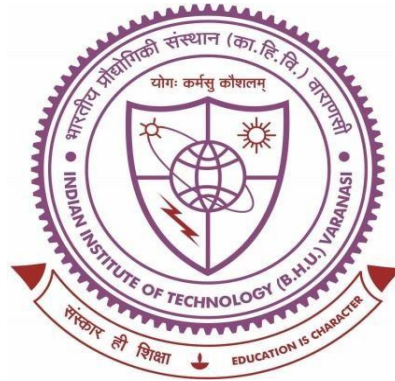


**DEVELOPMENT OF 1-D INVERSION ALGORITHM FOR
GEOELECTRICAL DATA AND APPLICATION OF
GEOELECTRICAL AND GIS FOR GROUNDWATER STUDY
IN SINGRAULI COALFIELD REGION, M.P, INDIA**



**Thesis submitted in partial fulfillment for the
Award of Degree**

Doctor of Philosophy

By

Dharmendra Kumar Singh

**DEPARTMENT OF MINING ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
(BANARAS HINDU UNIVERSITY)
VARANASI – 221005**

Roll no- 15151502

2023

Dedicated

to

My Dear Parents

Satya Narayan and Manju Devi

CERTIFICATE

It is certified that the work contained in the thesis titled " **Development of 1-D inversion algorithm for Geoelectrical data and application of Geoelectrical and GIS for groundwater study in Singrauli coalfield region, M.P, India**" by "Dharmendra Kumar Singh (Roll No. 15151502) has been carried out under my supervision and that this work has not been submitted elsewhere for the award of any degree or diploma.

It is further certified that the student has fulfilled all the requirements of the Comprehensive Examination, Candidacy, State of Art seminar, and Open seminar for the award of Ph.D. Degree.

N. Kishore
01/06/2023

Dr. Nawal Kishore

(Supervisor)

Department of Mining Engineering
Indian Institute of Technology (BHU)
VARANASI-221005

DR. NAWAL KISHORE
ASSISTANT PROFESSOR
DEPARTMENT OF MINING ENGINEERING
IIT-BHU, VARANASI (U.P.)-221005

DECLARATION BY THE CANDIDATE

I, **Dharmendra Kumar Singh**, certify that the work embodied in this thesis is a bonafide research work carried out by me, under the supervision of **Dr. Nawal Kishore** from **December-2015 to June-2023**, at the Department of Mining Engineering, Indian Institute of Technology (BHU) Varanasi. The matter embodied in this thesis has not been submitted elsewhere for the award of any other degree or diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not will fully copied any other's work, paragraphs, text, data, results, etc., reported in journals, books, magazines, reports, dissertations, theses, etc., or available at websites and have not included them in this thesis and have not cited as my own work.

Date: 1.06.2023

Place: IIT (BHU) Varanasi

Dharmendra Kumar Singh

(Dharmendra Kumar Singh)

CERTIFICATE BY THE SUPERVISORS

It is certified that the statement made above by the student is correct to the best of our knowledge.

N. Kishore
01/06/2023

Dr. Nawal Kishore
(Supervisor)

Department of Mining Engineering
Indian Institute of Technology
Banaras Hindu University
Varanasi-221005

Dr. NAWAL KISHORE
ASSISTANT PROFESSOR
DEPARTMENT OF MINING ENGINEERING
IIT-BHU, VARANASI (U.P.)-221005

Suprakash Gupta

Prof. Suprakash Gupta
(Head of Department)

Department of Mining Engineering
Indian Institute of Technology
Banaras Hindu University
Varanasi-221005

विभागाध्यक्ष/HEAD
खनन अभियंत्रिकी विभाग
Dept. of Mining Engg.
भारतीय प्रौद्योगिकी संस्थान (बनारस हिन्दू विश्वविद्यालय)
Indian Institute of Technology (Banaras Hindu University)
वाराणसी-221005/Varanasi-221005

COPYRIGHT TRANSFER CERTIFICATE

Title of the Thesis: Development of 1-D inversion algorithm for Geoelectrical data and application of Geoelectrical and GIS for groundwater study in Singrauli coalfield region, M.P, India.

