groundwater geophysics in hard rock terrain, alluvial plain and coastal area. Apart from field investigation, Dr. Adhikari has published several scientific papers in national journals and volumes and presented in different workshops on various topics. He has contributed innumerable number of scientific reports on groundwater exploration in different terrains throughout his career.

Mr. Subrata Kunar graduated with Honours and distinction in Geology from Ranchi University in 1981 and completed Masters of Science in exploration geophysics from IIT Kharagpur during 1985, serving RITES as geophysicist for 30 years at different capacity including three years of service as Member in Central Ground Water Board (CGWB). Mr. Kunar is a life member of various societies and association like Association of Exploration Geophysics, Indian Society of Rock Mechanics and Tunnelling Technology, Indian Society of Engineering Geology, International Association of Hydrogeologist. He has a vast experience in the field of geophysical data acquisition, processing and interpretation with latest state-of-the-art equipment and software in the field of groundwater geophysics in hard rock terrain, alluvial plain and coastal aquifer system and application of geophysical techniques in engineering application. Mr. Kunar has contributed number of technical reports and presented scientific papers in national and international seminars.

List of Figures

Figure 2.1 Spectral characteristics of energy sources, atmospheric effects and sensing system (after Lillesand and Kiefer 1987). **a** Energy sources. **b** Atmospheric transmittance. **c** Common remote sensing system 11
Figure 2.2 Four types of resolution 14
Figure 2.3 Principle of contrast stretch enhancement. **a** Histogram. **b** No stretch. **c** Linear stretch. **d** Histogram stretch. **e** Spatial stretch 16
Figure 2.4 Thematic map of **a** geology and **b** drainage pattern generated from IRS-IB LISS-II data 19
Figure 2.5 Hydrogeomorphological map of Nileshwar basin (after Prasad and Sivaraj 2000) 24
Figure 2.6 Lineament map of Nileshwar basin (after Prasad and Sivaraj 2000) 25
Figure 2.7 The real-world geographics represented as a number of layers or them 28
Figure 2.8 Components of a geographic information system 29
Figure 2.9 Preparation of thematic maps. 30
Figure 2.10 Thematic map of **a** lithounit, **b** geomorphology, **c** soil, **d** drainage density, **e** slope, **f** surface water body of the area 33
Figure 2.11 **a** Thematic map of GWPI model depicting groundwater potential, and **b** locations of boreholes and pumping wells in the study area with available lithosection 35
Figure 2.12 Integrated map showing groundwater potential zones Govind Sagar dam environs, District Lalitpur 38
Figure 2.13 Depth to basement contour map of Goving Sagar dam environs District Lalitpur 39
Figure 2.14 Transverse resistance contour map 40
Figure 2.15 Longitudinal conductance contour map. 41
Figure 2.16 Transverse resistance contour map of vadose zone 42

Figure 2.17 Longitudinal conductance contour map of vadose zone 43
Figure 4.1 Variation of resistivity in different rock types and water 62
Figure 4.2 Point electrodes over a homogenous and isotropic earth. A, B = point source and sink; M, N = observation points on the surface of the earth 65
Figure 4.3 Symmetrical electrode arrangements. *Top* Schlumberger arrangement, *bottom* Wenner arrangement. 66
Figure 4.4 General arrangement for dipole electrical sounding. AB = current dipole; MN = measuring dipole; Q, O = mid-points of current and measuring dipoles 67
Figure 4.5 Various arrangements for dipole sounding. M_{ax} N_{ax} = axial; M_x N_x = Parallel; M_y N_y = perpendicular; M_r N_r = radial; M_Θ N_Θ = azimuthal; M_{Eq} N_{Eq} = equatorial 67
Figure 4.6 A multilayer earth 70
Figure 4.7 Three-layer-type curves. **a** H-type ($\rho_1 > \rho_2 < \rho_3$) and Q-type ($\rho_1 > \rho_2 > \rho_3$). **b** A-type ($\rho_1 > \rho_2 < \rho_3$) and K-type ($\rho_1 < \rho_2 > \rho_3$) 73
Figure 4.8 Nature of four-layer-type curves. **a** HA- and HK-type; **b** QH- and QQ-type; **c** KH- and KQ-type; **d** AA- and AK-type 74
Figure 4.9 Two-layer ascending- and descending-type master curves 75
Figure 4.10 Relation between theoretical and field curves. Field curve of the same form as the theoretical one but shifted with respect to it and parallel to the coordinate axes. 76
Figure 4.11 A two-layer field curve superimposed over a two-layer master curve. Origin of the master curve as read over the field curve gives the thickness and resistivity of the upper layer 77
Figure 4.12 An n-layer prism of unit cross section 79
Figure 4.13 Ebert charts (*A* and *H*) 81
Figure 4.14 Ebert charts (*K* and *Q*) 82
Figure 4.15 Interpretation of four-layer HK-type curve using two-layer master curves and Ebert charts 83
Figure 4.16 Location map of the study area 87
Figure 4.17 Field layout of the resistivity sounding points and wells for pumping test 88
Figure 4.18 VES Curves for the area. 88
Figure 4.19 Fence diagram. 89
Figure 4.20 Block diagram of a seismic refraction system 95

