# TABLE OF CONTENTS

Declaration	iv
Certificate	v
Acknowledgement	vi
Preface	vii
Table of Contents	viii
List of Figures	xi
List of Tables	xvi
CHAPTER 1	
INTRODUCTION	1
1.1 REMOTE SENSING	1
1.2 MICROWAVE REMOTE SENSING	2
1.3 COMPARISON OF OPTICAL AND MICROWAVE REMOTE SENSING FOR FLOO	D AND
SOIL MOISTURE STUDIES	5
1.4 DIELECTRIC PROPERTIES OF NATURAL EARTH MATERIALS AT MICRO	WAVE
FREQUENCY	7
1.5 MICROWAVE BRIGHTNESS TEMPERATURE AND ITS DERIVED PARAMETERS	11
1.6 SCATTERING COEFFICIENT OF SYNTHETIC APERTURE RADAR	13
1.7 APPLICATIONS OF MICROWAVE REMOTE SENSING	14
1.8 NEED STATEMENTS	16
1.9 STUDY AREA	17
1.10 ORGANISATION OF THE THESIS	18
CHAPTER 2	
LITERATURE REVIEW	19
2.1 INTRODUCTION	19
2.2 LITERATURE REVIEW ON FLOOD DETECTION AND MONITORING	USING
MICROWAVE REMOTE SENSING	20
2.3 LITERATURE REVIEW ON FLOOD PREDICTION USING MICROWAVE RI	EMOTE
SENSING	22

2.4 LITERATURE REVIEW ON SOIL MOISTURE MEASUREMENT USING MICRO	WAVE
REMOTE SENSING	24
2.5 INFERENCES AND KNOWLEDGE GAPS FOR RESEARCH	26
CHAPTER 3	
OBJECTIVES AND METHODOLOGIES	28
3.1 OBJECTIVES	28
3.2 METHODOLOGIES	29
3.3 VALIDATION METHODS FOR THE EXPERIMENTAL RESULTS	33
3.4 REMOTE SENSING SOFTWARE USED	35
3.5 CONCLUSION	36
CHAPTER 4	
FLOOD DETECTION AND MONITORING USING MICROWAVE REMOTE SENSING	37
4.1 INTRODUCTION	37
4.2 FLOOD DETECTION AND MONITORING USING PASSIVE MICROWAVE BRIGH	TNESS
TEMPERATURE DIFFERENCE	38
4.3 FLOOD DETECTION AND MONITORING USING PASSIVE MICROWAVE RE	EMOTE
SENSING BY INTRODUCING A THRESHOLD TO BRIGHTNESS TEMPERATURE R	RATIOS
	49
4.4 FLOOD DETECTION AND MONITORING USING PASSIVE MICRO	WAVE
POLARIZATION INDEX	60
4.5 FLOOD DETECTION AND MONITORING USING ACTIVE MICROWAVE SCATT	ERING
COEFFICIENT	69
4.6 FLOOD BOUNDARY DELINEATION USING SAR DATA	81
4.7 CHAPTER CONCLUSIONS	92
CHAPTER 5	
FLOOD PREDICTION USING MICROWAVE REMOTE SENSING	93
5.1 INTRODUCTION	93
5.2 MONITORING POLARIZATION INDEX IN THE UPSTREAM OF RIVER BRAHMAI	PUTRA
FOR FLOOD PREDICTION IN LOWER BASIN OF THE VALLEY	94
5.3 MONITORING POLARIZATION INDEX IN THE BOUNDARY AREA OF THE	RIVER
BRAHMAPUTRA FOR FLOOD PREDICTION IN MORIGAON DISTRICT	104
5.4 FLOOD PREDICTION IN THE DOWNSTREAM AREAS OF BRAHMAPUTRA VALL	EY BY
USING PRECIPITATION DATA FROM MICROWAVE REMOTE SENSING SATELLITE	111

 5.5 FLOOD PREDICTION IN DOWNSTREAM AREA IN LOWER ASSAM BY USING

 PRECIPITATION DATA OF PARTS OF MEGHALAYA HILLS IN THE UPPER CATCHMENT

 119

 5.6 PREDICTION OF CLOUDBURST USING MICROWAVE REMOTE SENSING
 126

 5.7 CHAPTER CONCLUSIONS
 133

### CHAPTER 6

ARTIFICIAL	NEURAL	NETWORK	BASED	SOIL	MOISTURE	ESTIMATION	USING
MICROWAVE	E REMOTE	SENSING					135
6.1 INTRODU	CTION						135
6.2 THEORET	ICAL BACH	KGROUND					136
6.3 EQUIPME	NTS, SOFT	WARES AND	DATA US	ED			138
6.4 STUDY AI	REA						138
6.5 EXPERIM	ENTS DON	E					139
6.6 EXPERIM	ENTAL RES	SULTS AND V	ALIDATI	ON OF	RESULTS		143
6.7 CHAPTER	CONCLUS	IONS					147

#### CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH	148
7.1 CONCLUSIONS	148
7.2 KEY CONTRIBUTIONS FROM THIS RESEARCH	149
7.3 SCOPES FOR FUTURE RESEARCH	150

Bibliography	151

APPENDIX 1	
ABBREVIATIONS USED	157
APPENDIX 2	
BIO DATA	158
APPENDIX 3	
TRANSCRIPT OF THE PH.D. COURSE WORK	159

APPENDIX 4	
LIST OF PUBLICATIONS	160

## LIST OF FIGURES

Figure	Figure Caption	Page
No.		No.
1.1	Position of Microwaves in the Electromagnetic Spectrum	3
1.2	Passive Microwave Sensing	4
1.3	Airborne Active Microwave Sensing	5
1.4	Dielectric constant $\varepsilon$ of pure water versus frequency at $20^{\circ}$ C	8
1.5	Dielectric constant $\varepsilon$ for a loamy soil versus the volumetric soil moisture	9
	content in percentage	
1.6	Dielectric constant ( $\epsilon$ ) of vegetation versus the gravimetric soil moisture	10
	content in percentage	
1.7	Dielectric constant $\varepsilon$ of snow versus the volume fraction of water in	11
	percentage	
1.8	Study Area	18
3.1	Bhuvan flood map of some places of Jorhat district of 8 <sup>th</sup> June 2018	34
4.1	Flood affected areas of Jammu and Kashmir in September, 2014	41
4.2	Ascending pass horizontal polarization brightness temperature difference of	42
	$\{T_B(19 \text{ GHz}) - T_B(91 \text{ GHz})\}$ for Bandipur, Ganderbal, Srinagar, Reasi and	
	Anantnag during August-October, 2014	
4.3	Descending pass horizontal polarization brightness temperature difference	42
	of $\{T_B(19 \text{ GHz}) - T_B(91 \text{ GHz})\}$ for Bandipur, Ganderbal, Srinagar, Reasi	
	and Anantnag during August-October, 2014	
4.4	Ascending pass vertical polarization brightness temperature difference of	43
	$\{T_B (91 \text{ GHz}) - T_B (19 \text{ GHz})\}$ for Bandipur, Ganderbal, Srinagar, Reasi and	
	Anantnag during August-October, 2014	
4.5	Descending pass vertical polarization brightness temperature difference of	43
	$\{T_B(91 \text{ GHz}) - T_B(19 \text{ GHz})\}$ for Bandipur, Ganderbal, Srinagar, Reasi and	
	Anantnag during August-October, 2014	
4.6	Bhuvan flood image of flood progression during 8-9 September 2014 in the	46
	study area	

4.7	Pixel-wise analysis of flood indicated by passive microwave remote sensed	47
	brightness temperature difference method	
4.8	Methodology of flood detection & monitoring using TB ratio	52
4.9	Graph of brightness temperature ratio for Bordoloni with Nari and Likabali	54
	taken as Reference	
4.10	Graph of brightness temperature ratio changes for Gogamukh, Silapathar	57
	and Dipa by taking Nari and Likabali as places for calibration	
4.11	Pixel-wise analysis of flood indicated by passive microwave remote sensed	58
	brightness temperature ratio method	
4.12	Level-3 Global Image of 10 GHz Horizontal Polarization Brightness	62
	Temperature from AMSR-2 on 11th July 2017 acquired during descending	
	pass of GCOM-W1	
4.13	Geo-location of the pixel under study	63
4.14	Area under study for flood detection and monitoring using polarization	64
	index	
4.15	Temporal variation of <i>PI</i>	66
4.16	Crop area affected in the district of Morigaon in July 2017	67
4.17	Pixel-wise analysis of flood indicated by passive microwave remote sensed	67
	polarization index method	
4.18	SAR image of the area under study acquired on 2 <sup>nd</sup> July 2017 (Centre:	70
	92.2°E/26.3°N)	
4.19	Study locations of Morigaon district on the SAR image of Sentinel 1-A in	72
	VH polarization on 2 <sup>nd</sup> July 2017	
4.20	Study locations of Morigaon district on the SAR image of Sentinel 1-A in	73
	VH polarization on 14 <sup>th</sup> July 2017	
4.21	Study locations of Morigaon district on the SAR image of Sentinel 1-A in	73
	VH polarization on 26 <sup>th</sup> July 2017	
4.22	Study locations on the SAR image of Sentinel 1-A in VH polarization on	74
	26 <sup>th</sup> July 2017	
4.23	Variation of Backscattering coefficient in four places of Morigaon district	76
	in the month of July 2017 for VH polarization SAR image	
4.24	Variation of Backscattering coefficient in four places of Morigoan district	77
	in the month of July 2017 for VV polarization SAR image	
	in the month of carly 2017, for the point and still image	

