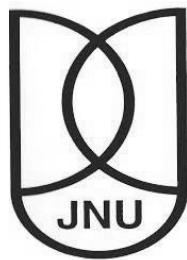


**Regulating ecosystem services in urbanising landscapes of Western Himalaya**

*Thesis submitted to Jawaharlal Nehru University  
in partial fulfilment of the requirements for the award of degree of*

**DOCTOR OF PHILOSOPHY**

**SONALI SHARMA**



SPATIAL ANALYSIS AND INFORMATICS LAB  
SCHOOL OF ENVIRONMENTAL SCIENCES  
JAWAHARLAL NEHRU UNIVERSITY  
NEW DELHI-110067, INDIA

2023

## ACKNOWLEDGEMENTS

First and foremost, I consider myself lucky to have been attached and work under the guidance of my great supervisor, Prof. P.K. Joshi, Professor, School of Environmental Sciences, Jawaharlal Nehru University, New Delhi, India. His continuous inspirations, guidance, resourcefulness, supports, productive ideas, and regular monitoring helped me exceedingly to carry out the research and made me achieve this milestone. His mentorship has shaped my understanding of the subject matter and has equipped me with the necessary skills to navigate challenges and overcome obstacles. I am deeply grateful to him for imparting invaluable knowledge and teachings that has positively impacted both my professional and personal life.

I am deeply grateful to the members of the Doctoral Research Committee (DRC), Prof. Krishan Kumar (SES) and Prof. Dipendra Nath Das (SSS, CSRD), for their invaluable support, guidance, and motivation throughout the completion of this research. Their invaluable input, in the form of insightful comments, critical suggestions and constructive ideas, has significantly enhanced the quality of this thesis.

I am deeply grateful to Prof. Dr. Christine Fürst for her warm hospitality during my stay at the Department of Sustainable Landscape Development, Martin Luther University Halle-Wittenberg, Germany. Her invaluable support, critical comments, inputs, and inspirational guidance greatly enhanced the scientific integrity of this thesis. I would also like to highly acknowledge her support with the technical and financial aspects of my research.

I would also like to express my gratitude and appreciation for the members of the Spatial Analysis and Informatics Lab (SAIL) for their thoughtful questions, constructive critiques and helpfulness throughout the years. I would like to thank all the former as well as present lab members – Kundan, Dr. Susanta, Dr. Anees, Dr. Praveen, Neha, Mani, Akshita, Jayshree, Varun and Ashish. Particularly, my sincere gratitude goes for Dr. Anees for his valuable quality assessments and very instructive solutions to my research problems. A special thanks also goes to Mr. Ishwar Chand, for arranging all needed logistics.

The journey of my PhD owes a deep gratitude for the friendship and love of Krati Sharma, Rashmi Singh Yadav, Sonali Rajput and Anita Gautam. Krati, in particular, guided and inspired me, profoundly influencing my personal growth. The support, friendship, and consistent presence of Arindan Mandal shaped my way throughout the good and hard times of my PhD journey. It would be difficult to forget the friendship and support of Janina Kleeman, Marcin Spyra, Hongmi Koo and Nica Claudia during my year-long stay in Germany. Big thanks for the coffee and cake breaks, and all the travel times with Nimisha Srivastava, Yuanyuan Chen, Somayeh Mohammadi Hamidi and Robert Starte that helped me to cherish my stay in Germany better.

Nothing would be possible without my family. I would like to express my heartfelt gratitude to my mother Mrs. Monika Sharma for her endless love, support, concern and motivation. I am deeply appreciative of the consistent support, routine-lessons and love provided by my father Mr. Nand Kishor Sharma. My brother, Sagar, has been my consistent support pillar for my parents and have aided and inspired me throughout this endeavor. Last but not the least, to my late grandfather- your presence and unwavering belief in my abilities have been invaluable, and I will forever stay grateful for your unwavering love and support.

Although it is not possible to acknowledge everyone individually, please know that your contributions, support, and encouragement have played an integral role in the successful completion of my doctoral studies. Thank you all for being a part of this incredible journey.