Name of the Student: Dharmendra Kumar Singh

Copyright Transfer

The undersigned hereby assigns to the Indian Institute of Technology (Banaras Hindu University) Varanasi all rights under copyright that may exist in and for the above thesis submitted for the award of the **DOCTOR OF PHILOSOPHY**.

Date: 1.06.2023

Place: IIT (BHU) Varanasi, India

Dharmendra kr Singh

Dharmendra Kumar Singh .

Note: However, the author may reproduce or authorize others to reproduce material extracted verbatim from the thesis or derivative of the thesis for the author's personal use provided that the source and the Institute's copyright notice are indicated.

ACKNOWLEDGEMENTS

Though words are seldom sufficient to express gratitude and feelings, it gives me an opportunity to acknowledge those who helped me during the course of my study.

*First of all, I bow with reverence to thank the **ALMIGHTY** who has enriched me with such a golden opportunity and infused the power in my mind to fulfill the task assigned to me. It is definitely a pleasing privilege for me to express my insightful gratefulness to **Mahamana Pandit Madan Mohan Malviya ji**, founder of this beautiful temple, Banaras Hindu University, and whose creation of this serene varsity gave me a perfect environment and facility to carry out this research work during my education.*

*I wish to express my deepest gratitude and indebtedness to my revered supervisor **Dr. Nawal Kishore**, Assistant Professor, Department of Mining Engineering, Indian Institute of Technology (Banaras Hindu University), Varanasi, for his constant support, kind encouragement, immensely valuable ideas, suggestions and for having unwavering attention. I have been amazingly fortunate to have a supervisor who gave me the freedom to explore on my own and at the same time the guidance to recover when my steps faltered. I shall remain indebted to him for his confidence in my work and most importantly for his kind affection during my Doctoral research. Simply his contribution is beyond the preview of acknowledgments and I feel very much honored and it has been a real privilege for me to get an opportunity to work under him, a teacher par excellence.*

*I render my sincere thanks to Prof. **Suprakash Gupta**, Head, Dept. of Mining Engineering, IIT BHU for giving me an opportunity to become a scholar of this esteemed department and for providing the necessary amenities required for my research work.*

*I acknowledge my Research Progress Committee (RPC) members, **Prof. Aarif Jaml**, Internal Subject Expert, and Assistant Professor **Dr. Kesheo Prasad**, External Subject Expert, Department of Civil Engineering, IIT-BHU.*

My parents have been a strong pillar of support for me and my research wouldn't have seen the day's light without their constant motivation. I owe them a lot. Thanks to my mother for being my rock and helping me in touch with reality throughout my life.

*Words fail to express my immense appreciation for my loving wife **Dr.Km Meena**, who has been a constant source of priceless love, moral motivation, and emotional support to me.*

Finally, I would like to thank everybody who was important in the successful realization of this thesis, as well as expressing my apology that I could not mention them personally one by one.

Date: 01/06/2023

Place: IIT(BHU), Varanasi

Dharmendra Kumar Singh
(Dharmendra Kumar Singh)

LIST OF FIGURES

	Titles	Page No.
Figure 1.1	Distribution of Earth's water (Gleick, 1993).	5
Figure 1.2	Distribution of groundwater (Bowen, 1928)	6
Figure 1.3	Geographical distributions of the various categories of assessment units.	11
Figure 1.4	Spatial distribution of depth to Groundwater level (a) During Pre-Monsoon, May 2012 (b) During Post-Monsoon, Nov 2012	15
Figure 3.1	Location map of the study area	62
Figure 3.2	Geological map of the study area	63
Figure 3.3	Drainage map of the study area	73
Figure 3.4	(a) Lithology of the test boreholes, (b) Lithology of observation boreholes	75
Figure 4.1	Electromagnetic spectrum and the photon energy of visible light (Jensen 2004).	80
Figure 4.2	Curves of Spectral reflectance of some selected objects (Singhal and Gupta, 1999).	81
Figure 4.3	Geomorphology map of the study	83
Figure 4.4	Slope map of the study area	87
Figure 4.5	Digital elevation model (DEM) of the study area.	88
Figure 4.6	Drainage map of the study area.	90
Figure 4.7	Lineament map of the study area.	91
Figure 4.8	Lineament density map of the study area.	93
Figure 4.9	Land use and land cover map of the study area	94
Figure 4.10	Impact of mining on water table (Llavina Pascual et al., 2013).	96
Figure 4.11	The methodology adopted for carrying out the research (Tiwari et al., 2016).	97
Figure 4.12	Sensor-based Electric water level probes	98
Figure 4.13	Location map of monitoring dug wells.	100
Figure 4.14	Spatial groundwater level variation map during the pre-monsoon season.	101

