Contents

List of Figures

List of Tables

List of Symbols

List of Abbreviations

Preface

1 Introduction **2**

1.1 Motivation of the Research Work 7

1.2 Contributions and Organization of the Thesis 9

2 Preliminaries and related work **16**

2.1 Preliminaries 16

2.1.1 Overview of Internet of Things 16

2.1.2 Overview of Knowledge Distillation 17

2.1.3 Overview of Long Range Communication Technology 18

2.1.4 Overview of Game Theory 21

2.2 Related work on noisy labels in dataset 22

2.3 Related work on River Water Pollution Assessment 24

2.4 Related work on River Water Pollution Monitoring 29

2.5 Conclusion 31

3 Identification of river water pollution level and automatic annotation of limited laboratory data **32**

3.1 Introduction 33

3.1.1 Motivation of this work 34

3.1.2 Major Contributions 35

3.2 Preliminaries and problem statement 36
3.2.1 Preliminary 37
3.2.2 Problem statement and overview of solution 37
3.3 River water dataset collection 38
3.3.1 Methodology for collection of river water dataset 38
3.3.2 Wireless communication protocols for IoT applications 40
3.3.3 Off-site (ex-situ) laboratory dataset 42
3.3.4 On-site (in-situ) real and massive sensory dataset 45
3.3.5 Hanna multi-parameter HI-9829 sensor used in our work 49
3.4 Data preprocessing techniques 49
3.4.1 Selection of distinguishable parameters 51
3.5 Estimation of river water pollution level (WQI) 54
3.5.1 Selection of recognizable parameters 56
3.5.2 Establishing weights for selected parameters 56
3.5.3 Calculating the sub-indices for selected parameters 57
3.5.4 Aggregation of weights and sub-indices 60
3.6 Experiments and results 61
3.6.1 Implementation details 61
3.6.2 Experimental results 62
3.6.3 Number of epochs 62
3.6.4 Number of river parameters 63
3.6.5 Class-wise accuracy 64
3.7 Conclusion 65

4 A sensor-based river water pollution assessment system with noisy data using deep neural network 66
4.1 Introduction and major contributions 66
4.1.1 Motivation of this work 68
4.1.2 Major Contributions 69
4.2 Preliminary 70
4.2.1 Problem statement and overview of solution 71
4.3 Sensor-based river water pollution assessment system using deep neural network 71
4.3.1 Automatic annotation of massive sensory data 72
4.3.2 Noise handling mechanism 73
4.3.3 Construction of deep learning classifier 77

4.3.4 Prediction of class labels . . . 81
4.4 Experimental evaluation of approach . . . 82
4.4.1 Implementation details . . . 82
4.4.2 Experimental results . . . 83
4.4.3 Number of LSTM layers and cell count . . . 84
4.4.4 Precision and recall . . . 84
4.4.5 Effect of using noise handling loss . . . 86
4.4.6 Class-wise accuracy for different rivers . . . 88
4.5 Comparison with existing approaches . . . 89
4.6 Conclusion . . . 90

5 Light-weight knowledge distillation deep learning approach to identify river water pollution in Internet of Things 92
5.1 Introduction . . . 93
5.1.1 Motivation . . . 94
5.1.2 Major Contributions: . . . 96
5.2 Preliminaries and problem statement . . . 96
5.2.1 Preliminary . . . 97
5.2.2 Problem statement and overview of solution . . . 97
5.3 Knowledge distillation deep learning approach to estimate river water quality index . . . 98
5.3.1 Construction of cumbersome DNN model (Teacher model) . . . 99
5.3.2 Obtain the compressed DNN model (Student model) . . . 101
5.3.3 Knowledge distillation (transfer of knowledge) to train student model . . . 102
5.3.4 Loss of student model . . . 102
5.3.5 Training of teacher and student model on dataset . . . 104
5.3.6 Compression . . . 104
5.4 Experimental evaluation and results . . . 105
5.4.1 RWM dataset . . . 106
5.4.2 Implementation details . . . 106
5.4.3 Experimental results . . . 107
5.5 Conclusion . . . 112

6 Energy-Efficient communication of river water pollution data using LoRa and Game Theory 114
6.1 Introduction . . . 115

6.1.1 Motivation 116
6.1.2 Major Contributions: 119
6.2 Preliminary 120
6.2.1 Preliminary 120
6.2.2 Problem statement and overview of solution 122
6.3 Energy-efficient transmission of river water pollution data 122
6.3.1 Energy consumption during CTD 124
6.3.2 Energy consumption during RTD 124
6.3.3 Energy consumption during remaining duty cycle 125
6.3.4 Energy consumption to maintain the stable state 125
6.3.5 ERWM problem formulation 126
6.3.6 ERWM problem solution 127
6.4 Holistic ERWM System 131
6.5 Experimental evaluation and results 132
6.5.1 RWM dataset 132
6.5.2 Implementation details 133
6.5.3 Experimental results 134
6.6 Real World Evaluation 137
6.7 Conclusion 139

7 Conclusion and future work **140**
7.1 Conclusion 140
7.2 Future Research Directions 144

References **146**

List of publications **155**