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The role of geospatial training in empowering women for environmental decision-making policies

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Abstract

Women significantly contribute to the development in geospatial technologies and their applications for remote sensing, showing scientific excellence and innovative approaches in different environmental domains. This research article presents a review of the contribution of women to geospatial studies and their potential to further the course of sustainable development by way of a critical literature review and capacity-building analysis. The results show that women researchers lead in introducing new methodologies on geospatial technologies, from developing new methods for monitoring with drones to further developing machine learning applications in environmental assessment. Women-led research covers important topics in wetland monitoring, studies of the effects of climate change, water quality management, and precision agriculture. These contributions contribute directly to several Sustainable Development Goals (SDG), particularly SDG5 (Gender Equality) and SDG6 (Clean Water and Sanitation). This study concludes that participation by women in geospatial science is highly necessary in solving complex problems of the environment with divergent viewpoints and their solutions. Further recommendations include an increase in targeted training, the use of inclusive approaches in research, the provision of mentorship opportunities, and integrating the leadership of women into environmental policy frameworks in view of achieving sustainable development goals.

Keywords: Gender equality, Geospatial training, Remote Sensing, GIS, Sustainable Development Goals.

1. Introduction

The geospatial technology industry has emerged as a means of addressing some of the world's most critical environmental concerns, from tracking climate change to water resource management and preserving biodiversity (Dwivedi et al., 2022; Rai et al., 2022; Srivastava et al., 2022). With the continued advancement of satellite imagery, remote sensing, Geographic Information Systems (GIS), and aerial drone technologies, their applications have been expanded in diverse sectors (Manfreda et al., 2018; Para, 2022), like environmental monitoring, natural disaster management, urban planning, and sustainable resource management.

Even as the discipline becomes increasingly important, there is a vast gender divide in geospatial research and technology development (McLafferty, 2005). Women make up only 30% of researchers, and a much smaller percentage work on remote sensing and geospatial technologies (UNESCO, 2019). This underrepresentation is even more troubling with the growing evidence that diverse groups of researchers produce more innovative solutions as well as comprehensive solutions to environmental problems (Ceci and Williams, 2011; Konkel, 2015; Fernandez-Bou et al., 2021). The lack of gender diversity in geospatial sciences is not only a missed opportunity for scientific advancement but also limits the capacity of the discipline for addressing global issues with diversity of ideas and approach (Reich and Reich, 2006; Marín-Spiotta et al., 2020; Mogk, 2021).

Recent studies including DiGiacomo et al. (2020, 2022); Hanlon et al. (2022); Huelsman et al. (2022); Joyce et al. (2022); Parkinson (2022); Rivarola et al. (2022); Carvalho et al. (2023); Fontana et al. (2023); Karale and Yuan et al. (2023); Krause et al. (2023); Mattilio et al. (2023); Southworth et al. (2023); Vogeler et al. (2023); and Yang et al. (2023), identified noteworthy contributions of women researchers in geospatial sciences in terms of scientific merit and innovative thinking across different environmental contexts. Pioneering novel drone-based water sampling techniques to advancing the application of machine learning in soil degradation mapping, women's research is propelling the geospatial technology potential (Hanlon et al., 2022; Huelsman et al., 2022; Aboutaib et al., 2023; Hosseini et al., 2023;). These advancements span most of the important domains from coastal wetland monitoring to air quality assessments, forest ecosystem analysis, and climate change impact studies (Wu et al., 2017; Demarquet et al., 2023). The contribution of women's participation in geospatial research goes beyond specific scientific studies but has broader impacts for sustainable development. Geospatial technology assists in solving some of the environmental challenges, e.g., water security, climate adaptation, and natural resource management, that disproportionately affect women, particularly in the developing world. Involvement of women in co-developing

technological solutions to such challenges is crucial in offering important insights that can render the applications more relevant, accessible, and impactful.

In addition, the geospatial technology capacity of women directly supports several of the United Nations Sustainable Development Goals (SDGs), viz., SDG5 (Gender Equality) and SDG6 (Clean Water and Sanitation). Geospatial technology skill building for women not only helps in narrowing the gender gap in Science, Technology, Engineering, and Mathematics (STEM) but also increases the capacity to address environment-related issues that are central to sustainable development.

This piece explores the current landscape of women's contributions to geospatial research, examining how they are pushing innovations in environmental monitoring and sustainable development. For this aim, we conduct an extensive investigation of the literature, especially considering and starting from the special issues 'Women in Remote Sensing' and 'Women in Environmental Informatics and Remote Sensing' (Southworth et al., 2023; Dąbrowska et al., 2024). These issues were presented by the 'Frontiers in Remote Sensing' journal in 2022 and 'Frontiers in Environmental Science' in 2024, with women as leading authors to promote and celebrate the research of women researchers. We examine the extensive methodological approaches employed by women researchers, ranging from the traditional remote sensing techniques to novel applications of machine learning and artificial intelligence. Furthermore, we examine significant training initiatives whose goal is to increase women's participation in geospatial technology, paying particular attention to capacity development programs in the developing world, such as the Hindu Kush Himalaya (HKH) region.

By documenting and analysing these contributions, this research aims to demonstrate the essential role of gender diversity in geospatial sciences and monitor potential avenues for increasing women's participation in the field of this crucial discipline. The findings presented here, in addition to praising the achievements of women researchers, are also a basis for developing more inclusive and efficient strategies in geospatial technology training and application towards ultimately providing more sustainable and equitable environmental solutions.

This review of women in geospatial technology first considers the persistent issues of underrepresentation and gender bias in STEM through a review of current publishing practices and systemic barriers; then it explores the likely impacts of dedicated training programs for women, focusing on the training series of SERVIR-Hindu Kush Himalaya (SERVIR-HKH) Women in Geoinformatics. Lastly, these aspects are linked to establish that, at the core, contributions by women and inclusive capacity building drive innovation in environmental sciences toward gender equality and sustainable development. Adopting an approach in this way allows the researcher not only to document successes but also to outline concrete pathways toward increasing

women's participation and leadership in geospatial technology and environmental decision-making.

2. Methods for thematic review

A thematic review of primary and secondary literature (articles, books, and online repositories) led by women as first authors was conducted on the application of geospatial technology in the different realms of Earth (Table 1). This review aims to highlight the contributions of female researchers in the field, recognizing their pivotal role in advancing methodological approaches implemented and the applications that leverage geospatial technologies. This investigation allowed for a comprehensive understanding of how female researchers address complex environmental issues, ranging from land-use planning to disaster management and water management studies.