I owe the successful completion of this doctoral work to the support of numerous institutions that provided financial support and facilitated my progress without difficulty. I would like to express my gratitude to the University Grants Commission (UGC) for their Junior Research Fellowship (JRF) and Senior Research Fellowship (SRF), which provided the necessary funds for my research. Additionally, I am thankful to the Deutscher Akademischer Austauschdienst (DAAD) for awarding me the bi-nationally supervised doctoral research grant, enabling me to travel to and reside in Germany for 12 months. The support received from the Sustainable Natural Resource Use in Arctic and High Mountainous Areas (SUNRAISE) and Urban Resilience and Adaptation for India and Mongolia (URGENT) projects, co-funded by the Erasmus+ Programme of the European Union

have been instrumental in providing me with exposure trips to Austria. The learnings from the international summer schools on 'Urban+Mountains', organized by the University of Salzburg, Austria, in cooperation with the Society for Urban Ecology (SURE), Salzburg, Austria were enriching, interactive and knowledge gaining platform. Interactions with international and national experts and the student communities across the world as part of these projects have provided new outlooks and provided platforms to discuss new ideas. I thank the project partners with whom constructive discussions have shaped pathways for future engagement. Also, the equipment support received through these projects at the SES, JNU has helped in efficiently completing the laboratory work, thus are duly acknowledged. Institutional endorsements provide the essential backbone for any research. With this in mind, I extend my gratitude to the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), India Meteorological Department (IMD), Office of the Registrar General & Census Commissioner, India, Soil and Land Use Survey of India (SLUSI), Indian Space Research Organisation (ISRO), and Earth System Grid Federation (ESGF) for their invaluable support. I am particularly thankful for the free-of-cost data they provided, which was instrumental in conducting my research work.

## TABLE OF CONTENTS

ACKNOWLEDGEMENTS.....	iii
TABLE OF CONTENTS.....	vi
LIST OF FIGURES .....	ix
LIST OF TABLES.....	xiii
LIST OF ABBREVIATIONS.....	xvi
<b>Chapter 1 .....</b>	<b>1</b>
<b>1. INTRODUCTION.....</b>	<b>1</b>
1.1 Background and context of research.....	1
1.2 Main concepts used in this research.....	3
1.3 Conceptual framework.....	13
1.4 Research objective and questions .....	16
1.5 Structure of the thesis.....	17
<b>Chapter 2 .....</b>	<b>20</b>
<b>2. LITERATURE REVIEW.....</b>	<b>20</b>
2.1 Overview.....	20
2.2 Spatial structure and dynamism .....	22
2.3 Regulating Ecosystem Services .....	26
2.4 Integrating ESs in landscape planning.....	29
2.5 Research gaps and relevance of the study.....	32
<b>Chapter 3 .....</b>	<b>37</b>
<b>3. STUDY AREA.....</b>	<b>37</b>
3.1 Western Himalaya.....	37
3.2 Dharamsala .....	40
3.3 Pithoragarh.....	42
<b>Chapter 4 .....</b>	<b>45</b>
<b>4. COMPOSITION AND CONFIGURATION IN URBANISING LANDSCAPES .....</b>	<b>45</b>
4.1 Introduction.....	45
4.2 Land use land cover classification .....	48