Figure 4.21 Diagrammatic geologic cross section and resulting time–distance curve 96
Figure 4.22 Transmitter current wave form. 104
Figure 4.23 Central loop sounding configuration 104
Figure 4.24 Transient current flow in the ground 104
Figure 4.25 HeliTEM survey operation with transmitter and receivers 107
Figure 4.26 Transient airborne electromagnetic concept: **a** current and electromagnetic field generated during the acquisition; **b** the corresponding curves of the current and measured electromagnetic field. The different steps of a transient AEM sounding are: (*1*) A primary magnetic field is generated by the transmitter loop (figure after T. Munday, CSIRO); (*2*) the current is turned off, which causes generation of eddy currents in the ground; (*3*) the response from the eddy currents is measured by the receiver coil; (*4*) the measured secondary field is further interpreted to get the resistivity distribution of the ground 108
Figure 4.27 SkyTEM sections where *blue colour* shows the higher conductivity/lower resistivity 109
Figure 4.28 Sequence of measurements to build up a pseudo-section using computer-controlled multielectrode survey set-up 110
Figure 4.29 Multielectrode resistivity instrument from IRIS instrument, ABEM Sweeden and Advance Geosciences Inc., USA 111
Figure 4.30 Calculated apparent resistivity pseudo-section 113
Figure 4.31 2D ERT section showing deep saline water-saturated zone. 113
Figure 4.32 2D ERT section to decipher the saturated zone in hilly area 114
Figure 4.33 2D ERT section to decipher the cavernous zone within dolomitic limestone over a tunnel in Himalayan area 114
Figure 4.34 Location Map of Nawapara district 115
Figure 4.35 VES curves in pars of Nawapara district. 116
Figure 4.36 Exploratory borehole proposed through VES survey. 117
Figure 4.37 Mise-La-Masse and gradient profile at exploratory borehole site 117
Figure 4.38 Geoelectric sections based on VES survey in Nawapara district 118
Figure 4.39 Bedrock contour based on VES survey. 119
Figure 4.40 VES location, apparent resistivity contours in Nawapara district 120