The special issue 'Women in Remote Sensing' features articles by various researchers, including DiGiacomo et al. (2020, 2022); Hanlon et al. (2022); Huelsman et al. (2022); Joyce et al. (2022); Parkinson (2022); Rivarola et al. (2022); Carvalho et al. (2023); Fontana et al. (2023); Karale and Yuan et al. (2023); Krause et al. (2023); Mattilio et al. (2023); Southworth et al. (2023); Vogeler et al. (2023); and Yang et al. (2023). The articles from the 'Women in Environmental Informatics and Remote Sensing' special issue comprise Aboutaib et al. (2023); Alberton et al. (2023); Hosseini et al. (2023); Montereale Gavazzi et al. (2023); Prokop et al. (2023); Ramos et al. (2023); and Worsa-Kozak et al. (2024) (Table 1). An extensive review study carried out by Bangira et al. (2022) was included, apart from the above-mentioned special issues, to incorporate the scope of remote sensing in the water quality monitoring. In addition, the study of the GNSS and InSAR applications for mapping landslide susceptibility and long-term subsidence carried out by Kulsoom et al. (2023) and Kakar et al. (2024) in the regions of Pakistan was also emphasized (Table 1).

2.1. The WoGIT by SERVIR-HKH

A series of training series "Women in Geospatial Information Technology (WoGIT)," was organized by The International Centre for Integrated Mountain Development (ICIMOD) under the SERVIR-HKH initiative in 2018 (ICIMOD, 2018) with the motive to empower women in geospatial technology and to bridge the gender imbalance in this technology sector (Thapa et al., 2019). The geospatial concepts and their applications in different environmental fields were introduced to women participants

Author(s)	Total Studies	Publication Years	Countries/ Regions	Research Categories	Geographic Region
	24	2020-2024	15+	8	
	Year	Research Focus	Methodology/ Technology	Key Findings/ Contributions	
Joyce et al.	2022	Diversity in Remote Sensing Publishing **Remote sensing**	Academic publishing analysis	Revealed gender and country bias in remote sensing publishing; proposed diversity action plan	Global
DiGiacomo et al.	2020, 2022	Coastal Wetland Monitoring **Drone**	UAS-based mapping vs. ground-based methods	UAS more effective for large-scale wetland monitoring; need for standardization	Southeastern USA
Hanlon et al.	2022	Water Quality Monitoring **water-quality drone**	Drone water sampling for cyanotoxins	Developed sophisticated protocol for hazardous freshwater monitoring	Ohio & Virginia, USA
Huelsman et al.	2022	Biodiversity Conservation **drone**	UAV-based spectroscopy	Advanced plant species identification and invasive species detection	Not specified
Prokop et al.	2023	River Monitoring **Drone machine-learning**	Drone + Deep Learning (U-Net)	End-to-end system for automated river pollution monitoring	Settlement areas
Aboutaib et al.	2023	Gully Erosion Assessment **machine-learning**	Random Forest, SVM, Logistic Regression	12% of areas studied require erosion action; vulnerability mapping	Mountainous/ semi-arid regions
Hosseini et al.	2023	Soil Property Prediction **machine-learning satellite**	Hybrid CNN-RNN with satellite imagery	Superior accuracy in soil physical/chemical property prediction	Not specified
Herrmann et al.	2023	Highland Grassland Fires **machine-learning**	Machine learning for fire analysis	Revealed discrepancies in authorized vs. actual burned areas	Brazil's Atlantic Forest
Karale & Yuan et al.	2023	Air Quality Monitoring **satellite machine-learning**	CNN with satellite data + ground measurements	Enhanced PM2.5 concentration estimation and air quality monitoring	Not specified
Carvalho et al.	2023	Coastal Morphological Dynamics **satellite**	Landsat imagery + Google Earth Engine	Long-term environmental monitoring of tropical barrier island	Brazil
Rivarola et al.	2022	Biodiversity Conservation **satellite**	NDVI analysis (2000-2020)	Assessed Park effectiveness in preventing biodiversity loss	Argentina (Nahuel Huapi National Park)
Southworth et al.	2023	Environmental Change Monitoring **satellite climate**	NDVI time series analysis	Climate and land-use change impact assessment	Not specified
Fontana et al.	2023	Urban Expansion Monitoring **satellite**	Historical Landsat data + spatial modeling	Tracked urban expansion for planning strategies	Porto Alegre, Brazil
Montereale Gavazzi et al.	2023	Marine Ecosystem Impact **remote sensing**	Integrated remote sensing technologies	Assessed fisheries impact on stony reefs; biodiversity loss documentation	Belgian waters

Author(s)	Total Studies	Publication Years	Countries/ Regions	Research Categories	Geographic Region
	24	2020-2024	15+	8	
	Year	Research Focus	Methodology/ Technology	Key Findings/ Contributions	
Parkinson	2022	Arctic Sea Ice Monitoring **climate satellite**	43-year satellite data analysis	Documented decreasing ice concentration and season lengths	Arctic
Vogeler et al.	2023	Forest Structure Modeling **satellite**	GEDI satellite data for predictive modeling	Enhanced forest ecosystem understanding and wildlife habitat modeling	Not specified
Krause et al.	2023	Forest Biomass Estimation	Terrestrial laser scanning	Improved biomass estimation accuracy	Not specified
Yang et al.	2023	Forest Management	Citizen science approach	Enhanced stakeholder engagement in environmental decision-making	Southeastern U.S.
Worsa-Kozak et al.	2024	Post-mining Heat Islands **satellite climate**	23-year Landsat thermal monitoring	Developed thermal activity monitoring methodology; identified climate hazards	Poland
Alberton et al.	2023	Leaf Phenology **remote sensing**	Phenocameras + remote sensing	Environmental aridity effects on plant responses and carbon exchange	Tropical ecosystems
Ramos et al.	2023	Tropical Ecosystem Phenology **remote sensing**	Remote sensing for phenology analysis	Insights into photosynthetic dynamics and ecosystem productivity	Tropical ecosystems
Mattilio et al.	2023	Precision Agriculture **machine-learning**	Machine learning for invasive species mapping	High-accuracy classification for leafy spurge control	Not specified
Bangira et al.	2023	Water Quality Monitoring Review **water-quality satellite**	Systematic review of RS in WQI monitoring	20-year boom in RS usage; Chl-a and TSS extensively studied with Landsat/Sentinel-2	Africa
Kulsoom et al.	2023	Landslide Susceptibility Mapping	Satellite InSAR SBAS-InSAR techniques	Validated landslide susceptibility model integrating SBAS-InSAR deformation measures with topographic, geological, and environmental parameters	Gilgit-Baltistan, Pakistan (Karakoram Highway)
Kakar et al.	2024	Ground Subsidence Monitoring	Satellite InSAR GNSS + Sentinel-1 InSAR integration	Long-term subsidence monitoring revealing ground deformation patterns linked to excessive groundwater extraction	Quetta and Mastung Districts, Balochistan, Pakistan

Table 1. *Literature Review: Women's Contribution in Geospatial Studies Author(s).*

from Nepal, Pakistan, Afghanistan, Bhutan, and Bangladesh (Figure 1). Contrasting training dimensions were customized for the participants belonging to different countries (Table 2). The training project allows to analyse the spatial distribution and number of women from these countries involved in the training and to evaluate the impact of these programs on women's geospatial scientific knowledge growth.

