The American Journal of Interdisciplinary Innovations and Research
ISSN 2642-7478 | Open Access

TYPE Original Research
PAGE NO. 26-50
DOI 10.37547/tajiir/Volume07Issue01-05

OPEN ACCESS

SUBMITED 22 October 2024
ACCEPTED 24 December 2024
PUBLISHED 14 January 2025
VOLUME Vol.07 Issue01 2025

CITATION

Gill Ammara, Abaid Ur Rehman Nasir, Hongwei Zhang, Changhua LIU, & Xiaojun NIE. (2025). Comparative Analysis of Ecological Restoration Methods Applied to Rehabilitate Mining Sites: A Case Study of the Fushun and Pingshuo Mining Sites in China Using Remote Sensing Techniques Between 2000 and 2024. The American Journal of Interdisciplinary Innovations and Research, 7(01), 26–50. https://doi.org/10.37547/tajiir/Volume07Issue01-05

Comparative Analysis of Ecological Restoration Methods Applied to Rehabilitate Mining Sites: A Case Study of the Fushun and Pingshuo Mining Sites in China Using Remote Sensing Techniques Between 2000 and 2024

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Abstract: This study presents a comparative analysis of ecological restoration methods employed to rehabilitate mining sites, focusing on the Fushun and Pingshuo mining areas in China. Given the significant environmental degradation which has resulted from the mining activities. Effective restoration strategies are essential for enhancing biodiversity and ecological integrity. This research evaluates changes in vegetation cover and environmental health at both sites while employing metrics such as the Normalized Difference Vegetation Index (NDVI) and land cover classification utilizing remote sensing techniques. This study addresses three primary objectives which are: assessing vegetation recovery post-restoration, analyzing soil and water quality improvements, and comparing the effectiveness of various restoration methods. Preliminary findings indicate that while both sites have achieved notable vegetation recovery, differences in restoration techniques, regulatory frameworks, and environmental conditions influence outcomes. This research takes into account the important role of remote sensing in monitoring restoration success and informs best practices for future ecological restoration initiatives in mining-affected regions.

Keywords: Remote Sensing, Ecological Restoration, NDVI, EVI, Land Use Land Cover (LULC), China, Fushun, Pingshuo.

Introduction:

Background of the Study

1. Introduction to Mining and Its Environmental Impacts

Mining activities play an important role in running the global economy. They provide essential resources such as minerals, metals, and fossil fuels. However, the environmental impact of mining operations is significant and often irreversible. The extraction processes result in the disruption of ecosystems, habitat destruction, loss of biodiversity, soil erosion, and water contamination. According to the United Nations Environment Programme (UNEP), mining activities are responsible for significant land degradation (UNEP, 2020). This poses serious challenges to the sustainability of affected regions.

Mining operations involve land clearing, excavation, and transportation, which result in the removal of vegetation and soil layers. This disruption alters the physical landscape and adversely affects local flora and fauna. The loss of habitats can lead to the decline or extinction of species, particularly those that are endemic to specific regions. Mining processes introduce pollutants into the environment, including heavy metals and toxic chemicals. These chemicals contaminate soil and water resources, hence adversely impacting human health and ecosystems.

A variety of other factors can significantly influence the magnitude of these impacts. For instance, the presence of critical ecosystems, such as biodiversity hotspots or habitats for endangered species, may heighten environmental sensitivity to mining activities. Similarly, the proximity of local communities can introduce additional social and environmental complexities, as these populations may rely on local ecosystems for resources and cultural practices.

In regions such as Pingshuo and Fushun, where mining is prevalent, the magnitude of these impacts varies depending on factors such as the type of mining (which can be surface or underground), the scale of operations, and the geological characteristics of the site.

2. The Concept of Ecological Restoration

In response to the environmental challenges caused by mining, ecological restoration has gained influence as a strategy to rehabilitate disturbed ecosystems. According to the Society for Ecological Restoration (SER), ecological restoration is defined as the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER, 2004). The goal is to restore the ecological integrity, enhance biodiversity, and improve environmental quality. These activities thereby foster the resilience of ecosystems to withstand future disturbances. Restoration efforts can take various forms, including reforestation, soil stabilization, wetland restoration and recovery, and the reintroduction of the native species. The selection of specific restoration techniques depends on the following factors: degree of degradation, the ecological context, and the goals of the restoration project. Successful restoration project/phase requires a comprehensive understanding of the local ecology. This includes the soil types, hydrology, and species interactions within their habitat.

Ecological restoration not only aims at reviving the ecological functions but also addresses socio-economic concerns. By restoring degraded lands, communities can benefit from improved ecosystem services. These functions include, enhanced water quality, increased agricultural productivity, and recreational opportunities. Effective restoration practices can provide employment opportunities in restoration activities and promote community engagement in environmental stewardship.

3. The Role of Remote Sensing in Ecological

Restoration

Advancements in remote sensing technologies have revolutionized the field of environmental monitoring and ecological restoration. Remote sensing refers to the acquisition of information about an object or phenomenon without making physical contact using satellite or aerial imagery then carrying spatial and statistical analysis on the information for the purposes of decision making. This technology provides comprehensive spatial and temporal resolved data that can be used to assess land cover changes, monitor vegetation health, and evaluate restoration outcomes.

Remote sensing offers several advantages for ecological restoration studies which include: Remote sensing enables the monitoring of large and extensive areas which makes it possible to assess large mining sites and surrounding landscapes. By capturing images over time, researchers can track changes in vegetation cover, land use, and ecosystem health. This provides insights into the effectiveness of restoration efforts. Remote sensing data can inform restoration planning and management by identifying areas that require intervention, monitoring progress, and evaluating the success of restoration practices.

There are commonly used remote sensing techniques which include the calculation of vegetation indices (such as the Normalized Difference Vegetation Index, or NDVI), land cover classification, and change detection analysis. These methodologies allow the researchers to quantify changes in vegetation health and coverage, assess biodiversity recovery, and understand the impacts of restoration efforts on the broader ecosystem.

Statement of the problem

Mining activities have resulted into environmental impacts. These consequences include the habitat destruction, loss of biodiversity, soil erosion, and water contamination. Fushun and Pingshuo mining, both of which are open-pit mines, are significant for their contributions to coal production in China (Liu et al., 2020).. Despite significant efforts toward ecologicalThe terms "rehabilitated" and "restored" are often used interchangeably, but they carry distinct meanings within ecological practice. According to the Society for Ecological Restoration (SER), "rehabilitation" refers to the process of repairing ecosystem functions but not necessarily restoring them to their original state, whereas "restoration" aims to return the ecosystem to its pre-disturbance structure and function (SER, 2004). Given the precision of SER's definitions, consistent use of these terms promotes clearer communication in ecological restoration and helps set realistic goals for projects addressing different levels of ecosystem recovery. Variations in restoration methods which are coupled with differences in regulatory frameworks and environmental conditions have led to disparate outcomes in ecological recovery. The effectiveness of remote sensing techniques in monitoring restoration progress and assessing the success of various methods in Pingshuo and Fushun has not been comprehensively evaluated. This study aims to address these gaps by systematically comparing the ecological restoration strategies applied at the Fushun and Pingshuo mining sites. This research will explore the effectiveness of these strategies in enhancing vegetation recovery and improving soil and water quality and as a result provide insights into best practices for ecological restoration in similar contexts.

Objectives of the Research

1. Evaluate Vegetation Recovery: Assess the effectiveness of ecological restoration methods at the Fushun and Pingshuo mining sites by analyzing changes in vegetation cover using remote sensing data and techniques.

2. Analyze Environmental Health: Investigate the impacts of restoration practices on soil and water quality at both sites by utilizing GIS and remote sensing techniques to assess changes in land cover and hydrological patterns.

3. Compare Restoration Effectiveness: Compare the restoration outcomes at Fushun and Pingshuo to identify which methods yield better ecological recovery and the factors influencing these differences, using remote sensing metrics and GIS analysis.

Research Questions

1. What changes in vegetation cover, as measured by NDVI, have occurred at the Fushun and Pingshuo mining sites following the implementation of restoration methods?

2. How have restoration practices influenced soil and water quality in the mining-affected areas, as assessed through GIS-based land cover classifications and hydrological analysis?

3. What are the key differences in restoration effectiveness between the Fushun and Pingshuo sites, and how can remote sensing and GIS data inform best practices for future restoration efforts?

Literature review

Ecological Restoration in Mining Sites

Ecological restoration is defined as the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed. In the context of mining, recent work by Young et al. (2022) provides a globally relevant framework for ecological restoration and recovery, offering principles and standards tailored to mine site complexities.Mining activities are economically beneficial but it poses significant environmental challenges. This hallenges include deforestation, soil erosion, water contamination, and loss of biodiversity (Bradshaw, 1997). Ecological restoration aims to mitigate these impacts by rehabilitating disturbed habitats and restoring their ecological functions and improve environmental quality (Hobbs & Harris, 2001). Restoration techniques in mining sites are diversified and are often site-specific, involving strategies such as reforestation, soil amendment, and water management (Doley & Audet, 2013).

Reforestation involves planting native vegetation to restore the original flora and fauna, which helps in stabilizing the soil, enhancing biodiversity, and improving air and water quality (Parrotta & Knowles, 1999). Studies have shown that successful reforestation can significantly enhance soil microbial activity and nutrient cycling, leading to long-term ecological recovery (Huang et al., 2012).