4.2.1 Materials and methodology.....	48
4.2.2 Results.....	49
4.3 Intensity and Stationarity analysis .....	57
4.3.1 Material and Methodology.....	57
4.3.2 Results.....	60
4.4 Composition and Configuration Analysis.....	68
4.4.1 Material and Methodology.....	68
4.4.2 Results.....	71
4.5 Learning outcomes and research implications.....	80
<b>Chapter 5 .....</b>	<b>82</b>
<b>5. REGULATING ECOSYSTEM SERVICES SUPPLY CAPACITY.....</b>	<b>82</b>
5.1 Introduction.....	82
5.2 Biophysical valuation of regulating ecosystem services .....	84
5.2.1 Material and methods.....	84
5.2.2 Results.....	95
5.3 Hotspot analysis .....	109
5.3.1 Material and methods.....	109
5.3.2 Results.....	111
5.4 Ecological priority sites for conservation and restoration .....	116
5.4.1 Material and methods.....	116
5.4.2 Results.....	117
5.5 Ecosystem service bundle analysis .....	120
5.5.1 Material and methods.....	120
5.5.2 Results.....	121
5.6 Learning outcomes and research implications.....	127
<b>Chapter 6 .....</b>	<b>129</b>
<b>6. FUTURE LAND USE AND CLIMATE CHANGE SCENARIOS .....</b>	<b>129</b>
6.1 Introduction.....	129
6.2 Possible land use land cover trajectories .....	131
6.2.1 Materials and methods .....	131

6.2.2 Results.....	133
6.3 Exploring future climate projections .....	139
6.3.1 Material and methodology .....	139
6.3.2 Results.....	140
6.4 Mapping RESs under future conditions.....	141
6.4.1 Material and methodology .....	141
6.4.2 Results.....	142
6.5 Learning outcomes and key findings .....	155
<b>Chapter 7 .....</b>	<b>157</b>
<b>7. DISCUSSION .....</b>	<b>157</b>
7.1 RESs in mountainous urban landscapes .....	157
7.2 Structural dynamism .....	159
7.3 Functional dynamism.....	163
7.4 Future landscape planning .....	167
7.5 Policy implications.....	172
<b>Chapter 8 .....</b>	<b>174</b>
<b>8. CONCLUSION.....</b>	<b>174</b>
8.1 Main findings and research contributions.....	174
8.2 Framework for Urban Landscape Development in Himalaya.....	177
8.2.1 Assessment.....	178
8.2.2 Intervention .....	179
8.3 Recommendations for future research .....	180
<b>REFERENCES .....</b>	<b>182</b>
<b>APPENDIX – I .....</b>	<b>246</b>
<b>APPENDIX – II.....</b>	<b>247</b>
5A.1 Validating accuracy of predicted NDVI.....	248
5A.2 Determining candidate resolution for bundle analysis.....	253
5A.3 Determining optimal number of clusters for ecosystem bundle analysis.....	255
<b>APPENDIX – III .....</b>	<b>262</b>

## LIST OF FIGURES

Figure 1.1 Conceptual framework adopted for monitoring regulating ecosystem services in urbanizing landscapes of western Himalaya.....	13
Figure 3.1 Map of Indian western Himalayan states and union territories. ....	38
Figure 3.2 Criteria (using principle of exclusion) for selection of representative cities of western Himalaya for the research work.....	39
Figure 3.3 Geographic location of Dharamsala in Himachal Pradesh state of Indian western Himalaya: Satellite image (Sentinel 2a, 03 <sup>rd</sup> April 2019) for sub-watershed limits overlaid by the city administrative boundary (yellow colour).....	42
Figure 3.4 Geographic location of Pithoragarh in Uttarakhand state of Indian western Himalaya: Satellite image (Sentinel 2a, 29 <sup>th</sup> April 2019) for sub-watershed limits overlaid by the city administrative boundary (yellow colour).....	44
Figure 4.1 Methodological flow diagram illustrating the research methodology employed to address objective 1.....	47
Figure 4.2 Distribution of land use land cover in Dharamsala city and outer zone.....	51
Figure 4.3 Distribution of land use land cover (%) at city and outer zone level in reference years in Dharamsala. ....	52
Figure 4.4 Distribution of varied land use land cover in Pithoragarh city and outer zone. ....	54
Figure 4.5 Distribution of land use land cover (%) at city and outer zone level in reference years in Pithoragarh.....	55
Figure 4.6 Interval level changes in terms of intensity during three study periods in Dharamsala. The uniform intensity at the outer zone level is depicted by a black dashed line, while at the city level, it is represented by a solid line. Respective intensity values for each level are placed next to the corresponding lines. ....	61
Figure 4.7 Category level changes in terms of intensity during three-time intervals in Dharamsala at the city and outer zone level. FO: forest, VEG: vegetation, GL: glacier, BL: barren land, CL: cropland, OA: open area, and BU: built-up. The black dashed line represents the uniform intensity, and its value is placed next to it.....	62