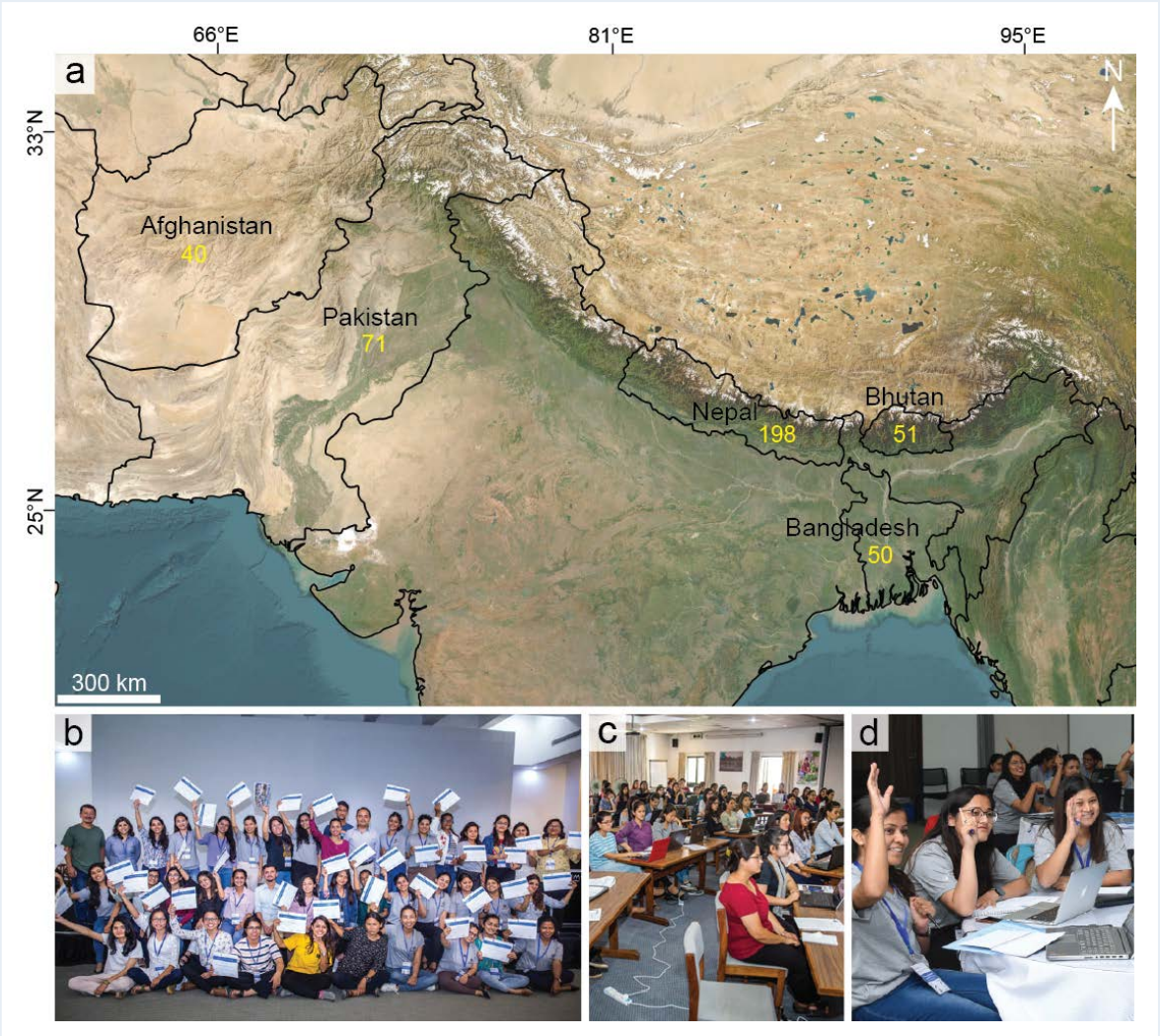

Figure 1. *(a) Spatial distribution of women participants from the Hind Kush Himalayan (HKH) region in the training using the data from Tripathi et al. (2022) and Google Earth imagery 2025. (b), (c), (d) Pictures from the in-person training workshops (modified from Tripathi et al., 2022).*

In this study, we collected spatial distribution data, the number of participants involved from each country, and pre-and post-training surveys of the level of understanding of participants based on the training (2021) (Tripathi et al., 2022) to assess the influence of this training on women's geospatial scientific knowledge growth, which shows a positive shift in scientific knowledge of the participants post-training (Figures 1 and 2). Putting together all the literature studies, the data,