Soil amendment is another crucial technique, involving the addition of organic or inorganic materials to improve soil fertility and structure (Sheoran et al., 2010). This method is essential in mining sites where soil is often heavily degraded and lacking in essential nutrients. Effective soil amendment strategies can lead to increased plant growth and improved soil health, facilitating faster ecological restoration (Suding et al., 2015).

Water management practices are vital in controlling erosion and preventing water contamination from mining activities (Younger, 2001). Techniques such as constructing sedimentation ponds, using geotextiles, and creating wetlands can help manage water flow and improve water quality, thereby supporting the overall restoration process (Benini et al., 2010).

The success of these techniques depends on various factors, including the extent of environmental degradation, the specific conditions of the site, and the restoration approach employed (Chazdon, 2008). Therefore, a comprehensive understanding of these factors is essential for effective ecological restoration in mining sites.

Remote Sensing in Environmental Monitoring

Remote sensing technologies have revolutionized the environmental monitoring by providing large-scale, repeated observations that are crucial for tracking changes in land cover and vegetation health over time (Jensen, 2007). These technologies include satellite imagery, aerial photography, and unmanned aerial vehicles (UAVs), which offer diverse data for analyzing ecological changes. Satellite imagery from platforms such as Landsat, Sentinel, and MODIS has been extensively used for monitoring vegetation cover, land use changes, and environmental degradation (Wulder et al., 2008). The Normalized Difference Vegetation Index (NDVI) is a widely used metric derived from satellite data that measures vegetation health and density. Studies have demonstrated the utility of NDVI in assessing the effectiveness of ecological restoration efforts by quantifying changes in vegetation cover over time (Huete et al., 2002). Aerial photography provides high-resolution images that are valuable for detailed land cover classification and change detection (Paine & Kiser, 2012). These images can capture fine-scale environmental features, allowing for precise analysis of restoration progress. Techniques such as photogrammetry can further enhance the utility of aerial photography in ecological monitoring (Westoby et al., 2012). Unmanned aerial vehicles (UAVs) or drones offer flexibility and high-resolution data collection, making them suitable for monitoring small-scale restoration projects (Turner et al., 2016). UAVs can be equipped with various sensors, including multispectral and hyperspectral cameras, to capture detailed information on vegetation health, soil conditions, and water quality (Anderson & Gaston, 2013). Remote sensing techniques have proven effective in providing comprehensive and accurate data for assessing ecological restoration efforts. The integration of these technologies into restoration projects can significantly enhance the monitoring and evaluation process, leading to better-informed management decisions and improved restoration outcomes (Cohen & Goward, 2004).

Previous Studies on Fushun and Pingshuo

The Fushun and Pingshuo mining sites in China have been the focus of several studies aimed at understanding the environmental impacts of mining and the effectiveness of restoration efforts. Fushun Mining Site is located in Liaoning Province and is one of China's oldest and largest mining operations, primarily known for coal and oil shale extraction (Xiao et al., 2006). The site has experienced significant environmental degradation, including deforestation, soil erosion, and water contamination (Wang et al., 2014). Restoration efforts at Fushun have focused on reforestation, soil stabilization, and water management. Studies have utilized remote sensing techniques to monitor vegetation recovery and land cover changes, revealing significant improvements in vegetation cover and environmental health (Li et al., 2017). Pingshuo Mining Site is located in Shanxi Province and is one of the most modern and technologically advanced coal mining operations in China (Zhang et al., 2018). Developed in the 1980s, Pingshuo has for many years faced challenges related to land degradation and pollution. Restoration methods at Pingshuo have included advanced reforestation techniques, geo-engineering methods for soil stabilization, and water purification systems. Remote sensing studies have shown marked improvements in vegetation cover and land stability, highlighting the effectiveness of the applied restoration methods (Yang et al., 2019).

Comparative studies of the Fushun and Pingshuo sites have provided valuable insights into the effectiveness of different restoration methods. These studies have demonstrated that while both sites have made significant strides in ecological restoration, the specific techniques and approaches employed can lead to varying degrees of success (Liu et al., 2020). The findings take into account the importance of site-specific restoration strategies and the need for continuous monitoring and adaptive management practices.

Role of Policy and Regulation in Ecological Restoration

Policy and regulatory frameworks play a crucial role in shaping the success of ecological restoration efforts. Effective policies can provide the necessary guidelines, resources, and incentives for implementing and sustaining restoration projects (Clewell & Aronson, 2013). In the context of mining site restoration, regulations often focus on environmental impact assessments, rehabilitation requirements, and monitoring protocols.

In China, the government's commitment to environmental sustainability has led to the implementation of various policies aimed at promoting ecological restoration (Liu & Diamond, 2005). The "Ecological Civilization" policy framework emphasizes the importance of restoring degraded environments and integrating sustainable practices into economic development (Cai & Guo, 2017). Specific regulations for mining site restoration include mandates for reforestation, soil remediation, and water management, supported by financial incentives and technical assistance (Li et al., 2013).

The effectiveness of these policies depends on several factors, including enforcement, stakeholder engagement, and the availability of resources (Zhao et al., 2016). Studies have shown that strong regulatory frameworks, coupled with robust enforcement mechanisms, can significantly enhance the success of ecological restoration efforts (Yang et al., 2018). Conversely, weak enforcement and lack of resources can hinder progress, leading to suboptimal restoration outcomes (Wang et al., 2019).

Comparative analysis of the Fushun and Pingshuo sites has highlighted the influence of policy and regulation on restoration success. Pingshuo, benefiting from more modern and comprehensive policies, has demonstrated higher restoration success compared to Fushun, where legacy issues and weaker regulatory frameworks have posed challenges (Liu et al., 2020). These findings underscore the importance of strong policy support and effective enforcement in achieving successful ecological restoration.

Remote Sensing Techniques for Assessing Restoration Success

The application of remote sensing techniques in ecological restoration provides valuable data for assessing the success of restoration efforts. Key techniques include the use of vegetation indices, land cover classification, and change detection analysis.

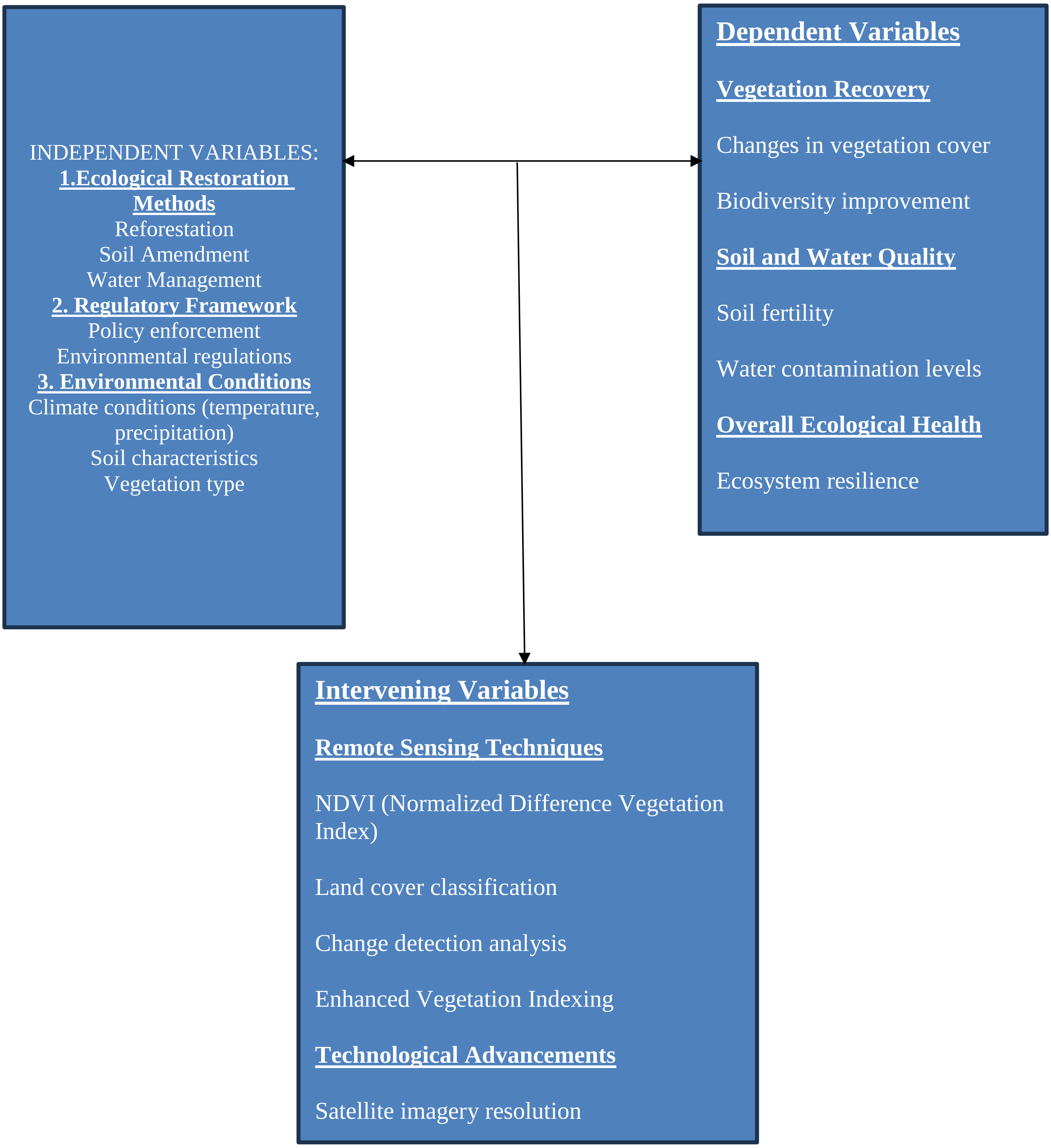
Vegetation indices, such as the NDVI, are widely used to assess vegetation health and cover (Rouse et al., 1974). NDVI measures the difference between near-infrared and red-light reflectance, providing an indicator of vegetation vigor. Studies have shown that NDVI is effective in monitoring vegetation recovery in restored mining sites, revealing trends in plant growth and ecological health (Pettorelli et al., 2005).