Figure 4.15	A map showing spatial variation in water level during the monsoon season.	103
Figure 4.16	Spatial groundwater level variation map during the post-monsoon season	104
Figure 4.17	Water level fluctuation (WLF) map for the year 2021	106
Figure 4.18	Geological map of the Singrauli coalfields.	108
Figure 5.1	Schlumberger electrode configurations (Telford et al. 1976).	113
Figure 5.2	General flow chart of Genetic Algorithm (GA).	117
Figure 5.3	Inversion of the three-layer model.	134
Figure 5.4	Inversion of Four-layer model.	135
Figure 5.5	Inversion of Five-layer model.	136
Figure 5.6	Inversion of Published data (VES-1).	137
Figure 5.7	Inversion of Published data (VES-2).	138
Figure 5.8	Inversion of Published data (VES-3).	139
Figure 5.9	Inversion of Published data(VES-4).	139
Figure 5.10	Inversion of Published data(VES-5).	140
Figure 5.11	Location of VES station.	141
Figure 5.12	Inversion of VES-1.	142
Figure 5.13	Inversion of VES-2.	143
Figure 5.14	Inversion of VES-3.	144
Figure 5.15	Inversion of VES-4.	145
Figure 5.16	Inversion of VES-5.	146
Figure 5.17	Inversion of VES-6.	147
Figure 5.18	Inversion of VES-7.	148
Figure 5.19	Inversion of VES-8.	149
Figure 5.20	Inversion of VES-9.	150
Figure 5.21	Inversion of VES-10.	151
Figure 5.22	Inversion of VES-11.	152
Figure 5.23	Inversion of VES-12.	153
Figure 5.24	Inversion of VES-13.	154
Figure 5.25	Inversion of VES-14.	155
Figure 5.26	Inversion of VES-15.	156

Figure 5.27	Inversion of VES-16.	157
Figure 5.28	Inversion of VES-17.	158
Figure 5.29	Inversion of VES-18.	159
Figure 5.30	Inversion of VES-19.	160
Figure 5.31	Inversion of VES-20.	161
Figure 5.32	Inversion of VES-21.	162
Figure 5.33	Inversion of VES-22.	163
Figure 5.34	Inversion of VES-23.	164
Figure 5.35	Inversion of VES-24.	165
Figure 5.36	Inversion of VES-25.	166
Figure 5.37	Inversion of VES-26.	167
Figure 5.38	Inversion of VES-27.	168
Figure 5.39	Inversion of VES-28.	169
Figure 5.40	Inversion of VES-29.	170
Figure 5.41	Inversion of VES-30.	171
Figure 5.42	Inversion of VES-31.	172
Figure 5.43	Inversion of VES-32.	173
Figure 5.44	Inversion of VES-33.	174
Figure 5.45	Inversion of VES-34.	175
Figure 5.46	Inversion of VES-35.	176
Figure 5.47	Inversion of VES-36.	177
Figure 5.48	Inversion of VES-37.	178
Figure 5.49	Inversion of VES-38.	179
Figure 5.50	Inversion of VES-39.	180
Figure 5.51	Inversion of VES-40.	181
Figure 5.52	Inversion of VES-41.	182
Figure 5.53	Inversion of VES-42.	183
Figure 5.54	Inversion of VES-43.	184
Figure 5.55	Inversion of VES-44.	185
Figure 5.56	Inversion of VES-45.	186
Figure 5.57	Inversion of VES-46.	187
Figure 5.58	Inversion of VES-47.	188