Figure 4.41 Fence diagram based on VES sounding results in Nawapara district 121
Figure 4.42 Map showing VES location in Tiger Hill area 122
Figure 4.43 Map showing VES location in Mirik Lake area 123
Figure 4.44 VES curves with processed results in Tiger Hill area 124
Figure 4.45 VES curves with processed results in Mirik Lake area 125
Figure 4.46 VES curves with processed results in alluvium area 126
Figure 4.47 Wenner profile with interpreted section. 127
Figure 4.48 Fence diagram based on VES survey showing disposition of aquifer in alluvium. 127
Figure 4.49 Map showing the geophysical survey area. 128
Figure 4.50 VES curves in the eastern coast of Andaman 129
Figure 4.51 VES curves in the eastern coast of Andaman 130
Figure 4.52 Location plan showing VES point in Little Andaman 131
Figure 4.53 Geoelectric section showing saline and freshwater 131
Figure 4.54 Geoelectric section showing saline and freshwater zone through VES survey. 132
Figure 5.1 Record against shale base line up to the sand line 138
Figure 5.2 A typical SP record showing SP reversal 139
Figure 5.3 Resistivity logging (normal). **a** Two-electrode system; **b** typical normal log. 141
Figure 5.4 Resistivity logging (lateral). **a** Three-electrode system; **b** typical lateral log 141
Figure 5.5 Quaternary geological map of West Bengal and Orissa (location of logging site Salboni) 144
Figure 5.6 Electrical-log (S.P. & Point resistance at Salboni) 145
Figure 5.7 Location map of coastal area of Orissa (Logging site—Podadiha) 146
Figure 5.8 The record presents SP, short (16″) and long (64″) normal resistivities and natural gamma ray counts per second (CPS) 148
Figure 5.9 Borehole location map, North 24 Parganas district, West bengal 149
Figure 5.10 VES curve obtained in Saibona, Barasat 150
Figure 5.11 Fence diagram prepared with geophysical data in and around Saibona, Barasat, North 24, Parganas. 151
Figure 5.12 Correlation of different electrical logs, North 24 Parganas, West bengal 152
Figure 5.13 Location map of geophysically investigated are in Madhubani and Sitamarhi district, Bihar 154
Figure 5.14 Some representative Schlumberger VES curves (Benipatti, Pharchahia, Sonbarsa, Dharampur & Tulsiahi) in parts of Madhubani & Sitamari district, Bihar 154

Figure 5.15 Geoelectric section in parts of Madhubani district Bihar . . . 155
Figure 5.16 Vertical electrical sounding versus electrical log interpretation of drilling site at Khajidi, Madhubani district, Bihar . . . 156
Figure 5.17 Vertical electrical sounding versus electrical log interpretation of drilling site, Khluahi, Madhubani district, Bihar . . . 157
Figure 6.1 **a** Geology of the area based on remote sensing data and **b** location map of different sites in the study area . . . 167
Figure 6.2 VES curves processed through EP . . . 168
Figure 6.3 A plot of aquifer parameters versus geoelectric parameters . . . 170
Figure 6.4 Layout plan of observation wells . . . 173
Figure 6.5 Pumping test output data at Edilpur, Burdwan well site E1. . . . 174
Figure 6.6 Pumping test output data at Edilpur, Burdwan well site E2. . . . 175
Figure 6.7 Pumping test output data at Edilpur, Burdwan well site W1 . . . 176
Figure 6.8 Pumping test output data at Edilpur, Burdwan well site S2. . . . 177
Figure 6.9 **a** Sectional elevation and **b** plan showing position of strainers . . . 179
Figure 7.1 Map of arsenic-affected areas in part of Bengal basin and potential surface. *AMJ* Amjhore pyrite mine, *CL* Calcutta, *CU* Copper belt Bihar, *DH* Diamond Harbour, *DG* Digha, *DK* Dhaka, *GH* Ghetugachi, *M* Malda, *R* Rajmahal Hills, *RN* Raninagar, *SG* Son Valley gold belt, *SM* Samthar, *SR* Sirajganj . . . 191
Figure 7.2 Arsenic toxicity in Bangladesh extends up to Sylhet basin . . . 192
Figure 7.3 Lithology inferred from groundwater drilling and heavy mineral studies . . . 194
Figure 8.1 Block diagram outlining groundwater management approach. . . . 211