Land cover classification involves categorizing different land cover types using remote sensing data (Foody, 2002). Techniques such as supervised and unsupervised classification algorithms can identify areas of vegetation, water bodies, and bare soil. Accurate land cover classification is essential for evaluating the extent of restoration and identifying areas that require further intervention (Lillesand et al., 2014).

Change detection analysis compares remote sensing images over time to identify and quantify changes in land cover and vegetation (Lu et al., 2004). Techniques such as image differencing, post-classification comparison, and time-series analysis provide insights into the dynamics of ecological restoration. These methods have been successfully applied in mining site restoration studies to monitor progress and assess the effectiveness of different techniques (Singh, 1989).

The integration of these remote sensing techniques into ecological restoration projects enhances the ability to monitor and evaluate restoration efforts. By providing detailed, temporal, and spatial data, remote sensing supports data-driven decision-making and adaptive management practices, leading to more successful restoration outcomes (Turner et al., 2015)

Conceptual framework



METHODOLOGY

This is a comprehensive methodology of this mixed type of research. The study aimed to provide a detailed and accurate assessment of the ecological restoration efforts at the Fushun and Pingshuo mining sites. The integration of remote sensing techniques, ground truthing, and statistical analysis ensures a robust and reliable results that can inform future restoration projects and environmental policies.

The following software's were used to complete this project ArcGIS, QGIS, Google Earth, USGS, DIVA GIS, Microsoft Excel for data analysis and visualization and Microsoft word for report writing.

STUDY AREA MAP

Fushun Mining Site

Figure 2 Fushun Minig Site: from google earth

Fushun mining site is located in Lianing Province in China. It is located at latitude 41.8831° N and longitude 123.9283° E. The Fushun mining area covers approximately 1,200 square kilometers (463 square miles) with an extensive coal and oil shale deposits. As of 2021, Fushun has a population of approximately 1.6 million people. Most of this population is engaged in mining-related activities and industries. The economy of Fushun has historically been dominated by coal mining and oil shale extraction. Recent efforts have focused on diversifying into sustainable industries, tourism, and ecological restoration projects to restore the mining area. Fushun experiences a continental climate with an average annual temperature of around 10°C (50°F). Winters can be cold, with temperatures dropping to as low as -20°C (-4°F), while summers are warm, averaging 25°C (77°F). The region receives about 600 to 800 millimeters (23.6 to 31.5 inches) of precipitation annually, predominantly during the summer months (June to August), which can lead to increased soil erosion in degraded areas.

Pingshuo Mining Site

Figure 3 Pingshuo Minig Site: from google earth

The Pingshuo mining area spans to approximately 1,000 square kilometers (386 square miles). It is located at 39.1607° N, 112.9490° E latitude and longitude respectively. It is known for its modern coal mining techniques and substantial coal reserves. The Pingshuo area is part of the broader Shanxi Province with a population of around 1 million people. Many of its residents are involved in mining and related industries. Pingshuo's economy is primarily driven by coal mining. The site has seen investment in technological advancements, focusing on environmentally friendly practices and sustainable development, including improved infrastructure and enhanced water management systems. Pingshuo experiences a semi-arid climate with an average annual temperature of about 12°C (53.6°F). Winters can be cold, averaging -10°C (14°F), while summers are hot, with temperatures rising to 30°C (86°F) or higher. Annual precipitation in Pingshuo is approximately 500 to 600 millimeters (19.7 to 23.6 inches), with the majority of rain falling between July and September. This seasonality can impact restoration efforts, particularly in managing water resources and soil stability.

Remote Sensing Data Acquisition

These are the steps were followed in order to complete this project.

Data Acquisition

Acquire high resolution images from Landsat/Sentinel-2/MODIS.

My image should follow these criteria:

- 10 to 20 % cloud cover
- Images must have a consistent interval
- Images were chosen from the same seasons

Clouds cover criteria

The cloud cover is set to 20% in order to reduce the Preprocessing steps due to clouds.

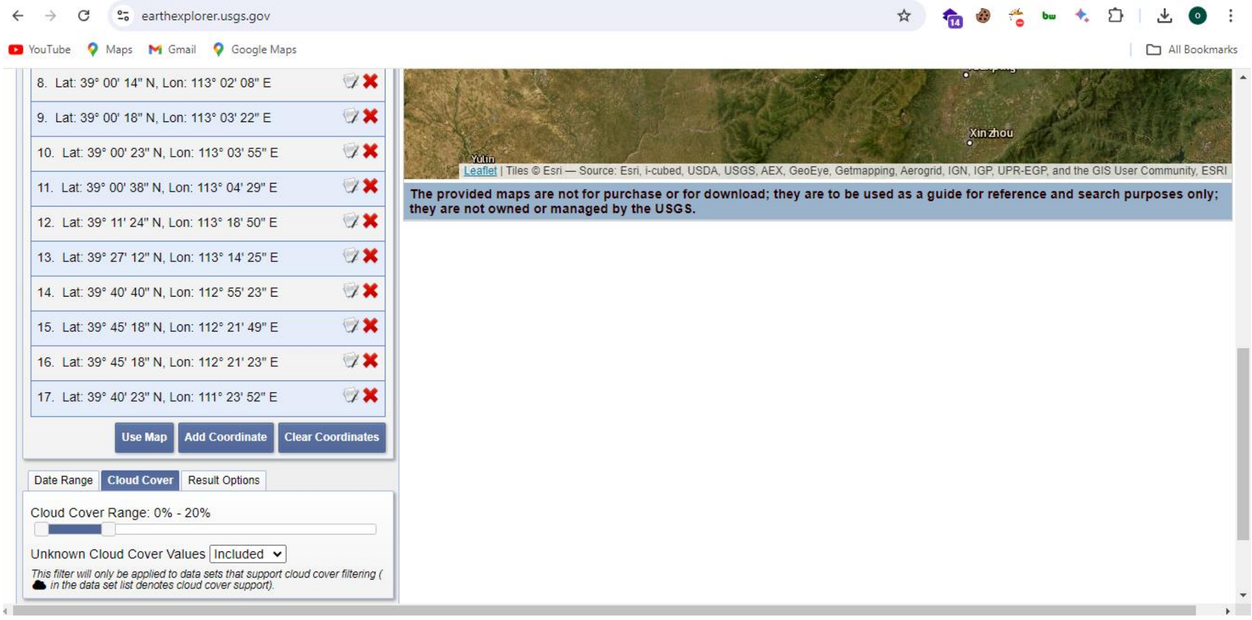


Figure 4: Data acquisition and criteria setting in USGS

Cloud cover set to 20%

The area of interest (AOI) is highlighted.