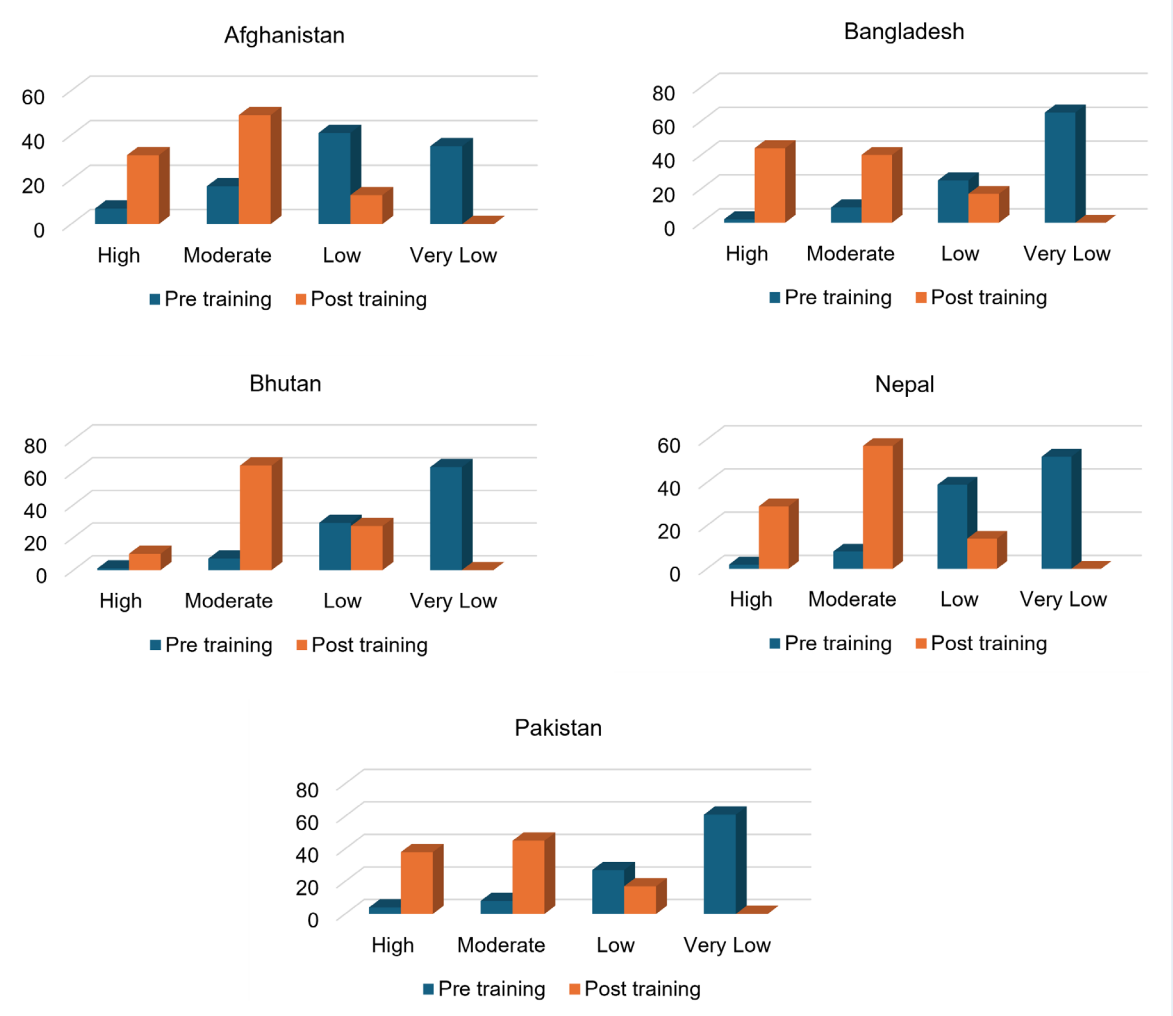

Figure 2. *Pre- and post-training survey showing the training improved the scientific knowledge of participants which is evidenced by positive shift in the number of participants in post training in all categories (modified from Tripathi et al., 2022).*

and the survey analysis from the SERVIR-HKH training initiative, it was possible to figure out the effectiveness of the geospatial technology training for women who belong to the different strata of society and the educational system.

3. Literature review for women's contribution in geospatial studies

These advances in geospatial research demonstrate the potential and contribution of women; at the same time, formidable systemic barriers persist to fuller participation and benefits derived therefrom. Gaps can be addressed through recognition of achievements from the past and investment in targeted training/support programs, including the WoGIT initiative that gives hands-on skills and opportunities to women in the field of geospatial. This review discusses not only the challenges faced by women in geospatial publishing but also their valuable contributions within a wide range of environmental applications.

Joyce et al. (2022) examined the lack of diversity in remote sensing academic publishing, revealing a gender and country of residence bias, with most editors being men from four countries. The study also highlights challenges faced by underrepresented communities, such as implicit bias and harsh reviews. It proposes an action plan to promote diversity and inclusivity, encouraging individuals to consider their roles in the field.

The Unoccupied Aircraft Systems (UAS)-based monitoring of coastal wetlands is more effective than ground-based methods due to its large-scale understanding of the wetland system (DiGiacomo et al., 2020, 2022). However, UAS-based mapping techniques lack standardization, which can be overcome by proper flight planning and survey design (DiGiacomo et al., 2022). Comparing UAS mapping results from the Southeastern USA with ground-based survey data shows similar estimations after adequate planning. DiGiacomo et al. (2022) use UAS for monitoring coastal wetland habitats, demonstrating its potential in large-scale ecological assessments. Hanlon et al. (2022) have utilized the unique drone water sampling technique for the characterization of cyanotoxins, phycocyanin, and nutrients in Grand Lake Saint Marys (GLSM), Lake Erie in Ohio, USA, and Lake Anna in Virginia, USA. The sampling method provides a sophisticated and immediate protocol for potentially hazardous surface waters on freshwater lakes. Huelsman et al. (2022) advanced remote sensing methods for biodiversity conservation by using drones for plant species identification, highlighting the potential of UAV-based spectroscopy to differentiate between invasive plant species. Prokop et al. (2023) also highlight the use of drones to monitor the rivers that gush in the settlement areas which are often under the

threat of environmental pollution. They proposed an end-to-end system, where a drone takes the measurements from the area, including the river, which is then automatically processed with deep learning on the server, and the outcome is a segmentation mask (from the U-Net network).

Aboutaib et al. (2023) evaluated the effectiveness of machine-learning models in determining vulnerability to water flow-induced gully erosion in mountainous and semi-arid regions with the Random Forest, Support Vector Machine, and Logistic Regression methods. In contrast, Hosseini et al. (2023) used a hybrid Convolutional Neural Network-Recurrent Neural Networks (CNN-RNN) deep learning model with satellite imagery and environmental parameters to predict soil physical and chemical properties, showing superior accuracy over individual models. Herrmann et al. (2023) also applied machine learning techniques to study highland grassland fires in Brazil's Atlantic Forest Biome, revealing discrepancies between authorized and actual burned areas, guiding policy revision and environmental governance.

By combining satellite data with ground measurements, Karale and Yuan et al. (2023) enhance the estimation of particulate matter (PM) concentrations in PM2.5 using CNN. The investigation of Carvalho et al. (2023) highlights the importance of long-term environmental monitoring by geospatial analysis (using Landsat imagery and Google Earth Engine) and environmental science to study the morphological dynamics of a tropical barrier island in Brazil. Rivarola et al. (2022) assessed Nahuel Huapi National Park's effectiveness in preventing biodiversity loss and habitat degradation using the Normalized Difference Vegetation Index (NDVI) from 2000 to 2020.

Southworth et al. (2023) and Fontana et al. (2023) have used remote sensing and time series analysis to monitor environmental change. Southworth et al. (2023) used NDVI to assess climate and land-use change impacts, while Fontana et al. (2023) used historical Landsat data and spatial modelling to track urban expansion in Porto Alegre, Brazil. Both studies highlight the importance of satellite-based time series data in capturing landscape transformations and informing ecological and urban planning strategies. With the integrated use of remote sensing technologies, Montereale Gavazzi et al. (2023) examined the ecological impact of bottom-contact fisheries on stony reefs in Belgian waters, highlighting the loss of biodiversity due to human activities disrupting natural habitats. Parkinson (2022) addresses the impacts of climate change by reporting on the dwindling Arctic Sea ice concentration and decreasing ice season lengths over the past 43 years, causing alarm for the Earth's climate system. A similar thread of climate change is followed by Vogeler et al. (2023), who explored the use of satellite data, specifically Global Ecosystem Dynamics Investigation GEDI, in creating predictive forest structure models, assessing biodiversity, and modelling wildlife habitats, thus enhancing our

comprehension of forest ecosystems. Krause et al. (2023) and Yang et al. (2023) focused on the forest and land-use research using innovative methodologies to improve data accuracy and stakeholder engagement. Krause et al. (2023) used terrestrial laser scanning for biomass estimation, while Yang et al. (2023) opted for citizen science to examine forest management and land-use transitions in the southeastern U.S., highlighting the importance of public participation in environmental decision-making. Worsa-Kozak et al. (2024) studied the post-mining heat island in Poland using Landsat satellite data. They developed a methodology for remote thermal activity monitoring over 23 years, using self-heating intensity index and air temperature thermal indicator to identify thermal hotspots and highlight environmental hazards from spontaneous combustion and greenhouse gas emissions. Beyond the optical remote sensing approaches, women researchers are making key developments in InSAR applications for the monitoring of natural hazards in challenging mountainous and semi-arid areas. Kulsoom et al. (2023) present the application of SBAS-InSAR techniques for mapping landslide susceptibility along the Karakoram Highway in Gilgit-Baltistan, Pakistan. This study develops a validated model of landslide susceptibility through the integration of the SBAS-InSAR deformation measures and parameters that are topographic, geological, and environmental in nature. Similarly, Kakar et al. (2024) integrated GNSS and Sentinel-1 InSAR data for the long-term subsidence monitoring of Quetta and Mastung Districts, Baluchistan, Pakistan. Their integrated approach has revealed significant ground deformation patterns linked to the excessive extraction of groundwater in water-stressed areas. Alberton et al. (2023) and Ramos et al. (2023) investigated the leaf phenology in tropical ecosystems, emphasizing its role in carbon exchange and ecosystem productivity. By using phenocameras and remote sensing, these studies reveal how environmental aridity affects plant responses, which is essential for understanding photosynthetic dynamics. Similarly, Mattilio et al. (2023) showcase precision agriculture by mapping leafy spurge infestations using a novel machine learning application. Their research, based on high-accuracy classification models, offers insights into controlling invasive species for sustainable land management.

