

Table of contents

Title	Page No.
<i>Certificates</i>	ii-iv
<i>Acknowledgement</i>	v-vi
<i>Table of contents</i>	vii-xii
<i>List of figures</i>	xiii-xvii
<i>List of tables</i>	xviii-xix
<i>List of Abbreviations and Symbols</i>	xx-xxi
<i>Preface</i>	xxii-xxiii
<i>Abstract</i>	xxiv-xxvi
Chapter-1 Introduction	1-20
1.1 General	1
1.2 Coal in India	4
1.2.1 Coal production	7
1.2.2 Coal despatches	8
1.2.3 Coal reserves	8
1.3 Rare earth elements (REEs)	10
1.4 Global distribution of REEs in coal	15
1.5 Distribution of REEs in Indian coal	17
1.6 Statement of the problem	17
1.7 Research Objectives	18
Chapter-2 Overview of the study area	21-47
2.1 Introduction	21
2.2 Physiography and Drainage	27
2.3 Rainfall and climate	28
2.4 Soils	29
2.5 Geological Settings	29
2.6 General geology of Son-valley	31

2.7 Stratigraphy of Sohagpur coal measures	43
2.7.1 Talchir formations	44
2.7.2 Barakar formations	44
2.7.3 Barren measures	46
2.7.4 Raniganj formations	46
2.8 Brief description of Dhanpuri opencast mine	47
Chapter-3 Review of Literature	48-69
3.1 Previous works	48
3.2 Research gap	68
Chapter-4 Methods of study	70-100
4.1 Introduction	70
4.2 Methods of coal sampling	72
4.3 Crushing of coal samples	72
4.4 Sample preparation	74
4.5 Geochemical analysis	75
4.6 Proximate analysis	75
4.6.1 Moisture	75
4.6.2 Volatile matter	76
4.6.3 Ash	77
4.6.4 Fixed Carbon	78
4.7 Ultimate analysis	79
4.8 Gross calorific value (GCV)	80
4.9 X-ray diffraction (XRD)	81
4.10 Scanning electron microscope with energy dispersive x-ray analysis	82
4.11 Fourier transform infrared spectroscopy	84
4.12 Inductive coupled plasma mass spectroscopy	87
4.13 Leaching experiment on sample (Experiment 1 - Slow method)	88
4.13.1 Materials	88
4.13.2 Experimental methods	88

4.13.3 Standard test method	91
4.13.4 Analysis method	92
4.14 Leaching experiments on samples (Experiment 2 - Fast method)	93
4.14.1 Materials	93
4.14.2 Calcination of samples	94
4.14.3 Experimental methods	94
4.14.4 Acidic and basic leaching experiments	97
4.14.5 Analysis method	97
4.14.6 Experiment samples	98
4.15 Factors affecting leaching	99
4.16 Statistical data calculation	99
Chapter-5 Megascopic analysis of coal	101-108
5.1 Introduction	101
5.2 Sapropelic coal	101
5.3 Banded or Humic coal	102
5.3.1 Vitrain	102
5.3.2 Clarain	102
5.3.3 Durain	104
5.3.4 Fusain	105
5.4 Origin of bands in coal	105
5.5 Diessel's classification of coal	106
5.6 Macroscopically seam profile	106
Chapter-6 Geochemical Characterization of coal	109-134
6.1 Introduction	109
6.2 Proximate analysis	110
6.3 Moisture	114
6.4 Ash	114
6.5 Volatile matter	117
6.6 Fixed carbon	117

6.7 Gross calorific value of coal	117
6.8 Distribution of proximate constituents	119
6.9 Ultimate analysis	121
6.10 Trace element	123
6.11 X-ray diffraction study	124
6.12 Fourier transform infrared (FTIR) spectroscopy	126
6.13 Scanning electron microscopic with elemental distribution concentration(SEM with EDX)	130
Chapter-7 Rare earth elements (REEs) in coal	135-149
7.1 Introduction	135
7.2 Occurrence of REEs in coal	137
7.3 Characteristics of coal ash	143
7.4 Enrichment of REEs in coal ash	144
7.5 Significance of REEs concentration in coal and it's by products	145
7.6 Pearson coefficient correlation between rare earth elements	146
7.7 Rare earth elements correlation with gross caloric value (GCV)	146
7.8 Ratio of LREEs with HREEs	148
Chapter-8 Laboratory experiments by leaching on coal and coal by-products	150-178
8.1 Experiment No. 1: Leaching on coal by water and acidic solution	151
8.2 Introduction	151
8.3 Trace elements in coal and in solution	154
8.4 Water leaching	154
8.5 Acidic leaching	157
8.6 Mobilization of REEs	161
8.7 Recovery of REEs	162
8.8 Change in surface morphology	164
8.9 Experiment No. 2: Leaching on coal by acidic solution and basic solution	165

8.10 Introduction	165
8.11 Recovery from sample A1(I)	167
8.12 Recovery from sample B2(I)	169
8.13 Recovery from sample C3(I)	171
8.14 Recovery of REEs by acidic solution and basic solution	171
8.15 Calcined samples leaching results	173
8.16 Morphological features and elemental composition of coal and shaly coal samples	175
8.17 Co-extraction of uranium and thorium	176
Chapter-9 Discussion	179-209
9.1 Introduction	179
9.2 Coal characterization	179
9.2.1 Megascopic characterization	179
9.2.2 Geochemical characterization	180
9.2.3 Pearson coefficient correlation of geochemical characterization	186
9.2.4 Mineral contents in coal	189
9.2.5 Surface morphology of coal	190
9.2.6 Trace elements in coal	191
9.3 Occurrence of rare earth elements in coal	193
9.3.1 Pearson coefficient correlation between rare earth elements	195
9.3.2 REEs correlation with gross caloric value (GCV)	200
9.4 Recovery of trace elements and REEs from coal (Experiment 1)	201
9.4.1 PCC of trace elements in water samples	204
9.4.2 PCC of trace elements in acidic water samples	205
9.4.3 PCC of rare earth elements in acidic water samples	205
9.5 Recovery of rare earth elements through leaching by different chemicals (Experiment 2)	206
Chapter-10 Conclusions & Suggestions for future work	210-214

10.1 Conclusions	210
10.2 Suggestions for future work	214
References	215-266
List of publications	267-268