4.25	Variation of Backscattering coefficient in five places of Dhemaji district in	78
	the month of August 2018 for VV polarization SAR image	
4.26	Pixel-wise analysis of flood indicated by SAR backscattering coefficient	79
	observation based method in VV polarization	
4.27	Area under study (Longitude: 92.22°E, Latitude: 26.35°N)	82
4.28	Study area before the occurrence of the flood on 2 <sup>nd</sup> July 2017 as seen in a	84
	VH SAR image	
4.29	Study area before the occurrence of the flood on 2 <sup>nd</sup> July 2017 as seen in a	84
	VV SAR image	
4.30	Study area during flooding on 14 <sup>th</sup> July 2017 as seen in a VH SAR image	85
4.31	Study area during flooding on 14th July 2017 as seen in a VV SAR image	85
4.32	Study area after the occurrence of flood on 26 <sup>th</sup> July 2017 as seen in a VH	86
	SAR image	
4.33	Study area after the occurrence of flood on 26 <sup>th</sup> July 2017 as seen in a VV	86
	SAR image	
4.34	Boundary pixels for studying scattering coefficient variation in all	88
	directions	
4.35	The study location being flooded as on 14 <sup>th</sup> July 2017	89
4.36	Variation of backscattering coefficient inside the flooded area	90
4.37	Variation of backscattering coefficient horizontally in the flood boundary	90
4.38	Variation of backscattering coefficient vertically in the flood boundary	90
4.39	Variation of backscattering coefficient in the flood boundary in angular	91
	direction	
5.1	Damages caused by flood over the years in Assam	95
5.2	Area for monitoring of PI value for flood prediction	96
5.3	Variation of PI average values during August-September 2015	97
5.4	Bhuvan image of Kaziranga National Park on 22 <sup>nd</sup> August 2015 shows no	98
	flood	
5.5	Bhuvan image of Kaziranga National Park on 23rd August 2015 shows	99
	flooding spots	
5.6	Bhuvan image of Kaziranga National Park on 2 <sup>nd</sup> September 2015 shows	99

	flooding spots	
5.7	Bhuvan image of Kaziranga National Park on 6 <sup>th</sup> September 2015 shows no	100
	flood	
5.8	Variations of computed average PI and flood affected crop area as per	101
	ASDMA report in the Brahmaputra valley in 2014	
5.9	Variations of computed average PI and flood affected crop area as per	102
	ASDMA report in the Brahmaputra valley in 2015	
5.10	Variations of computed average PI and flood affected crop area as per	103
	ASDMA report in the Brahmaputra valley in 2016	
5.11	Morigaon District	106
5.12	Pixels chosen for computing PI average values	106
5.13	Variation of average PI values and crop area affected in 2015	108
5.14	Variation of average <i>PI</i> values and crop area affected in 2016	109
5.15	Variation of average PI values and crop area affected in July 2017	110
5.16	Points of precipitation measurement on and around the river Brahmaputra	113
5.17	Methodology used for prediction of flood in Assam	114
5.18	Sum of precipitation values obtained for the places upstream of Kaziranga	116
	area during descending pass of the satellite	
5.19	Sum of precipitation values obtained for the places upstream of Kaziranga	118
	area during ascending pass of the satellite	
5.20	Places under study for prediction of flood in lower Assam	121
5.21	Sum of precipitation values obtained for the places in and around lower	123
	Assam area during descending pass of the satellite	
5.22	Sum of precipitation values obtained for the places in and around lower	125
	Assam area during ascending pass of the satellite	
5.23	Sample images containing TB values at (a) 19 GHz and (b) 91 GHz	129
5.24	Methodology for detection of heavy rainfall producing cloud	130
5.25	High positive value obtained on the 207 <sup>th</sup> day (26 <sup>th</sup> July) of 2014 for Tehri	130
5.26	High positive value obtained on the 262 <sup>nd</sup> day (19 <sup>th</sup> September) of 2014 for	131
	South Garo Hills	
5.27	High positive value obtained from the 244 <sup>th</sup> to 247 <sup>th</sup> day (1st to 4th	131
	September) of 2014 for Kashmir Valley	
5.28	High positive value obtained on 29th June 2016, for Pithoragarh in	132