The systematic review of the literature was carried out by Bangira et al. (2023), on the scope of RS in the water quality monitoring Water Quality Indicators (WQIs) in the reservoirs of Africa. Their study reveals the boom of the usage of the remote sensing approach over the past 20 years in monitoring water quality. Their results also reveal that WQIs like chlorophyll-a (Chl-a) and suspended solids (TSS) have been studied extensively in Africa with the aid of Landsat and Sentinel-2 imageries.

4. Results and discussion

4.1. Geospatial approaches driving sustainable development

From the investigation of peer-reviewed articles and books, including women as leading authors in the geospatial technology research enhances the diversity of perspectives, which broadens both the relevance and scientific scope of findings. Although contributions from both women and men across various subfields are substantial, ensuring equitable representation is essential for fostering innovation and achieving sustainable development goals (Table 1).

The diverse geospatial approaches were implemented; including the use of drones and Unoccupied Aircraft Systems (UAS) for water sampling, coastal wetland habitat monitoring, environmental and biodiversity conservation and monitoring rivers (DiGiacomo et al., 2022; Hanlon et al., 2022; Huelsman et al., 2022; Rivarola et al., 2022; Carvalho et al., 2023; Karale and Yuan, 2023; Mattilio et al., 2023; Prokop et al., 2023; Vogeler et al., 2023; Yang et al., 2023), application of Machine and deep learning to determine physical and chemical properties of soil, erosion and identify vulnerable sites in semi-arid and soil degradation mapping (Aboutaib et al., 2023; Herrmann et al., 2023; Hosseini et al., 2023), monitoring of air and water quality and Arctic Sea ice (Parkinson, 2022; Bangira et al., 2023; Karale and Yuan, 2023) and to determine the adverse impacts of climate change (Parkinson, 2022; Fontana et al., 2023; Krause et al., 2023; Montereale Gavazzi et al., 2023; Southworth et al., 2023; Vogeler et al., 2023; Worsa-Kozak et al., 2024).

There are 30% of women researchers in the world with a small proportion in the field of remote sensing (UNESCO, 2019; Southworth et al., 2023). Despite this disparity, our literature investigation suggests that the articles authored by women as leading authors demonstrate scientific excellence. These research articles reveal the rich tapestry of the combination of geospatial technology used to tackle environmental challenges, especially in remote and far-flung and populated and also emphasize the need for greater representation in academia. They showcase women's significant contributions in remote sensing field and lay the groundwork for future research and represent a significant milestone in advancing gender equality, technology, and environmental science, highlighting the diversity and collaborative potential within the field (DiGiacomo et al., 2020, 2022; Hanlon et al., 2022; Huelsman et al., 2022; Joyce et al., 2022; Parkinson, 2022; Rivarola et al., 2022; Southworth et al., 2023; Aboutaib et al., 2023; Alberton et al., 2023; Carvalho et al., 2023; Fontana et al., 2023; Hosseini et al., 2023; Karale and Yuan, 2023; Krause et al., 2023; Mattilio et al., 2023; Montereale Gavazzi et al., 2023; Prokop et al., 2023; Ramos et al., 2023; Southworth et al., 2023; Vogeler et al., 2023; Yang et al., 2023;

Dąbrowska et al., 2024; Worsa-Kozak et al., 2024). Importantly, they underscore the critical role of gender equality in promoting Sustainable Development Goal (SDG5). The study of Joyce et al. (2023) highlights the gender bias in remote sensing academic publishing, highlighting the underrepresentation of women and diverse voices. The research underscores the need for inclusive practices promoting gender equality in science and academia, as diverse perspectives can enhance innovation and tackle environmental challenges, aligning with the SDG5 goal. The United Nations Educational, Scientific and Cultural Organization (UNESCO) highlights SDG5, which emerged in 2015 with the aim of "achieving gender equality and empowering all women and girls" (United Nations, 2021; Küfeoğlu, 2022). UNESCO emphasizes science and gender equality to change the traditional mindset, end the biases, and defeat the stereotypes against women (UNESCO, 2019).

The innovative water sampling methodology developed by Hanlon et al. (2022) is crucial for sustainable water management by providing advanced techniques for monitoring water quality in freshwater bodies, ensuring clean and safe water access for communities, which supports SDG6. Access to clean and safe water is crucial for women, who often bear the burden of water collection in many communities. Over the past 20 years the advancement in remote sensing technology has improved the accuracy of water quality monitoring, as discussed by Bangira et al. (2023), and the inclusion of easier ways of sampling of water has provided a way for better water management. The research articles dedicated to water quality monitoring and groundwater prospecting (Bangira et al., 2023) shed light on the effective use of remote sensing and GIS techniques to manage water resource sustainability and assess the groundwater resources. These studies provide valuable insights that are beneficial for effective water management but also highlight important findings that directly or indirectly support the achievement of the SDG6, which aims to ensure safe drinking water and sanitation.

4.2. Training women in geospatial technology

Women frequently face barriers in the workplace in developing nations, such as discrimination at work, insufficient maternity policies, and few opportunities for career advancement. Many qualified women leave the industry or are discouraged from entering the industry because of this hostile environment. Geospatial training programs can help address these issues by providing women with the necessary skills and knowledge to thrive in this field. As highlighted in the literature studies above, gender and cultural diversity in geospatial research generated broader solutions for tackling issues related to sustainability. Given persisting obstacles to women's

participation, specific programs such as the SERVIR-HKH WoGIT training series are vital for encouraging equity and enhancing the discipline's capacity to solve environmental challenges. The ICIMOD developed the SERVIR-HKH initiative, which was aimed at providing geospatial technology training to the young and early-career women of third-world countries (Thappa et al., 2019; Tripathi et al., 2022). SERVIR is a joint initiative of The United States Agency for International Development (USAID) and the National Aeronautics and Space Administration (NASA) and geospatial organizations in Asia, Africa, and Latin America, collaborates with countries to tackle climate change, food security, water and disasters, land use, and air quality using satellite data and geospatial technology. The robust assessment, design, implementation, and monitoring (ADIM) approach was developed by SERVIR-HKH with different training types (both in-person and remote) to promote capacity building, active user engagement, and the development of new partnerships (Thapa et al., 2021; Tripathi et al., 2022). This approach was oriented to assess the country-specific gaps, preparing the customized material for users belonging to different countries. SERVIR-HKH initiative initiated the "Empowering Women in Geoinformatics" (WoGIT) training series between 2018 to 2021 to promote a gender-balanced workforce of young women (STEM) professionals in the Hindu Kush Himalaya (Thapa et al., 2019; Tripathi et al., 2022). The HKH region is characterized by complex topography, temperature variability, and ecological diversity. The region faces numerous challenges, including melting glaciers, environmental changes, globalization, and socioeconomic pressures (Ebi et al., 2007; Wester et al., 2019). Nine trainings (two in-person and seven virtual) focused on geospatial technology, including water management, have been organized in five countries of this region (Nepal, Pakistan, Afghanistan, Bhutan, and Bangladesh) from 2018 to 2021 benefiting 410 women (Tripathi et al., 2022) (Figures 1 and 2). The training covered different topics in the geospatial domain utilizing the open-source mapping, image calculation, stream delineation, SERVIR-HKH services, and customized materials for country-specific needs. The training was provided based on geospatial technology and effective use of GIS regarding different topics from water management to glacial studies (Table 2).