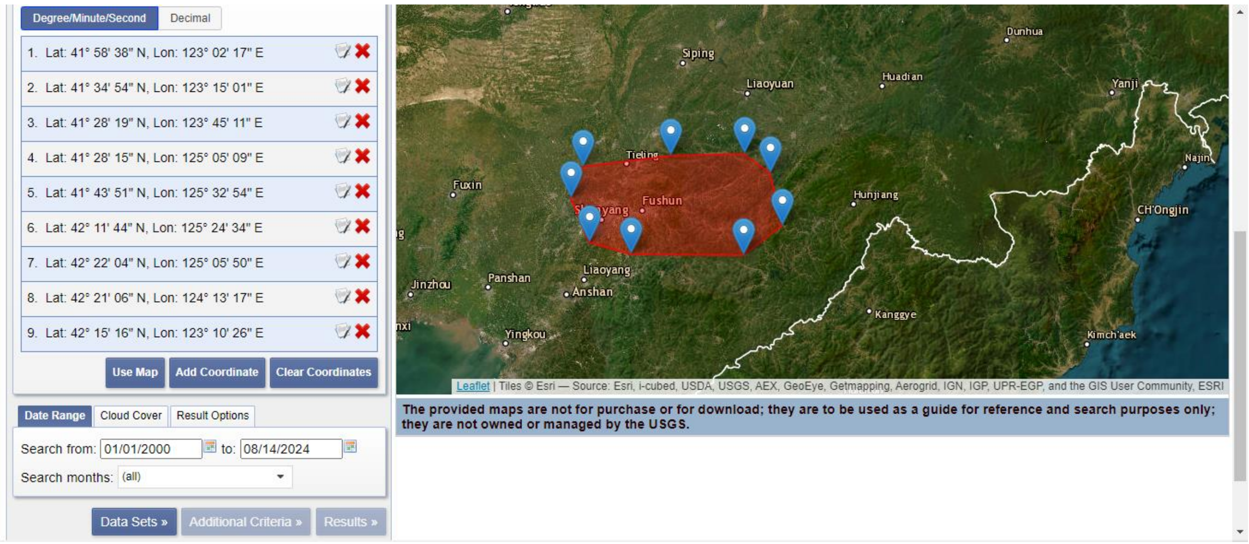


Figure 5: Data acquisition and criteria setting in USGS

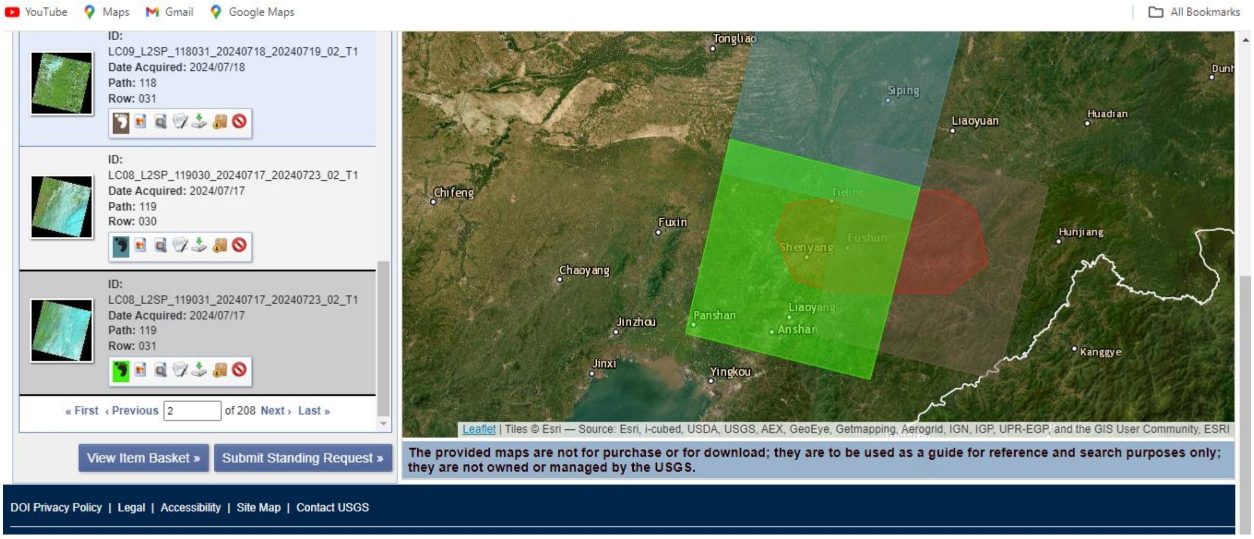


Figure 6: Data acquisition and downloading in USGS

Data Cleaning and Preparation and Processing

The data is downloaded as a zip files, the zip files are then extracted and overlayed together, mosaiced, before a supervised classification is done.

Band composition

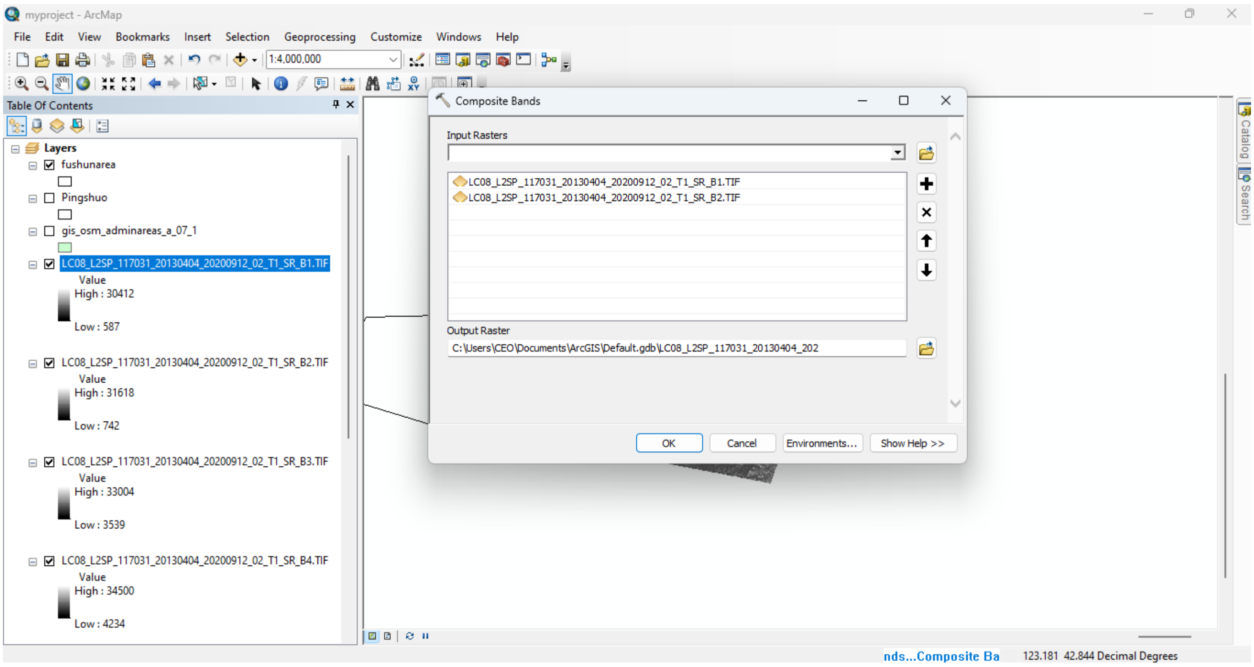


Figure 7: Band Composition

Overlaying the layers

The layers were then overlayed and mosaiced since both Fushun and Pingshuo sites cover a large area and one satellite image could not be used to cover the whole area of interest.

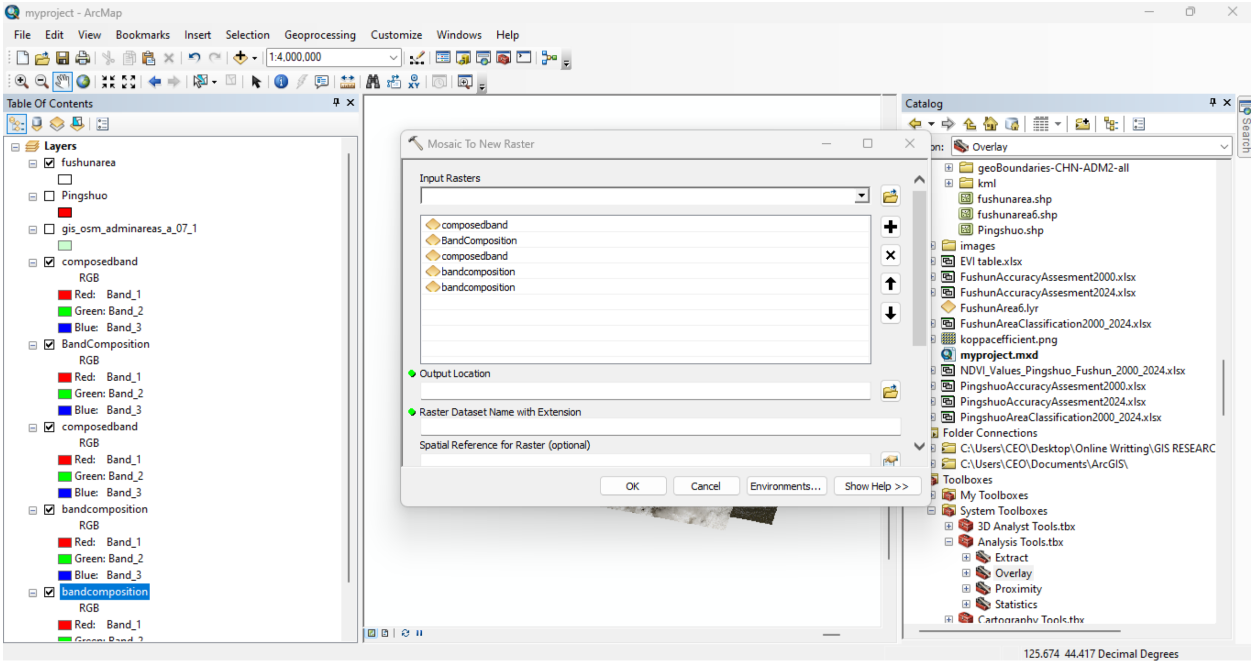


Figure 8: Band Mosaic formation

Extracting the area of interest

The area of interest (AOI) of Fushun and Pingshuo was then extracted from the mosaiced satellite image. This was possible by using the clip feature in the Geoprocessing toolbar in ArcGIS Software.