	Uttarakhand	
6.1	An Artificial Neuron	137
6.2	Typical layers of an ANN	137
6.3	The districts and the boundaries of the state of Meghalaya in India	139
6.4	Methodologies of ANN based soil moisture estimation using brightness	140
	temperature	
6.5	Soil samples collected in zip locked bags from different places	141
6.6	Bar-graph between actual and estimated soil moisture values for ANN 1	146
6.7	Bar-graph between actual and estimated soil moisture values for ANN 2	146

### LIST OF TABLES

Table	Table Caption	Page
No.		No.
1.1	Typical applications of the microwave bands in remote sensing	15
4.1	Data used in Brightness Temperature difference method	40
4.2	Brightness temperature difference {TBh (19 GHz) – TBh (91 GHz)} values	44
	during flooding and non-flooding days	
4.3	Brightness temperature difference {TBv (91 GHz) – TBv (19 GHz)} values	45
	during flooding and non-flooding days	
4.4	Brightness temperature values and ratios at 37 GHz in horizontal	53
	polarization during descending Passes for the areas in Dhemaji district	
4.5	Brightness temperature values of some areas in Dhemaji district for	56
	October 2012 to September 2013	
4.6	Brightness temperatures obtained at 10 GHz during descending passes from	65
	AMSR-2 sensor on board GCOM-W1 satellite	
4.7	Geo-locations of the pixels under study in the SAR image of Morigaon	71
	district	
4.8	Geo-locations of the pixels under study in the SAR image of Dhemaji	72
	district	
4.9	Scattering coefficient variation in different locations of Morigaon for VH	75
	polarization image of Sentinel 1A	
4.10	Scattering coefficient variation in different locations of Morigaon for VV	76
	polarization image of Sentinel 1A	
4.11	Variation of backscattering coefficient with flooding in Jonai in 2018	77
5.1	Longitudes and Latitudes of Pixels chosen for PI computation	107
5.2	Sample values of $T_B$ , PI and average PI for 5 <sup>th</sup> of August, 2015	107
5.3	Precipitation values (in mm/hr) obtained from AMSR 2 with respect to	115
	descending pass for the month of August 2014, upstream of Kaziranga	
	National Park	
5.4	Precipitation values (in mm/hr) obtained from AMSR 2 with respect to	116

	descending pass for the month of August, 2014, upstream of Kaziranga	
	National Park	
5.5	Precipitation values obtained from AMSR 2 with respect to descending	122
	pass for the month of September, 2014 for selected places in lower Assam,	
	West Khasi Hills and Garo Hills	
5.6	Precipitation values obtained from AMSR 2 with respect to ascending pass	124
	for the month of September, 2014 (lower Assam, West Khasi Hills and	
	Garo Hills area)	
5.7	Areas considered for detection of cloud capable of producing cloudburst	128
5.8	Actual Cloudburst dates against the early warning dates	132
6.1	List of transfer functions used in training and configuring the ANNs	141
6.2	List of training algorithms used in training and configuring the ANNs	142
6.3	Accuracy of ANN 1 in estimating soil moisture for 'Gradient descent with	144
	adaptive learning rate' algorithm and 'Elliot symmetric sigmoid' transfer	
	function	
6.4	Accuracy of ANN 1 in estimating soil moisture for 'Resilient	144
	backpropagation' algorithm and 'Symmetric sigmoid transfer function'	
	transfer function	
6.5	Accuracy of ANN 2 in estimating soil moisture for 'Gradient descent with	145
	adaptive learning rate' algorithm and 'Elliot symmetric sigmoid' transfer	
	function	
6.6	Accuracy of ANN 2 in estimating soil moisture for 'Levenberg-Marquardt	145
	optimization' algorithm and 'Linear' transfer function	