Highest engagement of women in training sessions belongs to Nepal with 198 participants which is followed by Pakistan and Bhutan with 71 and 51 participants respectively. Bangladesh and Afghanistan represent the countries with the lowest engagement of women participants in this training (Figure 2).

The spatial distribution of the participants from different countries suggests that there is much awareness of the remote sensing or geospatial technology in Nepal and the women are highly encouraged to be in STEM. The previously organised women focused technology programme 'Miss Technology' has also played a part in the impressive participation of women in this training. Geopolitical tension between

countries was the main factor that limited the participation of women from other countries (Thappa et al., 2019).

Training	Country
Flood inundation mapping, damage assessment	Bangladesh
Drought mapping	Pakistan, Nepal
Agricultural drought, glacier dynamics applications	Afghanistan
Stream and catchment delineation	Bhutan

Table 2. *Geospatial themes focused during WoGIT training series.*

The other challenges include the traditional gender roles or less access to education and less availability of resources for women's training programs (Matin et al., 2021). However, Pakistan has satisfactory infrastructure and capacities for utilizing the geospatial data extensively, but it lacks platforms for sharing geospatial data beyond single use (ICIMOD, 2016).

A survey was carried out at WoGIT 2021 before and after the training, which revealed that training significantly improved scientific knowledge and understanding of participants belonging to different countries (Figures 1 and 2). The number of participants in percentage from all the countries show positive shift in scientific knowledge post training, falling under the umbrella of high, moderate, low and very low scientific knowledge categories. For instance, Afghanistan, Bangladesh, Bhutan, Nepal, and Pakistan demonstrated significant improvement, with 31%, 42%, 9%, 27%, and 34%, respectively, post-training in the 'High' scientific knowledge level category (Figure 2). Bhutan stands out in the 'Moderate' category with a 56% increase in scientific knowledge level. The positive influence of the training is also clear from the reducing trend in the number of participants who reported having a 'low' or 'very low' scientific knowledge level post training. In all the countries, no participant demonstrated a very low level of understanding of the training and the scientific knowledge post training (Figure 2). Post-training, participants in Afghanistan, Bangladesh, Bhutan, Nepal, and Pakistan reported a decrease in 'low' scientific knowledge levels (28%, 8%, 2%, 25%, and 10%, respectively) (Figure 2).

The training programme (WoGIT series) has revamped the geospatial skills and improved the scientific knowledge, increased the skills in flood and drought assessment and policy making engagement of the women, which in turn rises their capability to tackle the environmental challenges of HKH region and promoting gender equality in the geospatial field. This directly backs the arguments that

improved inclusion and targeted support drive field advancement and progress towards SDG5 and SDG6.

These gains indeed reflect real improvements in technical capacity, thereby translating into increased involvement in environmental decision-making. Participants received hands-on training in several thematic areas: flood inundation mapping and damage assessment in Bangladesh, drought mapping and agricultural vulnerability assessment in Pakistan and Nepal, glacier dynamics applications in Afghanistan, and stream and catchment delineation in Bhutan. These enhanced capacities have a direct bearing on evidence-based policy formulation relating to the management of water resources, disaster preparedness, and climate adaptation in the HKH region. By transferring these capacities to and among women, training has laid out a clear pathway from technical capacity building to active environmental governance and policy processes, enabling the realization of SDG5 pertaining to gender equality in STEM and SDG6 on sustainable water management.

5. Message to address the gender gap

The above discussion of the studies proves the paramount importance of geospatial approaches proposed by women in geospatial technology fields and provides a clear understanding of its usefulness and the encouragement of women researchers in STEM. Initiatives to increase the inclusivity of women in geospatial research and training programs are critical initial steps in bridging the gender gap. However, maintaining sustainable diversity in geospatial research necessitates a change toward long-term inclusive practices, such as gender-neutral research teams, and policies that support a diverse range of viewpoints.

5.1. Sustainable methods for achieving gender equality in geospatial research

This calls for systematic changes, rather than temporary, in a number of important areas: inclusive hiring and promotion practices that actively recruit and advance women within the ranks in geospatial institutions; mentorship and professional development programs that team early-career women with established researchers; funding mechanisms that prioritize gender-balanced and women-led research teams; research environments that incorporate diverse perspectives in the design and implementation of studies; work-life balance policies that support women in all career stages, especially within developing countries.

The review of 'the WoGIT 2021 training program' by ICIMOD to train young women of HKH region in geospatial technology sheds light on the significance of the training to solve the environmental challenges including water management and the improvement of the scientific skills and knowledge level of the women. The WoGIT 2021 training series has been successful and reinforce concepts and encourages women to actively participate in water management and policy making.

5.2. Integration of training into policy frameworks

Similar training programs that empower women in scientific and policy-making fields related to the environment should be scaled up and integrated within national and regional environment policy frameworks. Such programs can build on existing momentum for women's leadership in environmental fields by integrating geospatial training into professional development curricula within environmental agencies, creating pathways for trained women to serve in decision-making bodies such as Water Management Committees, Environmental Planning Boards, and Climate Adaptation Task Forces, and facilitating knowledge transfer through a train-the-trainer model, in which WoGIT graduates mentor subsequent cohorts.
They can also enhance intersectoral collaboration by linking trained professionals with policymakers, NGOs, and community organizations. However, this must be attended by efforts to understand the challenges and obstacles that many women face-particularly those in developing countries-so greater participation in both virtual and in-class trainings can occur. Geospatial training should be made accessible to a larger and more diverse community of women, including students, ocean scientists, engineers, planners, natural resource managers, and policymakers, as well as those whose domestic responsibilities or cultural barriers limit their ability to engage in traditional workplaces.

5.3. Building capacity for environmental decision-making

The training will impart practical skills to the women in the application of remote sensing in the monitoring of water quality, assessment of the availability of the resource, and its efficient management to prepare them for active participation in policymaking. Participants acquire the following capabilities: Produce evidence-informed environmental assessments to underpin policy briefs. Communicate technical geospatial findings to nontechnical stakeholders. Contribute spatial data analysis to climate adaptation planning. Participate meaningfully in multi-stakeholder environmental governance processes. This direct capacity-building

approach addresses the gap in technical expertise and policy influence so that the voice of women, along with their analytical capacities, informs environmental decision-making at the local, national, and regional levels.