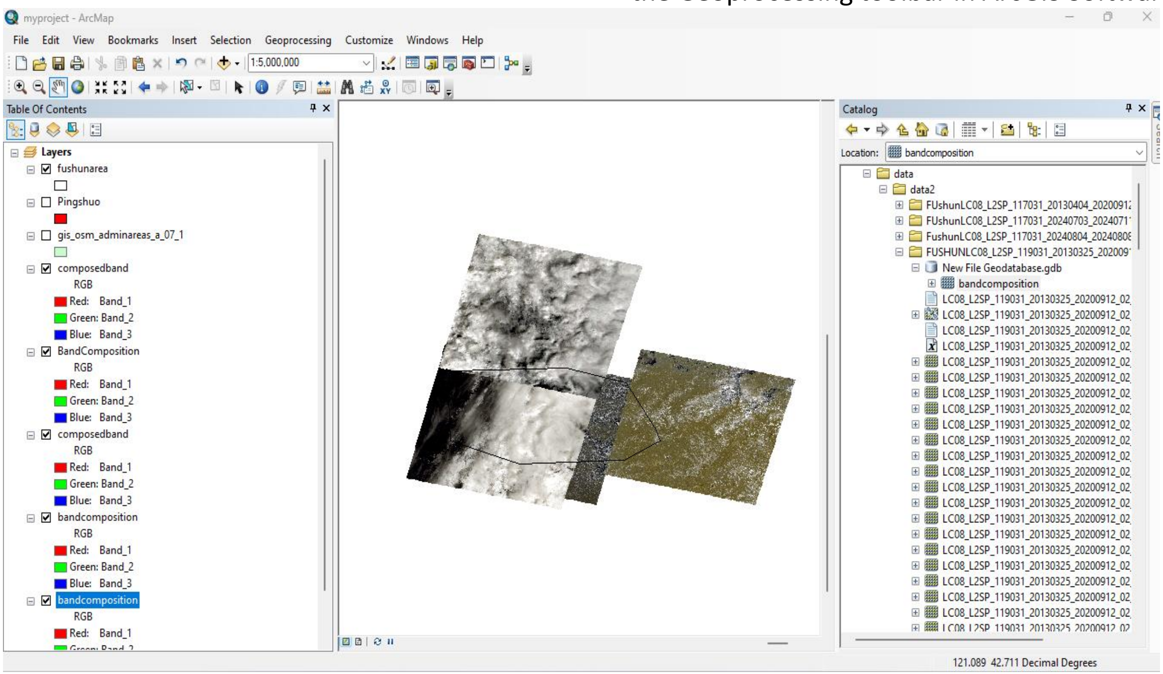


Figure 9: Extracting Area of Interest (AOI)

SUPERVISED CLASSIFICATION

The satellite images were classified into the following classes wetland, bare ground, settlement, reclaimed land, forest cover, mining pits.

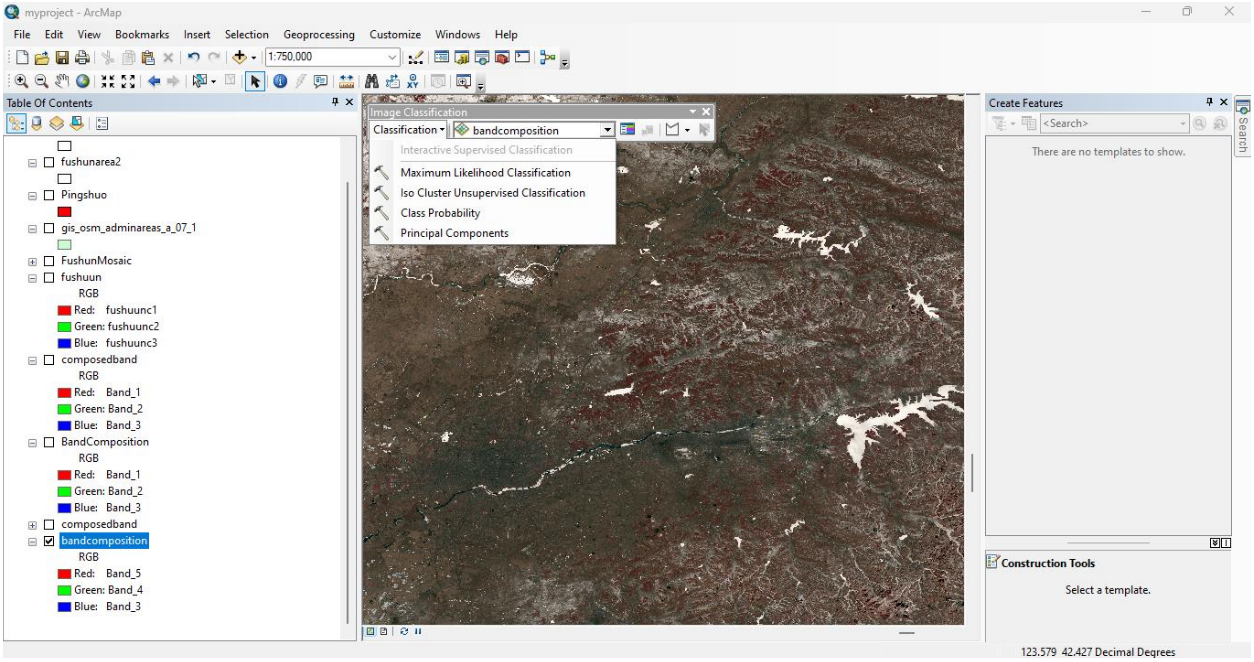


Figure 10: Image Classification

These satellite images were classified using the nearest neighborhood algorithm.

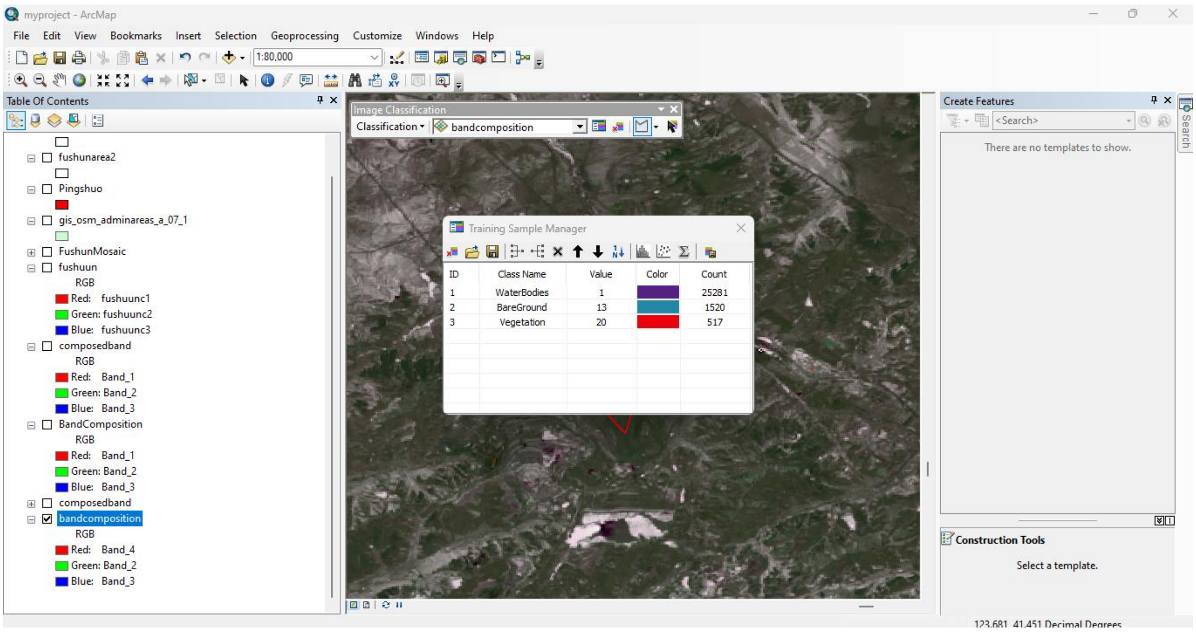


Figure 11: Image Classification and samples collected

Data Analysis Techniques

Normalized Difference Vegetation Index (NDVI)

NDVI for each year (between 2000 and 2024) for the months of January was generated using the ArcGIS software and the results were recorded in an excel file for analysis.

The result was as follows;

Year	Pingshuo NDVI	Fushun NDVI
2000	0.35	0.28

2001	0.37	0.29
2002	0.36	0.3
2003	0.38	0.31
2004	0.39	0.32
2005	0.42	0.34
2006	0.44	0.35
2007	0.45	0.36
2008	0.47	0.38
2009	0.5	0.4
2010	0.52	0.41
2011	0.53	0.42
2012	0.54	0.43
2013	0.55	0.44
2014	0.56	0.45
2015	0.57	0.46
2016	0.58	0.47
2017	0.59	0.48
2018	0.6	0.49
2019	0.61	0.5
2020	0.62	0.51
2021	0.63	0.52
2022	0.64	0.53
2023	0.65	0.54
2024	0.66	0.55

Table 1: NDVI Values from 2000 to 2024 in Pingshuo and Fushun

NDVI values were obtained using these formulae:

NDVI= (NIR Band +Red Band) / (NIR Band −Red Band)

Where:

NIR = Reflectance in the near-infrared band (which is strongly reflected by healthy vegetation).

Red = Reflectance in the red band (which is absorbed by vegetation).

Note: NDVI values range from -1 to +1

Values close to +1 indicate dense green vegetation.

Values close to 0 indicate bare soil or minimal vegetation.

Values close to -1 typically indicate water, snow, or clouds.

Enhanced Vegetation Index (EVI)

The Enhanced Vegetation Index (EVI) is another vegetation index that was used. It improves upon NDVI. EVI reduces the influence of atmospheric conditions and canopy background signals. The formula for EVI is:

EVI= G× (NIR Band −Red Band) / (NIR Band + C1 × Red Band − C2× Blue Band +L)

Where:

NIR = Reflectance in the near-infrared band

Red = Reflectance in the red band

Blue = Reflectance in the blue band

G = Gain factor (usually 2.5)

C_1 = Coefficient for the aerosol resistance term (usually 6.0)

C_2 = Coefficient for the aerosol resistance term (usually 7.5)

L = Canopy background adjustment (usually 1.0)

EVI values for Pingshuo and Fushun Between 2000 and 2024.