Figure 4.8 Transition level changes in terms of intensity during three time periods in Dharamsala at the city and outer zone level. The black dashed line represents the uniform intensity, and its value is placed next to it.....	64
Figure 4.9 Interval level changes in terms of intensity during three time periods in Pithoragarh. The uniform intensity at the outer zone level is depicted by a black dashed line, while at the city level, it is represented by a solid line. Respective intensity values for each level are placed next to the corresponding lines. ....	65
Figure 4.10 Category level changes in terms of intensity during three time periods in Pithoragarh at the city and outer zone level. FO: forest, VEG: vegetation, WB: waterbody, BL: barren land, CL: cropland, OA: open area, and BU: built-up. The black dashed line represents the uniform intensity, and its value is placed next to it. ....	66
Figure 4.11 Transition level changes in terms of intensity during three time periods in Pithoragarh at the city and outer zone level. ....	68
Figure 4.12 Temporal distribution of selected landscape metrics quantified at city and outer zone landscape level of Dharamsala.....	72
Figure 4.13 Spatial distribution of selected landscape metrics at 250 m cell size in 2002, 2010, 2016, and 2021 in Dharamsala and its outer zone. ....	75
Figure 4.14 Temporal distribution of selected landscape metrics quantified at city and outer zone landscape level of Pithoragarh. ....	77
Figure 4.15 Spatial distribution of selected landscape metrics at 100 m cell size in 2001, 2008, 2016, and 2021 in Pithoragarh and its outer zone.....	79
Figure 5.1 Methodological flow chart representing the general structure of ecosystem services assessment for objective 2. ....	84
Figure 5.2 Soil texture, Elevation (meter) and Slope (degree) maps of Dharamsala (row 1) and Pithoragarh (row 2). ....	85
Figure 5.3 Spatial patterns and variations in four physical RESs in Dharamsala and its outer zone. Column 1 to 4 represent the distribution of Soil Erosion Regulation (SER), Flood Regulation (FR), Carbon Sequestration (CS) and Local Climate regulation (LCR), respectively. Row 1 to 4 represent year 2002, 2010, 2016 and 2021, respectively.....	102

Figure 5.4 Spatial patterns and variations in four physical RESs in Pithoragarh and its outer zone. Column 1 to 4 represent the distribution of Soil Erosion Regulation (SER), Flood Regulation (FR), Carbon Sequestration (CS) and Local Climate regulation (LCR), respectively. Row 1 to 4 represent year 2001, 2008, 2016 and 2021, respectively..... 109

Figure 5.5 Spatial patterns of hotspots and coldspots of each RESs in Dharamsala and its outer zone for year 2002 (row 1) and 2021 (row 2). Here SER is Soil Erosion Regulation, FR is Flood Regulation, CS is Carbon Sequestration and LCR is Local Climate Regulation. Superscripts double star (\*\*) and single star (\*) denote hotspots or coldspots that were significant at 99% and 95% level, respectively, while the one with no superscript was significant at 90%. ....113

Figure 5.6 Spatial patterns of hotspots and coldspots of each RESs in Pithoragarh and its outer zone for year 2001 (row 1) and 2021 (row 2). Here SER is Soil Erosion Regulation, FR is Flood Regulation, CS is Carbon Sequestration and LCR is Local Climate Regulation. Superscripts double star (\*\*) and single star (\*) denote hotspots or coldspots that were significant at 99% and 95% level, respectively, while the one with no superscript was significant at 90%. ....116

Figure 5.7 Spatial agreement between hotspots and coldspot maps of each RESs indicated by respective numbers, and identified EPCS and EPRS in Dharamsala and outer zone. ....118

Figure 5.8 Spatial agreement between hotspots and coldspot maps of each RESs indicated by respective numbers, and identified EPCS and EPRS in Dharamsala and outer zone. .... 120