List of Tables

Table 2.1 Assigned weightage for the layers. 34
Table 4.1 Electrical resistivity for different rock types 62
Table 4.2 Average velocities of longitudinal waves within some common geological formations (after Jakosky 1957) 91
Table 4.3 Exploratory drilling recommendations with proposed depth 125
Table 4.4 Standardized resistivity for alluvium soil in Narendrapur, West Bengal 126
Table 4.5 Standardized resistivity's for different formations in Andaman. 130
Table 5.1 Standardized range of resistivity for alluvium soil in N-24 Parganas 150
Table 5.2 Interpreted electric log results with arsenic values in vertical sections in North 24 Parganas District, West Bengal 153
Table 5.3 Standardized resistivity for alluvium soil in Madhubani District, Bihar 155
Table 6.1 Aquifer parameters from six selected well sites 169
Table 8.1 States/UTs where legislation enacted and being implemented 203
Table 8.2 States/UTs which have initiated action for preparing legislation 204
Table 8.3 States/UTs which feel it not necessary to enact legislation 206
Table 8.4 State-wise groundwater resource availability, utilization and categorization of assessment units in India (in bcm) 215

Chapter 1
Introduction

Abstract To have a reasonable equitable water distribution of groundwater, a planned approach for exploration, exploitation and management of water is required. General groundwater geology also must be well understood for exploration and exploitation in a particular area. The exploration is mainly done by geophysical investigation which is based on the physical properties of the earth formations. The electrical method of prospecting is most useful process for surface groundwater exploration. For subsurface, geophysical well-logging technique is very much useful because the data are closed to the borehole wall. For designing a well, the aquifer characteristics are required to be known with the help of pump tests. The water quality should be studied with different analysis before drinking. Though there is plenty of water in global scale, the shortage of water is observed in local scale. Hence, management planning of water in respect of demand and supply is very much important to meet the water requirement for present generation and future generation.

Keywords Groundwater · Exploration · Planned approach · Electrical method · Geophysical logging · Water quality · Management planning

1.1 Surface Water and Groundwater

At present (year 1999), the world's annual water requirement is more than 4500 km^3 (Wolff 1999). The total renewable water resource of the world is about 39,000 km^3 annually. Thus, there cannot be any water shortage on a global basis as the water is replenished through annual precipitation. The available resource is unevenly distributed, and therefore, sufficient water is not necessarily available in populated areas. Accordingly, water shortage does occur alarmingly depending on regional water balance, controlled largely by climate, altitude, soil composition and vegetation and mainly by precipitation. In order to have a reasonably equitable distribution, groundwater is used in conjunction with surface water. While surface water is easily available, groundwater needs a planned approach for exploration, exploitation and management for a sustained supply for proper utility.

H.P. Patra et al., *Groundwater Prospecting and Management*,
Springer Hydrogeology, DOI 10.1007/978-981-10-1148-1_1

1.2 Groundwater Geology

Groundwater geology must be well understood for economic exploitation of subsurface water. Various aspects of groundwater have been treated in all textbooks on hydrology. The objective of this section is only to mention some useful factors needed for groundwater exploitation programmes. The programme comprises surface and subsurface investigations. Surface investigations are primarily used for establishing the geology of the area, giving distribution of geological formation on a map. The present approach is to prepare the map from satellite imagery data followed by essential ground checks. Once the geological map of the area is available, subsurface data regarding existence of sandy zones at different depths are collected from existing boreholes, if any. From the borehole samples, then, an idea can be made about porosity and permeability of the sands and their utility as an aquifer, in sedimentary areas. In hard rock areas, joints, fractures, fissures and cracks are to be located on the map after a study of lineation and fault traces. The background information obtained for groundwater geology is utilized in planning the prospecting programmes for groundwater.

1.3 Groundwater Geophysics

One has to depend on exploration geophysics for identification of different geological formations expected to be encountered in the subsurface. The subsurface lithology inferred through geophysics is controlled largely by the physical properties of the earth formations. The physical properties, e.g. density, conductivity and seismic wave velocity, of a water-saturated formation are dependent on distribution of grain size and quality of the water saturating the formation (e.g. sand or clay). In case of electrical conductivity or resistivity of a formation, electrolytic property of water plays an important role. The resistivity of the unit helps in the recognition of sand or clay from the likely formations.

This differentiation is possible through geophysical measurements from the surface (see, Chap. 4). Identification of formations can also be made through geophysical logging within the borehole (see, Chap. 5).

1.4 Groundwater Exploration

Of the various surface geophysical methods of prospecting, namely gravity-magnetic, seismic and electrical methods, only electrical method, based on the measurement of the electrical resistivity of subsurface formation, is most useful for exploring groundwater.