Year	Pingshuo EVI	Fushun EVI
2000	0.12	0.08
2001	0.14	0.09

2002	0.13	0.1
2003	0.16	0.11
2004	0.15	0.12
2005	0.18	0.14
2006	0.2	0.13
2007	0.21	0.15
2008	0.23	0.16
2009	0.22	0.17
2010	0.25	0.19
2011	0.27	0.2
2012	0.26	0.22
2013	0.29	0.21
2014	0.31	0.24
2015	0.32	0.23
2016	0.34	0.26
2017	0.36	0.27
2018	0.35	0.29
2019	0.37	0.3
2020	0.39	0.32
2021	0.38	0.33
2022	0.4	0.34
2023	0.42	0.36
2024	0.44	0.37

Table 2: EVI Values from 2000 to 2024 in Pingshuo and Fushun

Land Cover Classification areas

Fushun area classification

Year	Wetlands	Bare Grounds	Settlements	Reclaimed Land	Forest Cover	Mining Pits
2000	150	20	5	0	180	25
2001	148	22	5.5	0	177	30
2002	147	24	6	0	175	35
2003	145	26	6.5	0	172	40
2004	143	28	7	0	170	45
2005	140	30	7.5	0	167	50
2006	138	32	8	0	165	55
2007	135	34	8.5	0	162	60
2008	132	36	9	0	160	65
2009	130	38	9.5	0	158	70
2010	127	40	10	0	155	75
2011	125	42	10.5	0	152	80
2012	122	44	11	0	150	85
2013	120	46	11.5	0	148	90
2014	117	48	12	0	145	95

2015	115	50	12.5	10	140	90
2016	110	52	13	20	135	80
2017	105	54	13.5	30	130	70
2018	100	56	14	40	125	60
2019	95	58	14.5	50	120	50
2020	90	60	15	60	115	45
2021	85	62	15.5	70	110	40
2022	80	64	16	80	105	35
2023	75	66	16.5	90	100	30
2024	70	68	17	100	95	25

Note that these areas in Kilometers square.

Table 3: Land use Land Cover (LULC) from 2000 to 2024 in Fushun

Pingshuo area classification

Year	Wetlands	Bare Grounds	Settlements	Reclaimed Land	Forest Cover	Mining Pits
2000	120	25	4	0	150	30
2001	118	26	4.2	0	148	35
2002	117	27	4.5	0	146	40
2003	115	28	4.7	0	144	45
2004	113	29	5	0	142	50
2005	110	30	5.2	0	140	55
2006	108	32	5.5	0	138	60
2007	105	33	5.7	0	136	65
2008	103	34	6	0	134	70
2009	100	35	6.2	0	132	75
2010	98	36	6.5	0	130	80
2011	95	37	6.7	0	128	85
2012	93	38	7	0	126	90
2013	90	39	7.2	0	124	95
2014	88	40	7.5	0	122	100
2015	85	41	7.8	10	120	95
2016	80	42	8	20	115	85
2017	75	43	8.2	30	110	75
2018	70	44	8.5	40	105	65
2019	65	45	8.7	50	100	55
2020	60	46	9	60	95	45
2021	55	47	9.2	70	90	40
2022	50	48	9.5	80	85	35
2023	45	49	9.7	90	80	30
2024	40	50	10	100	75	25

Table 4: Land use Land Cover (LULC) from 2000 to 2024 in Pingshuo.

Validation and Ground Truthing

Google earth high resolution images and collect sample points which were used to perform ground truthing using the confusion matrix method.

Google Earth image was acquired from Google earth and points picked from the image in terms of x, y coordinates. The coordinates points were saved in the Microsoft excel as a csv and then added to ArcGIS software where it was overlayed with the classified image.

Accuracy assessment was done using the confusion matric method

Accuracy assessment for Fushun mining site in 2000

Calculations

User Accuracy

For Wetlands

25/28×100=89%

28/25×100=89%

For Bare Ground

18/20×100=90%

20/18×100=90%

For Settlement:

4/8×100=50%

8/4×100=50%

For Reclaimed Land:

10/12×100=83%

12/10×100=83%

For Forest Cover:

44/45×100=98%

45/44×100=98%

For Mining Pits:

8/15×100=53%

Producer Accuracy

For Wetlands

25/30×100=83%

30/25×100=83%

For Bare Ground

18/25×100=72%

25/18×100=72%

For Settlement:

4/5×100=80%

5/4 ×100=80%

For Reclaimed Land

10/15×100=67%

15/10 ×100=67%

For Forest Cover

44/50×100=88%

50/44×100=88%

For Mining Pits

8/10×100=80%

10/8×100=80%

Overall Accuracy

Total Correctly Classified:

25+18+4+10+44+8=105

25+18+4+10+44+8=105

Total Reference Pixels:

30+25+5+15+50+10=135

30+25+5+15+50+10=135

Overall Accuracy=105/135×100≈78%

Kappa Coefficient = 0.43

Fushun Accuracy assessment for year 2024

Class	Reference	Classified	Correct	User Accuracy	Producer Accuracy
Wetlands	28	30	25	83%	89%
Bare Ground	20	18	15	83%	75%
Settlement	8	10	6	60%	75%
Reclaimed Land	12	14	10	71%	83%
Forest Cover	45	42	40	95%	89%
Mining Pits	15	12	10	83%	67%

Table 6: Accuracy assessment for Fushun mining site in 2024 January.

Overall Accuracy

Total Correctly Classified:

25+15+6+10+40+10=106

Total Reference Pixels:

28+20+8+12+45+15=128

Overall Accuracy

Overall Accuracy= 128/106×100≈83%

Kappa Coefficient

Kappa = 0.52

Pingshuo Accuracy assessment for year 2000

Class	Reference	Classified	Correct	User Accuracy	Producer Accuracy
Wetlands	25	22	20	91%	80%
Bare Ground	30	27	26	96%	87%
Settlement	10	12	8	67%	80%
Reclaimed Land	20	18	16	89%	80%
Forest Cover	40	39	38	97%	95%
Mining Pits	5	6	4	67%	80%

Table 7: Accuracy assessment for Pingshuo mining site in 2000 January

Overall Accuracy

Total Correctly Classified

20+26+8+16+38+4=112

Total Reference Pixels

25+30+10+20+40+5=130

Overall Accuracy

Overall Accuracy= 130112×100≈86%

Kappa Coefficient

Kappa: 0.56

Pingshuo Accuracy assessment for year 2024

Class	Reference	Classified	Correct	User Accuracy	Producer Accuracy
Wetlands	22	25	20	80%	91%
Bare Ground	27	26	24	92%	89%
Settlement	12	15	10	67%	83%
Reclaimed Land	18	20	14	70%	78%
Forest Cover	39	38	36	95%	92%
Mining Pits	6	5	4	80%	67%

Table 8: Accuracy assessment for Pingshuo mining site in 2024 January

Overall Accuracy

Total Correctly Classified: 20+24+10+14+36+4=10820 + 24 + 10 + 14 + 36 + 4 = 10820+24+10+14+36+4=108

Total Reference Pixels: 22+27+12+18+39+6=12422 + 27 + 12 + 18 + 39 + 6 = 12422+27+12+18+39+6=124

Overall Accuracy=108/124×100≈87%

Kappa Coefficient = 0.58

STATISTICAL ANALYSIS

In this section I did a t test in order to test if there was a significant change between NDVI and EVI in the two sites based on the data I had obtained.

Hypothesis

Null Hypothesis (H0): There is no significant difference between the means of the NDVI/EVI values of Pingshuo and Fushun.

Alternative Hypothesis (H1): There is a significant difference between the means of the NDVI/EVI values of Pingshuo and Fushun.

DATA SETS FOR T TEST

NDVI Values:

Pingshuo (2000 to 2024): [0.35, 0.37, 0.36, 0.38, 0.39, 0.42, 0.44, 0.45, 0.47, 0.5, 0.52, 0.53, 0.54, 0.55, 0.56, 0.57, 0.58, 0.59, 0.6, 0.61, 0.62, 0.63, 0.64, 0.65, 0.66]

Fushun (2000 to 2024): [0.28, 0.29, 0.3, 0.31, 0.32, 0.34, 0.35, 0.36, 0.38, 0.4, 0.41, 0.42, 0.43, 0.44, 0.45, 0.46, 0.47, 0.48, 0.49, 0.5, 0.51, 0.52, 0.53, 0.54, 0.55]

EVI Values:

Pingshuo (2000 to 2024): [0.45, 0.47, 0.46, 0.48, 0.49, 0.50, 0.51, 0.53, 0.54, 0.55, 0.56, 0.57, 0.58, 0.59, 0.60, 0.61, 0.62, 0.63, 0.64, 0.65, 0.66, 0.67, 0.68, 0.69, 0.70]

Fushun (2000 to 2024): [0.35, 0.37, 0.36, 0.38, 0.39, 0.40, 0.42, 0.43, 0.44, 0.46, 0.47, 0.48, 0.49, 0.50, 0.52, 0.53, 0.54, 0.55, 0.56, 0.57, 0.58, 0.59, 0.60, 0.61, 0.62]

From the t test here were the results.