Figure 5.59	Inversion of VES-48.	189
Figure 5.60	Inversion of VES-49.	190
Figure 5.61	Inversion of VES-50.	191
Figure 5.62	Inversion of VES-51.	192
Figure 5.63	Inversion of VES-52.	193
Figure 5.64	Inversion of VES-53.	194
Figure 5.65	Inversion of VES-54.	195
Figure 5.66	Inversion of VES-55.	196
Figure 6.1	A regular shape cylinder	199
Figure 6.2	A potential source kept at the surface of the layered earth.	204
Figure 6.3	Current flow from a single source electrode (Telford et al., 1976).	209
Figure 6.4	Two current and two potential electrodes on the surface of homogeneous isotropic ground of resistivity (Telford et al. 1976).	209
Figure 6.5	(a) Symmetrical electrode arrangement of Wenner array, (b) Schlumberger array (Telford et al. 1976).	212
Figure 6.6	Layered model showing longitudinal conductance (S) and transverse resistance (T).	214
Figure 6.7	Electrical resistivity ranges for some common rocks, soils, and ores.	221
Figure 6.8	Resistivity meter (IGIS SSR-MP-ATS).	222
Figure 6.9	VES data acquisition in the Singrauli Coalfield region.	227
Figure 6.10	Investigation Map of resistivity survey of the study area.	229
Figure 6.11	(a) Location Map of villages around Gorbi mines. (b) Map of VES location in villages around Gorbi mines.	230 230
Figure 6.12	(a) Lithologic log of borehole BH-4. (b) Correlation of VES-9 interpreted depth and borehole (BH-4) depth.	232
Figure 6.13	(a) Lithologic log of borehole BH-11. (b) Correlation of VES-10 interpreted depth and borehole (BH-11) depth.	234
Figure 6.14	(a) Lithologic log of borehole BH-8. (b) Correlation of VES-40 interpreted depth and borehole (BH-8) depth.	235

Figure 6.15.	Geoelectrical cross-section along profile A-A'.	239
Figure 6.16	Geoelectrical cross-section along profile B-B'.	240
Figure 6.17	Geoelectrical cross-section along profile C-C'.	242
Figure 6.18	Geoelectrical cross-section along profile D-D'.	243
Figure 6.19	Geoelectrical cross-section along profile E-E'.	245
Figure 6.20	(a-f) Iso-apparent resistivity Contour maps and 3D Surface maps	249-254
Figure 6.21.	Overburden Isopach Map (a) 2D Contour map of the overburden thickness,(b) 3D Surface map of overburden thickness.	258
Figure 6.22	Total Transverse resistance (T) Map (a) 2D contour map of T ,(b) 3D surface map T .	260
Figure 6.23	Total longitudinal conductance (S) map (a) 2D Contour map of S ,(b) 3D surface map of S .	262
Figure 6.24.	Total longitudinal Resistivity (ρ_l) map (a) 2D Contour map of (ρ_l), (b) 3D Surface map of (ρ_l).	264-265
Figure 6.25	Total Transverse Resistivity (ρ_t) Map (a) 2D Contour map of (ρ_t), (b) 3D Surface map of (ρ_t).	266
Figure 6.26	Map of Coefficient of Anisotropy (λ) (a) 2D Contour map of (λ), (b) 3D Surface map of (λ).	268

LIST OF TABLES

	Titles	Page No.
Table 3.1.	Stratigraphic succession of the Singrauli coalfields (after GSI unpublished report)	64
Table 4.1:	Land use/ Land cover classification scheme used in the study area.	95
Table 5.1	Some analogies between biological evolution and Genetic Algorithms	116
Table 5.2	Result of the Three-layer model	133
Table 5.3	Result of four layers model	134
Table 5.4	Result of the five-layer model	135
Table 5.5	Result of VES-1	137
Table 5.6	Result of VES-2	138
Table 5.7	Result of VES-3	138
Table 5.8	Result of VES-4	139
Table 5.9	Result of VES-5	140
Table 5.10	Result of VES-1	142
Table 5.11	Result of VES-2	143
Table 5.12	Result of VES-3	144
Table 5.13	Result of VES-4	145
Table 5.14	Result of VES-5	146
Table 5.15	Result of VES-6	147
Table 5.16	Result of VES-7	148
Table 5.17	Result of VES-8	149
Table 5.18	Result of VES-9	150
Table 5.19	Result of VES-10	151
Table 5.20	Result of VES-11	152
Table 5.21	Result of VES-12	153
Table 5.22	Result of VES-13	154
Table 5.23	Result of VES-14	155
Table 5.24	Result of VES-15	156
Table 5.25	Result of VES-16	157