Figure 5.9 Spatial distribution of bundles over study period in Dharamsala and outer zone. .... 123

Figure 5.10 Flower diagram illustrating average distribution of RESs in each bundle over the study period in Dharamsala and outer zone..... 123

Figure 5.11 Spatial distribution of bundles over study period in Pithoragarh and outer zone.... 126

Figure 5.12 Flower diagram illustrating average distribution of RESs in each bundle over the study period in Pithoragarh and outer zone. .... 126

Figure 6.1 Methodological flow chart representing the general structure of future ecosystem services assessment for objective 3..... 130

Figure 6.2 Spatial distribution of various LULC classes under three land use land cover trajectories in Dharamsala and outer zone for the year 2040. .... 134

Figure 6.3 Spatial distribution of various LULC classes under three land use land cover trajectories in Pithoragarh and outer zone for the year 2040. .... 137

Figure 6.4 Spatial distribution of SER, FR(a) and NPP, LCR (b) in 2040 under different land use land cover trajectories and climate scenarios in Dharamsala and its outer zone. ....	147
Figure 6.5 Spatial distribution of SER, FR(a) and NPP, LCR (b) in 2040 under different land use land cover trajectories and climate scenarios in Pithoragarh and its outer zone. ....	154
Figure 8.1 Decision making framework for urban landscape development in Himalaya. ....	179
Figure 5A.1 Raw curve number ( <i>column 1</i> ) vs slope adjusted curve number ( <i>column 2</i> ) values for Dharamsala and Pithoragarh. ....	248
Figure 5A.2 Scatter plot of the original Landsat NDVI vs. ESTARFM Predicted NDVI value at 5000 random points. ....	249
Figure 5A.3 Visual comparisons among Predicted, original Landsat and MODIS NDVI images. The inset map emphasizing to the built-up area of urban center – <i>Dharamsala</i> . ....	250
Figure 5A.4 Scatter plot of the original Landsat NDVI vs. ESTARFM Predicted NDVI value at 5000 random points. ....	251
Figure 5A.5 Visual comparisons among Predicted, original Landsat and MODIS NDVI images. The inset map emphasizing to the built-up area of urban center – Pithoragarh. ....	252
Figure 5A.6 Moran's I and Coefficient of variation (CV) in Dharamsala at selected candidate resolutions. ....	254
Figure 5A.7 Moran's I and Coefficient of variation (CV) in Pithoragarh at selected candidate resolutions. ....	254
Figure 5A.8 Elbow method showing optimal <i>k</i> at four time points in Dharamsala. ....	256
Figure 5A.9 Elbow method showing optimal <i>k</i> at four time points in Pithoragarh. ....	257
Figure 5A.10 Silhouette analysis for k-means clustering at 4, 5, 6 and 7 centers in Dharamsala for year 2002, 2010, 2016, and 2021. ....	258
Figure 5A.11 Silhouette analysis for k-means clustering at 3, 4, 5 and 6 centers in Pithoragarh for year 2001, 2008, 2016, and 2021. ....	260
Figure 6A.1 Decile map of each RES (Row 1 to 4) and overlaid decile map of all RESs (Row 5) for Dharamsala and Pithoragarh (Column 1 and Column 2, respectively). ....	266
Figure 6A.2 Predicted vs actual LULC map 2021 in Dharamsala and outer zone. ....	267
Figure 6A.3 Predicted vs actual LULC map 2021 in Pithoragarh and outer zone. ....	267