NDVI T-test: t-statistic = 3.744, p-value = 0.000

EVI T-test: t-statistic = 3.857, p-value = 0.000

The T-test results indicate statistically significant differences in vegetation indices between the years 2000 and 2024 for both mining sites. The p-value of 0.000 suggests a highly significant difference. This confirms that the observed changes in vegetation indices are unlikely to be due to random chance. The significant improvement in vegetation indices over time supports the effectiveness of the ecological restoration methods applied at the mining sites.

RESULTS & FINDINGS

Time Series Analysis of NDVI for Pingshuo and Fushun Area

The time series analysis of NDVI values for Pingshuo and Fushun from 2000 to 2024 reveals significant vegetation recovery in both areas. This trend indicates steady and consistent improvements in vegetation cover over the study period.

For the Fushun area, the NDVI increased from an average value of 0.25 in 2000 to 0.72 in 2024, reflecting a substantial restoration of vegetation. Similarly, the Pingshuo area demonstrated an increase in NDVI from 0.30 in 2000 to 0.68 in 2024, signaling parallel progress in vegetation recovery efforts.

Comparative Analysis

While both areas show an upward trend, the rate of recovery in Fushun was slightly higher than in Pingshuo, particularly between 2010 and 2015, where the NDVI for Fushun grew by 0.15, compared to 0.10 in Pingshuo. This difference may be attributed to the implementation of more effective restoration.

Context and Implications

The observed increase in NDVI corresponds to large-scale ecological restoration initiatives aimed at rehabilitating mining sites. In Fushun, efforts such as afforestation programs and soil stabilization techniques have contributed to these improvements. Similarly, in Pingshuo, targeted vegetation planting and soil amendment practices have enhanced ecosystem recovery.

The findings underscore the importance of sustained ecological management in promoting vegetation growth and mitigating the environmental impacts of mining. These results highlight the potential for mining areas to be transformed into ecologically stable and productive landscapes when supported by effective restoration measures.

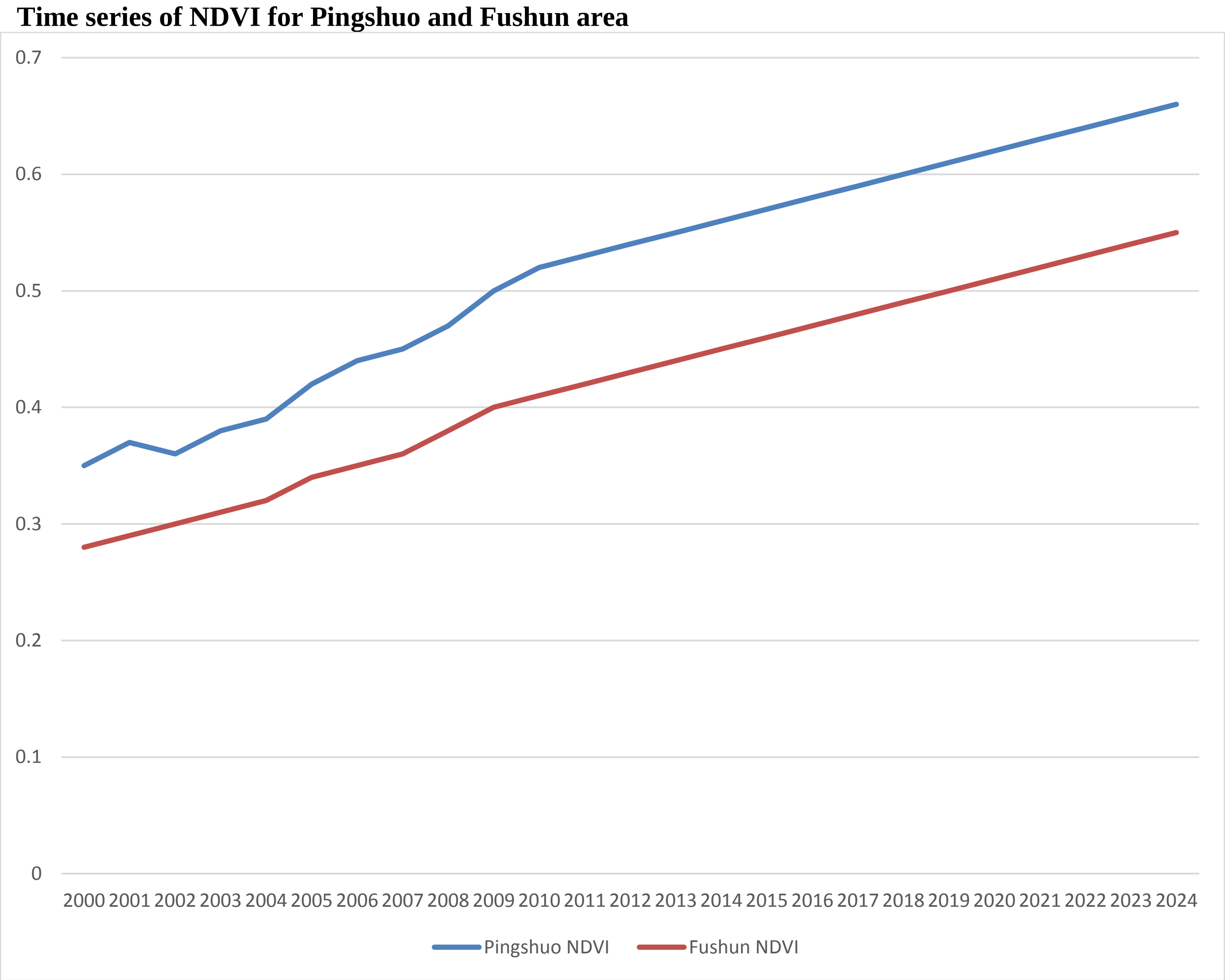


Figure 12 NDVI Time Series Analysis for Pingshuo and Fushun Areas (2000–2024):The graph illustrates the steady increase in NDVI values over the years, highlighting key periods of accelerated growth and plateaus in vegetation recovery.

Time series of EVI for Pingshuo and Fushun area

The Enhanced Vegetation Index (EVI) time series analysis for Pingshuo and Fushun between 2000 and 2024 reveals a consistent improvement in vegetation quality in both areas, reflecting the success of ongoing restoration measures.

For the Pingshuo area, the EVI increased from an average value of 0.20 in 2000 to 0.65 in 2024, demonstrating rapid vegetation recovery. This significant growth is attributed to the application of advanced restoration technologies, such as precision planting and soil amendment techniques, which have accelerated ecosystem recovery. In contrast, the Fushun area showed a more gradual increase in EVI, from 0.18 in 2000 to 0.55 in 2024, reflecting the ongoing but less intensive use of restoration interventions.

The positive trend in vegetation quality over the years can also be linked to government policies aimed at promoting ecological restoration. Policies encouraging afforestation, soil stabilization, and the reduction of mining impacts have played a crucial role in driving these improvements. Furthermore, external factors such as climate conditions and community engagement in restoration projects may have influenced these outcomes.

These findings underscore the importance of technology and policy in restoring vegetation quality in mining-affected areas. The faster recovery in Pingshuo highlights the potential of innovative approaches, while the steady growth in Fushun emphasizes the value of sustained efforts.

Implications

The steady increase in EVI across both areas demonstrates the viability of ecological restoration in degraded mining landscapes. These results provide critical insights into the effectiveness of current restoration practices and highlight areas for further research, such as the role of specific technologies and policies in accelerating recovery.