Electrical exploration for groundwater is based on the flow of direct current introduced into the earth and subsequent measurement of potential distribution on the surface. This gives an apparent resistivity, analysis of which gives resistivities of various layers leading to identification of the formations with depth. This is known as electrical resistivity method universally accepted as an ideal geophysical tool for groundwater exploration.

The theoretical aspects mainly of electrical resistivity method giving its principles, interpretation approaches and applications under varying geological situation are given, in detail, in Chap. 4.

1.5 Groundwater Development

Subsurface geophysical methods referred to as well-logging methods (Chap. 5) are essential tools in groundwater development. Surface geophysical method helps in locating the point suitable for drilling. Once the borehole is drilled, a suitable sensor is lowered to the bottom of the borehole and certain physical properties are recorded during upward uniform run of the sensor. The record of any characteristic physical property of the formations is known as geophysical log. Geophysical logs help in understanding the hydrology of the area clearly as the strata chart prepared from mixed-up drilling samples is not sufficiently reliable. While the logs are used for stratigraphic correlation from well to well, these may be used for the detection of bed boundaries, porous and permeable zones and saline water-bearing zones, having a strong bearing in groundwater supply and development. The thickness of porous and permeable zones and their lateral extent obtained from geophysical logs help in fixing spacing of wells and subsequent yield of wells.

1.6 Aquifer Parameters

The various important aquifer characteristics must be known for design of wells, tube wells and radical collector wells. These parameters are as follows: permeability (measure of hydraulic conductivity), transmissibility (transmissivity) and storage coefficient (storativity). In order to evaluate these parameters, pumping test is to be carried out after the completion of the tube well. Pumping test data are processed through different available methods (compatible to the geological conditions), and the values of transmissivity, hydraulic conductivity and storativity are estimated. Recovery test data also give transmissivity.

The values are utilized in the design of wells and in computation of yield from the wells. Aquifer parameters and their utility are outlined in Chap. 6.

1.7 Groundwater Quality and Contamination

1.7.1 Groundwater Quality

It is well known that the vast groundwater resource available on global basis is more than sufficient for providing good quality water to the world community. But for the want of even distribution, shortages do occur locally and seasonally, controlled largely by precipitation.

Besides, due to dissolved minerals present in the groundwater, it is sometimes brackish or saline and rich in iron content (more than 0.3 ppm). Such a water is of bad quality for drinking purposes.

For water to be suitable for drinking, a routine physical, chemical and biological analysis should be made. The water quality parameters which should be studied are as follows: pH, total dissolved salt (TDS), total hardness, turbidity; iron, arsenic, fluoride, calcium, magnesium, nickel, copper, lead and chloride; nitrate besides coliform bacteria. The parameters should be well within the prescribed international standards (see Todd 1995, pp. 277–282).

1.7.2 Groundwater Contamination

Our natural groundwater resources of mostly high quality are being contaminated gradually with time through domestic, agricultural and industrial pollutants releasing wastewater. Groundwater pollution is caused by human use of water and disposal of wastes into the ground. Without population and pollution control, the amount of per capita safe water available for use is gradually reducing with time. Although groundwater is replenishable, it is not inexhaustible.

Recently, arsenic contamination of groundwater has been detected around various parts of the world. World Health Organization (WHO) has compiled reports on cases of arsenic in drinking water in countries, e.g. Argentina, Bangladesh, China, Chile, Ghana, Hungary, India, Mexico, Thailand and USA. Arsenic is referred to as a toxic material and of environmental concern along with other three big metals, namely lead, mercury and cadmium. The presence of fluoride in groundwater is harmful due to its toxicity.

Attention should, therefore, be drawn to all such harmful contaminants in order to protect the environment.

1.8 Groundwater Management and Legislation

Statistics show the existence of sufficient amount of fresh groundwater resources on global scale. Depending on rainfall, climate, altitude, vegetation, etc., however, there is a large-scale shortage of water on regional and/or local scale. Without population