6. Conclusions and recommendations

This review discusses the uses of geospatial technology, focusing on the WoGIT 2021 training for women from developing countries. It highlights how such training amplifies women's contribution to geospatial science for gender equality and, consequently, SDG5 and SDG6. The WoGIT 2021 training, having been conducted for young women, especially those from Nepal, improved their skills in conducting assessments of flood and drought and increased their capacities to engage in policy processes. We recommend systemic and evidence-based approaches for long-term diversity in geospatial research. Institutions should explicitly work toward gender balance among research teams, actively encourage mentorship and networking, and provide an enabling environment to support women within the discipline. Successful initiatives such as WoGIT should be scaled up through national and regional policy frameworks to broaden the participant pool, including those who cannot access formal job opportunities. Integrating women who are trained in geospatial technology into environmental decision-making panels and policy development is necessary. We recommend multidisciplinary research teams and provide early-career female researchers with funding and publishing opportunities. Overcoming systemic barriers, which are particularly great in developing countries, will involve eliminating or at least reducing such barriers, providing resources, and offering equitable access to technology and networks. Targeted initiatives such as WoGIT can help boost women's technical competencies considerably and enable them to contribute to environmental decision-making. Scaling up these models into wider institutional and policy frameworks will accelerate progress toward gender equality and sustainable water management and enhance the potential of the geospatial field to address environmental challenges.

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References

Aboutaib F., Krimissa S., Pradhan B., Elaloui A., Ismaili M., et al., (2023). Evaluating the effectiveness and robustness of machine learning models with varied geo-environmental factors for determining vulnerability to water flow-induced gully erosion. Frontiers in Environmental Science, 11. https://doi.org/10.3389/fenvs.2023.1207027.

Alberton B., Martin T.C., Da Rocha H.R., Richardson A.D., Moura M.S., et al., (2023). Relationship between tropical leaf phenology and ecosystem productivity using phenocameras. Frontiers in Environmental Science, 11. https://doi.org/10.3389/fenvs.2023.1223219.

Bangira T., Matongera T.N., Mabhaudhi T., and Mutanga O., (2023). Remote sensing-based water quality monitoring in African reservoirs, potential and limitations of sensors and algorithms: A systematic review. Physics and Chemistry of the Earth, Parts A/B/C, 134. https://doi.org/10.1016/j.pce.2023.103536.

Carvalho B.C., Gomes C.L., and Guerra J.V., (2023). Spatio-temporal morphological variability of a tropical barrier island derived from the Landsat collection. Frontiers in Remote Sensing, 4. https://doi.org/10.3389/frsen.2023.1111696.

Ceci S.J., and Williams W.M., (2011). Understanding current causes of women's underrepresentation in science. PNAS, 108(8), 3157-3162. https://doi.org/10.1073/pnas.1014871108.

Dąbrowska D., Rivas Casado M., and Costa M.J., (2024). Editorial: Women in environmental informatics and remote sensing. Frontiers in Environmental Science, 12. https://doi.org/10.3389/fenvs.2024.1501739.

Demarquet Q., Rapinel S., Dufour S., and Hubert-Moy L., (2023). Long-Term Wetland Monitoring Using the Landsat Archive: A Review. Remote Sensing, 15(3), 820. https://doi.org/10.3390/rs15030820.

DiGiacomo A.E., Bird C.N., Pan V.G., Dobroski K., Atkins-Davis C., et al. (2020). Modeling Salt Marsh Vegetation Height Using Unoccupied Aircraft Systems and Structure from Motion. Remote Sensing, 12(14), 2333. https://doi.org/10.3390/rs12142333.

DiGiacomo A.E., Giannelli R., Puckett B., Smith E., Ridge J.T., et al., (2022). Considerations and tradeoffs of UAS-based coastal wetland monitoring. Frontiers in Remote Sensing, 3. https://doi.org/10.3389/frsen.2022.924969.

Dwivedi Y.K., Hughes L., Kar A.K., Baabdullah A.M., Grover P., et al., (2022). Climate change and COP26: Are digital technologies and information management part of the problem or the solution? An editorial reflection and call to action. International Journal of Information Management, 63. https://doi.org/10.1016/j.ijinfomgt.2021.102456.

Ebi K.L., Woodruff R., von Hildebrand A., and Corvalan C., (2007). Climate change-related health impacts in the Hindu Kush-Himalayas. EcoHealth, 4, 264-270. https://doi.org/10.1007/s10393-007-0119-z.

Fernandez-Bou A.S., Ortiz-Partida J.P., Dobbin K.B., Flores-Landeros H., Bernacchi L.A., et al., (2021). Underrepresented, understudied, underserved: Gaps and opportunities for advancing justice in disadvantaged communities. Environmental Science & Policy, 122, 92-100. https://doi.org/10.1016/j.envsci.2021.04.014.

Fontana A.G., Nascimento V.F., Ometto J.P., and Do Amaral F.H., (2023). Analysis of past and future urban growth on a regional scale using remote sensing and machine learning. Frontiers in Remote Sensing, 4. https://doi.org/10.3389/frsen.2023.1123254.

Hanlon R., Jacquemin S.J., Birbeck J.A., Westrick J.A., Harb C., et al., (2022). Drone-based water sampling and characterization of three freshwater harmful algal blooms in the United States. Frontiers in Remote Sensing, 3. https://doi.org/10.3389/frsen.2022.949052.

Hosseini F.S., Vahid S., Choi S., and Jamshidi M., (2023). Spatial prediction of physical and chemical properties of soil using optical satellite imagery: a state-of-the-art hybridization of deep learning algorithm. Frontiers in Environmental Science, 11. https://doi.org/10.3389/fenvs.2023.1279712.

ICIMOD (2016). Report of national consultation workshop on needs assessment for SERVIR-HKH in Pakistan. Workshop held on February 23 at Pakistan council of research in water resources (PCRWR), Islamabad.

ICIMOD (2018). Empowering Women in GIT. Training Report, Kathmandu.

Joyce K.E., Nakalembe C.L., Gómez C., Suresh G., Fickas K., et al., (2022). Discovering Inclusivity in Remote Sensing: Leaving No One Behind. Frontiers in Remote Sensing, 3. https://doi.org/10.3389/frsen.2022.869291.

Kakar N., Zhao C., Li G., and Zhao H., (2024). GNSS and Sentinel-1 InSAR Integrated Long-Term Subsidence Monitoring in Quetta and Mastung Districts, Balochistan, Pakistan. Remote Sensing, 16(9), 1521. https://doi.org/10.3390/rs16091521.

Karale Y., and Yuan M., (2023). Spatially lagged predictors from a wider area improve PM2.5 estimation at a finer temporal interval – A case study of Dallas-Fort Worth, United States. Frontiers in Remote Sensing, 4. https://doi.org/10.3389/frsen.2023.1041466.