Table 5.26	Result of VES-17	158
Table 5.27	Result of VES-18	159
Table 5.28	Result of VES-19	160
Table 5.29	Result of VES-20	161
Table 5.30	Result of VES-21	162
Table 5.31	Result of VES-22	163
Table 5.32	Result of VES-23	164
Table 5.33	Result of VES-24	165
Table 5.34	Result of VES-25	166
Table 5.35	Result of VES-26	167
Table 5.36	Result of VES-27	168
Table 5.37	Result of VES-28	169
Table 5.38	Result of VES-29	170
Table 5.39	Result of VES-30	171
Table 5.40	Result of VES-31	172
Table 5.41	Result of VES-32	173
Table 5.42	Result of VES-33	174
Table 5.43	Result of VES-34	175
Table 5.44	Result of VES-35	176
Table 5.45	Result of VES-36	177
Table 5.46	Result of VES-37	178
Table 5.47	Result of VES-38	179
Table 5.48	Result of VES-39	180
Table 5.49	Result of VES-40	181
Table 5.50	Result of VES-41	182
Table 5.51	Result of VES-42	183
Table 5.52	Result of VES-43	184
Table 5.53	Result of VES-44	185
Table 5.54	Result of VES-45	186
Table 5.55	Result of VES-46	187
Table 5.56	Result of VES-47	188
Table 5.57	Result of VES-48	189

Table 5.58	Result of VES-49	190
Table 5.59	Result of VES-50	191
Table 5.60	Result of VES-51	192
Table 5.61	Result of VES-52	193
Table 5.62	Result of VES-53	194
Table 5.63	Result of VES-54	195
Table 5.64	Result of VES-55	196
Table 6.1	Resistivity ranges for different lithological units	237
Table 6.2	Apparent resistivity(ohm-m) at half the current electrode distance(AB/2).	247
Table 6.3	Overburden thickness (H) and Dar-Zarrouk parameters (S, T, ρ_1, ρ_t, λ)	256
Table 6.4	Longitudinal Conductance/Protective capacity rating (Oladapo and Akintorinwa, 2007)	263
Table 6.5	Identification of Aquifers and Recommendation for tube wells/dug wells	270

LIST OF ABBREVIATIONS/SYMBOLS

GA	Genetic Algorithm
DC	Direct current
VES	Vertical Electrical Sounding
NRSA	National Remote Sensing Agency
LULC	Land use/Land cover
GEC	Groundwater Estimation Committee
NITI	National Institution for Transforming India
BCM	Billion cubic meters
CGWB	Central Ground Water Board
mbgl	meters below ground level
GIS	Geographic information system
NCL	Northern Coalfields Ltd
STPS	Super thermal power plants
CPCB	Central Pollution Control Board
CMPDIL	Central Mine Planning & Design Institute Limited
AVO/AVA	Amplitude Versus Offset/Angle
TDS	Total Dissolved Solids
MCM	million cubic meters
CRD	cumulative rainfall departure
ERT	Electrical Resistivity Tomography

K	Hydraulic conductivity
S	Total longitudinal unit conductance
T	Total transverse unit resistance
GSI	Geological Survey of India
MECL	Mineral Exploration Corporation Limited
EM	Electromagnetic energy
SRTM	Shuttle Radar Topography Mission
DEM	Digital elevation model
SOI	Survey of India
amsl	above Mean Sea Level
SGA	Simple Genetic Algorithm
RRMSE	Relative Root Mean Square Error
GLS	Generalized least squares
SADE	Self-adaptive differential evolution
CRS	Common Reflection Surface
GBM	Ganges-Brahmaputra-Meghna
Wd	Weathered,
S.St	Sandstone
λ	Coefficient of anisotropy
BH	Borehole