## LIST OF TABLES

Table 1.1 Definitions of Ecosystem Services (ESs).....	5
Table 1.2 Definitions of Regulating Ecosystem Services (RESS). .....	8
Table 4.1 LULC Class-wise User’s Accuracy (UA), Producer’s Accuracy (PA), overall accuracy (OA) and kappa coefficient for Dharamsala. ....	56
Table 4.2 LULC Class-wise User’s Accuracy (UA), Producer’s Accuracy (PA), overall accuracy (OA) and kappa coefficient for Pithoragarh. ....	56
Table 4.3 Definitions of selected landscape metrics along with their respective category (Source: McGarigal & Marks (1995)). ....	69
Table 4.4 Formulas of selected landscape metrics (Source: McGarigal & Marks (1995)).....	70
Table 5.1 Dataset and analysis tools used for estimation of RESs. (*) denotes inputs from Objective 1.....	84
Table 5.2 Net seasonal NPP of Dharamsala over the study period (2002-2021). ....	99
Table 5.3 Area (km <sup>2</sup> ) and proportion (%) of five LCR classes within urban extent in Dharamsala over the study period (2002-2021). ....	101
Table 5.4 Net seasonal NPP of Pithoragarh over the study period (2001-2021). ....	107
Table 5.5 Area (km <sup>2</sup> ) and proportion (%) of five LCR classes within urban extent in Pithoragarh over the study period (2001-2021). ....	108
Table 6.1 Dataset and analysis tools used for estimation of RESs. (*) denotes inputs from objective 1 while (**) denotes inputs from objective 2.....	130
Table 6.2 Synthesis of possible land use land cover trajectories differentiating the socio-economic developments in relation to land use.....	133
Table 6.3 Agreement/disagreement based on the accuracy with which the quantity and location are predicted for 2021 LULC in Dharamsala. ....	133
Table 6.4 Areal comparison of various LULC classes under different trajectories in Dharamsala in 2021 and 2040. ....	136
Table 6.5 Agreement/disagreement based on the accuracy with which the quantity and location are predicted for 2021 LULC in Pithoragarh. ....	136

Table 6.6 Areal comparison of various LULC classes under different trajectories in Pithoragarh in 2021 and 2040.....	138
Table 6.7 Area (km <sup>2</sup> ) and proportion (%) of five LCR classes within urban extent in Dharamsala under three land use land cover trajectories for the year 2040. ....	146
Table 6.8 Area (km <sup>2</sup> ) and proportion (%) of five LCR classes within urban extent in Pithoragarh under three LULC trajectories for the year 2040.....	153
Table 4A.1 Details of satellite data used for Land use land cover map synthesis. ....	246
Table 4A.2 LULC classes used in current study. Note: Here the classes with an asterisk (*) are of both Pithoragarh and Dharamsala, except waterbody.....	246
Table 5A.1 Five-day antecedent rainfall in Dharamsala. Data of the nearest point were retrieved from the IMD gridded datasets .....	247
Table 5A.2 Five-day antecedent rainfalls in Pithoragarh. Data of the nearest point were retrieved from the IMD gridded datasets. ....	247
Table 5A.3 Maximum light use efficiency ( $\epsilon_{(max)}$ ) values of various LULC types adopted from (Nayak <i>et al.</i> (2010). ....	247
Table 5A.4 Range of RESs classes obtained using natural jenks classification scheme in Dharamsala for 2002-2021. ....	252
Table 5A.5 Range of RESs classes obtained using natural jenks classification scheme in Pithoragarh for 2001-2021.....	253
Table 6A.1 Transitional probabilities estimated for different LULC classes for 2021 in Dharamsala. ....	262
Table 6A.2 Transitional probabilities estimated for different LULC classes for BAU 2040 in Dharamsala. ....	262
Table 6A.3 Transitional probabilities estimated for different LULC classes for ESP 2040 in Dharamsala. ....	263
Table 6A.4 Transitional probabilities estimated for different LULC classes for SED 2040 in Dharamsala. ....	263
Table 6A.5 Transitional probabilities estimated for different LULC classes for 2021 in Pithoragarh. ....	264