Konkel L., (2015). Racial and Ethnic Disparities in Research Studies: The Challenge of Creating More Diverse Cohorts. Environmental Health Perspectives, 123(12), A297-A302. https://doi.org/10.1289/ehp.123-A297.

Krause P., Forbes B., Clark M., Disney M., Wilkes P., et al., (2023). Using terrestrial laser scanning to support biomass estimation in densely stocked young tree plantations. Frontiers in Remote Sensing, 34(24). https://doi.org/10.1080/01431161.2013.848308.

Kulsoom I., Hua W., Hussain S., Chen Q., Khan G., et al., (2023). SBAS-InSAR based validated landslide susceptibility mapping along the Karakoram Highway: a case study of Gilgit-Baltistan, Pakistan. Scientific Reports, 13, 3344. https://doi.org/10.1038/s41598-023-30009-z.

Küfeoğlu S., (2022). SDG-5 Gender Equality. In Emerging Technologies: Value Creation for Sustainable Development. Sustainable Development Goals Series. Springer, Cham. https://doi.org/10.1007/978-3-031-07127-0_7.

Manfreda S., McCabe M.F., Miller P.E., Lucas R., Pajuelo Madrigal V., et al., (2018). On the Use of Unmanned Aerial Systems for Environmental Monitoring. Remote Sensing, 10(4), 641. https://doi.org/10.3390/rs10040641.

Marín-Spiotta E., Barnes R.T., Berhe A.A., Hastings M.G., Mattheis A., et al., (2020). Hostile climates are barriers to diversifying the geosciences. Advances in Geosciences, 53, 117-127. https://doi.org/10.5194/adgeo-53-117-2020.

Mattilio C.M., Tekiela D.R., and Norton U., (2023). Remote mapping of leafy spurge (*Euphorbia esula*, L.) in Northwestern Colorado. Frontiers in Remote Sensing, 4. https://doi.org/10.3389/frsen.2023.1086085.

McLafferty S., (2005). Women and GIS: Geospatial Technologies and Feminist Geographies. Cartographica: The International Journal for Geographic Information and Geovisualization, 40(4), 37-45. https://doi.org/10.3138/1341-21JT-4P83-1651.

Mogk D.W., (2021). The intersection of geoethics and diversity in the geosciences. In Di Capua G., Bobrowsky P.T., Kieffer S.W., Palinkas C., (eds.), Geoethics: Status and Future Perspectives, Geological Society, London, Special Publications, 508, pp. 67-99. https://doi.org/10.1144/SP508-2020-66.

Montereale Gavazzi G., Paoletti S., Podholova P., Kapasakali D., and Kerckhof F., (2023). Protected yet unmanaged: insights into the ecological status of conservation priority stony reefs in Belgian waters based on the integrative use of remote sensing technologies. Frontiers in Environmental Science, 11. https://doi.org/10.3389/fenvs.2023.1253932.

Parkinson C.L., (2022). Arctic sea ice coverage from 43 years of satellite passive-microwave observations. Frontiers in Remote Sensing, 3. https://doi.org/10.3389/frsen.2022.1021781.

Rai P.K., Mishra V.N., and Singh P., (eds.) (2022). Geospatial Technology for Landscape and Environmental Management: Sustainable Assessment and Planning. Springer, Singapore. https://doi.org/10.1007/978-981-16-7373-3.

Ramos D.M., Andrade J.M., Alberton B.C., Moura M.S., Domingues T.F., et al., (2023). Multiscale phenology of seasonally dry tropical forests. Frontiers in Environmental Science, 11. https://doi.org/10.3389/fenvs.2023.1275844.

Reich S.M., and Reich J.A., (2006). Cultural Competence in Interdisciplinary Collaborations: A Method for Respecting Diversity in Research Partnerships.

American Journal of Community Psychology, 38, 51-62. https://doi.org/10.1007/s10464-006-9064-1.

Rivarola M.D., Dein J., Simberloff D., and Herrero H.V., (2022). Assessing Protected Area Zoning Effectiveness With Remote Sensing Data: The Case of Nahuel Huapi National Park, Argentina. Frontiers in Remote Sensing, 3. https://doi.org/10.3389/frsen.2022.901463.

Southworth J., Ryan S.J., Herrero H.V., Khatami R., Bunting E.L., et al., (2023). Latitudes and land use: Global biome shifts in vegetation persistence across three decades. Frontiers in Remote Sensing, 4. https://doi.org/10.3389/frsen.2023.1063188.

Thapa R.B., Matin M.A., and Bajracharya B., (2019). Capacity Building Approach and Application: Utilization of Earth Observation Data and Geospatial Information Technology in the Hindu Kush Himalaya. Frontiers in Environmental Science, 7. https://doi.org/10.3389/fenvs.2019.00165.

Thapa R.B., Tripathi P., Matin M.A., Bajracharya B., and Hernandez-Sandoval B.E., (2021). Strengthening the Capacity on Geospatial Information Technology and Earth Observation Applications. In Bajracharya B., Thapa R.B., Matin M.A. (eds.), Earth Observation Science and Applications for Risk Reduction and Enhanced Resilience in Hindu Kush Himalaya Region. Springer, Cham, pp. 269-289. https://doi.org/10.1007/978-3-030-73569-2_14.

Tripathi P., Thapa R.B., Bajracharya B., and Maden U., (2022). Closing the STEM gender gap: Training women in Earth observation and geospatial information technology. ICIMOD Report. https://doi.org/10.53055/ICIMOD.1005.

UNESCO, (2019). Women in Science. Fact Sheet No. 55, FS/2019/SCI/55. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000370742 (accessed 20 December 2025).

United Nations, (2021). United Nations Entity for Gender Equality and the Empowerment of Women (UN-Women): Strategic Plan 2022-2025. https://docs.un.org/en/UNW/2021/6 (accessed 22 December 2025).

Vogeler J.C., Fekety PA., Elliott L., Swayze N.C., Filippelli S.K., et al., (2023). Evaluating GEDI data fusions for continuous characterizations of forest wildlife habitat. Frontiers in Remote Sensing, 4. https://doi.org/10.3389/frsen.2023.1196554.

Wester P., Mishra A., Mukherji A., and Shrestha A.B., (eds.) (2019). The Hindu Kush Himalaya Assessment: Mountains, Climate Change, Sustainability and People. Springer, Cham. https://doi.org/10.1007/978-3-319-92288-1.

Worsa-Kozak M., Górniak-Zimroz J., Szrek A., and Chudy K., (2024). Remote detection and monitoring of post-mining heat island. Frontiers in Environmental Science, 12. https://doi.org/10.3389/fenvs.2024.1305149.

Wu W.T., Zhou Y.X., and Tian B. (2017). Coastal wetlands facing climate change and anthropogenic activities: A remote sensing analysis and modelling application.

Ocean & Coastal Management, 138, 1-10. https://doi.org/10.1016/j.ocecoaman.2017.01.005.

Yang D., Fu C., Herrero H.V., Southworth J., and Binford M., (2023). Linking forest management to surrounding lands: a citizen-based approach towards the regional understanding of land-use transitions. Frontiers in Remote Sensing, 4. https://doi.org/10.3389/frsen.2023.1197523.

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