Table 6A.6 Transitional probabilities estimated for different LULC classes for BAU 2040 in Pithoragarh.....	264
Table 6A.7 Transitional probabilities estimated for different LULC classes for ESP 2040 in Pithoragarh.....	264
Table 6A.8 Transitional probabilities estimated for different LULC classes for SED 2040 in Pithoragarh.....	265
Table 6A.9 Driving models of CORDEX-WAS-44 under RCM RegCM4-4 provided by Indian Institute of Tropical Meteorology (IITM).....	265
Table 6A.10 Driving models of NASA NEX GDPP climate datasets.....	265
Table 6A.11 Range of RESs classes obtained using natural jenks classification scheme in Dharamsala for year 2040.....	268
Table 6A.12 Range of RESs classes obtained using natural jenks classification scheme in Pithoragarh for year 2040.....	268

## LIST OF ABBREVIATIONS

AI	Aggregation Index
AMC	Antecedent Moisture Condition
APAR	Absorbed Photosynthetically Active Radiation
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BAU	Business-As-Usual
CASA	Carnegie Ames Stanford Approach
CBD	Conservation on Biological Diversity
CICES	Common International Classification of Ecosystem Services
CL	City Level
CMIP5	Coupled Model Intercomparison Project Phase 5
CN	Curve Number
CORDEX	COordinated Regional Climate Downscaling EXperiment
CS	Carbon Sequestration
DEM	Digital Elevation Model
EPCS	Ecological Priority Conservation Sites
EPRS	Ecological Priority Restoration Sites
ESB	Ecosystem Service Bundle
ESP	EcoSystem Protection
ESs	Ecosystem Services
ESTARFM	Enhanced Spatial and Temporal Adaptive Reflectance Fusion Model
ETM+	Enhanced Thematic Mapper Plus
FLAASH	Fast Line-of-sight Atmospheric Analysis of Hypercubes
FR	Flood Regulation
GEE	Google Earth Engine
GIS	Geographic Information Systems
GLOCHAMORE	Global Change and Mountain Regions
HSG	Hydrologic Soil Group
IGBP	International Geosphere-Biosphere Program

IHDP	International Human Dimensions Programme on Global Environmental Change
IHR	Indian Himalayan Ranges
IITM	Indian Institute of Tropical Meteorology
IMD	Indian Meteorological Department
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
ISRO	Indian Space Research Organisation
LCM	Land Change Modeller
LCR	Local Climate Regulation
LMs	Landscape Metrics
LPI	Largest Patch Index
LSI	Landscape Shape Index
LST	Land Surface Temperature
LUE	Light Use Efficiency
LULC	Land Use Land Cover
MEA	Millennium Ecosystem Assessment
MEs	Mountain Ecosystems
MLC	Maximum Likelihood Classification
MMF	Morgan Morgan Finney Model
MOVING	Mountain Valorisation through Interconnectedness and Green growth
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NEX-GDPP	NASA's Earth Exchange Globally Downscaled Projections
NPP	Net Primary Productivity
OLI	Operational Land Imager
OZL	Outer Zone Level
PD	Patch Density
PES	Payment for Ecosystem Services
RCP	Representative Concentration Pathways
RES	Regulating Ecosystem Services



SDGs	Sustainable Development Goals
SEA	Strategic Environmental Assessment
SED	Socio-Economic Development
SER	Soil Erosion Regulation
SHDI	Shannon's Diversity Index
SHP_MN	Mean Shape Index
SLUSI	Soil and Land Use Survey of India
TEEB	The Economics of Ecosystem and Biodiversity
UK NEA	United Kingdom National Ecosystem Assessment
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Environment Protection



Co-funded by the  
Erasmus+ Programme  
of the European Union



## Last Page

The appended material is based on research carried out at the partner institution of URGENT Project, and has potentially utilised the equipment support, inputs based on course revised/developed and training programs (*lecture series, research seminar and webinars*) through the URGENT Project.

The document is part of thesis part of PhD/MSc/MA research work carried out at the Jawaharlal Nehru University. Purposefully limited pages are shared to avoid copyright and other issues. However, the full thesis can be shared on request.

The complete thesis can be obtained from Prof P K Joshi ([pkjoshi27@hotmail.com](mailto:pkjoshi27@hotmail.com) or [pkjoshi@mail.jnu.ac.in](mailto:pkjoshi@mail.jnu.ac.in)).