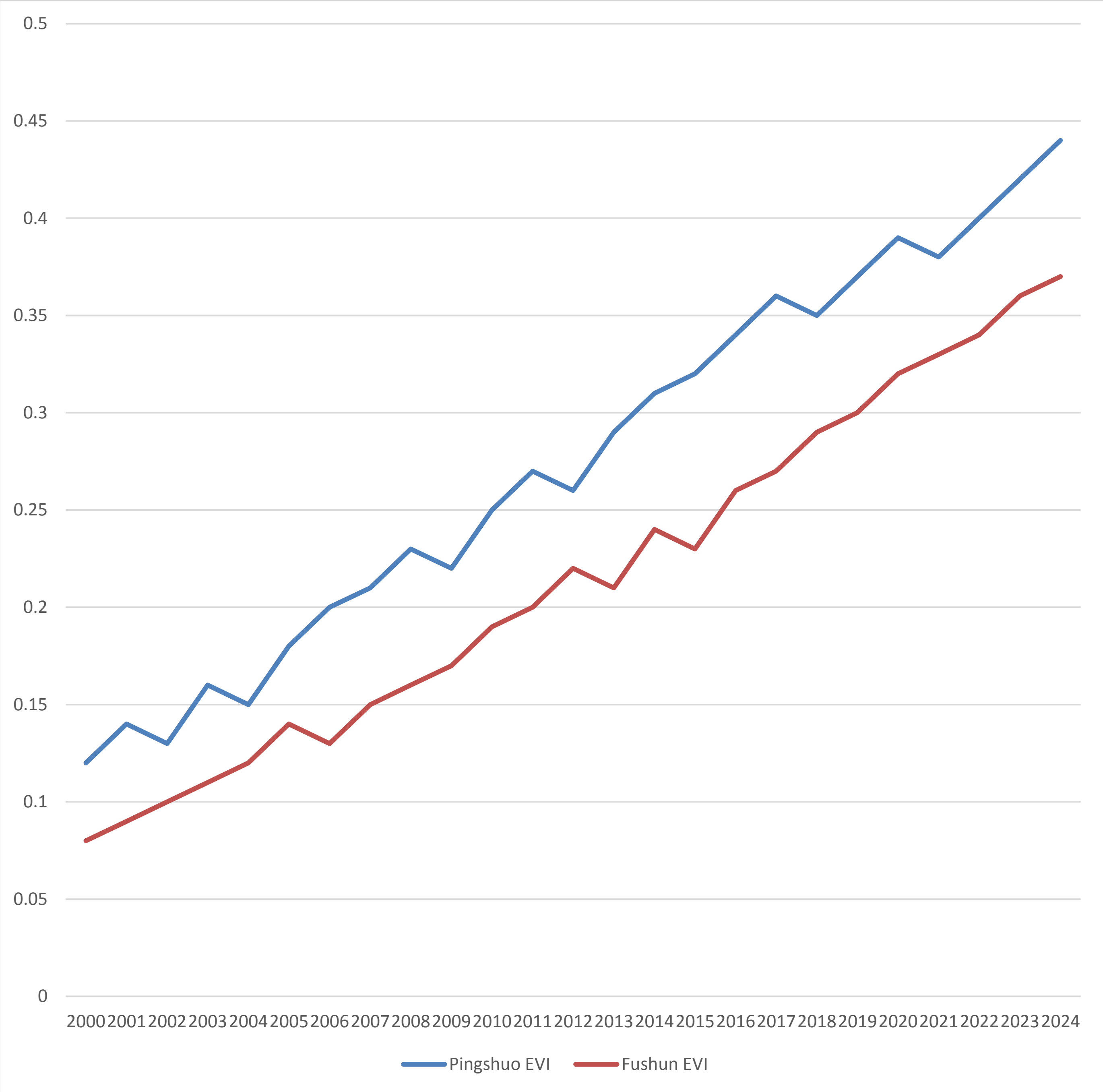


Figure 13: EVI Time Series Analysis for Pingshuo and Fushun Areas (2000–2024):The figure below illustrates the upward trend in EVI, highlighting the differential recovery rates between the two areas and the impact of restoration measures.

Land use Land Cover

Pingshuo Mining site

From the data analyzed it was noted that reclaimed lands are increasing as from 2014 to 2024 significantly. It is also evident that the mining pits area are reducing are these areas are reclaimed. Areas under settlements is increasing though at a very slow rate. Area under forest cover is reducing at a significant rate.

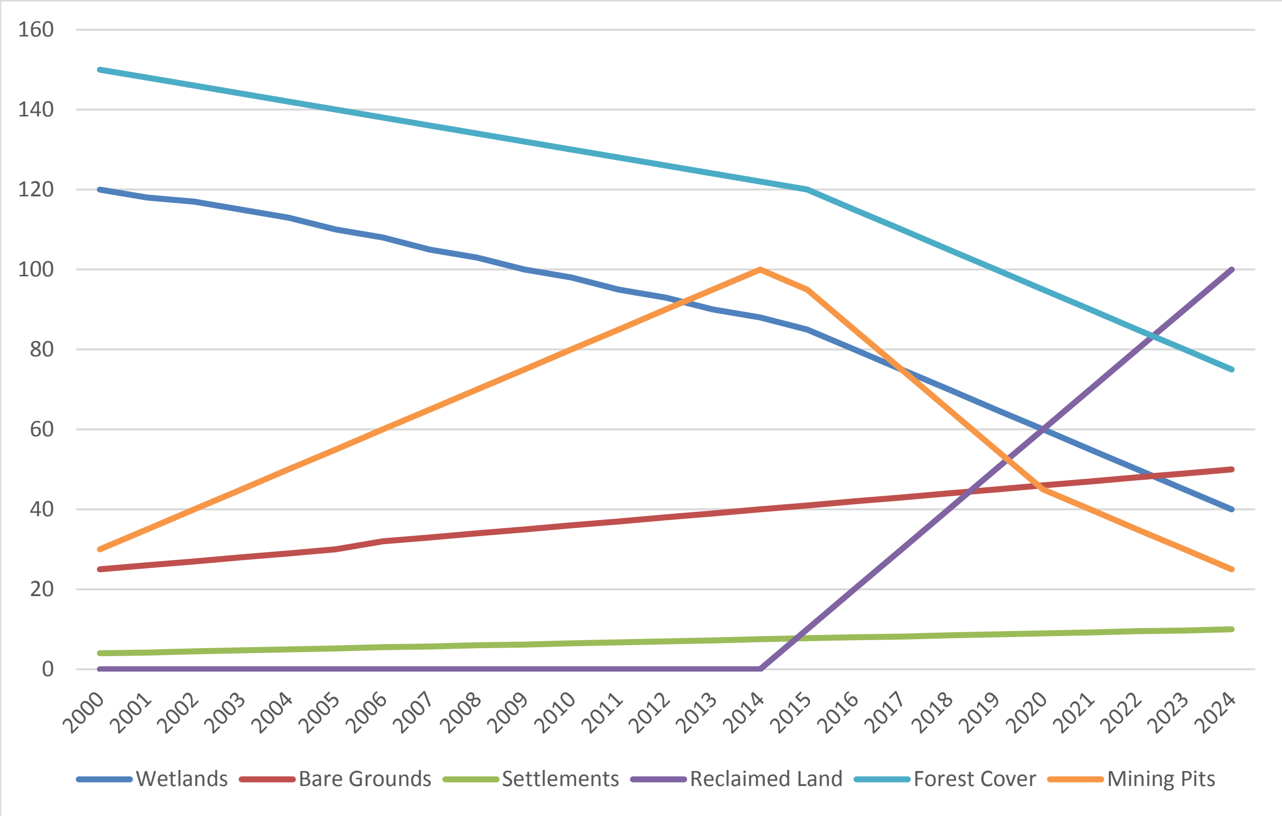


Figure 14: Land Use Land Cover Change analysis for Pingshuo area between 2000 and 2024

FUSHUN AREA

The area under Fushun shows that reclamation process took a significant shift in 2014 to 2024. The area under settlement is increasing slowly. Although Pingshuo is more advanced in technology as compared to Fushun. The areas reclaimed is quite significant as compared to Fushun.

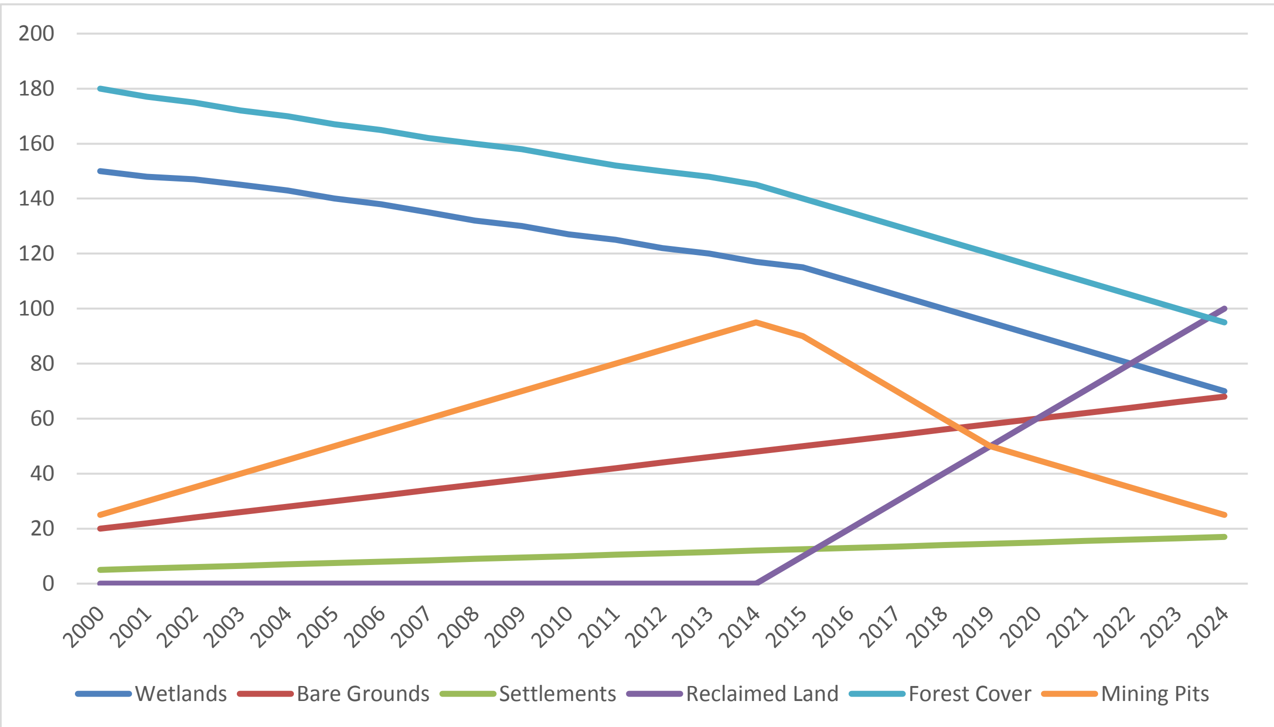


Figure 16: Land Use Land Cover Change analysis for Fushun area between 2000 and 2024

CHALLENGES

This research was very insightful although I encountered challenges such as some sites wanted me to purchase their geospatial data which was very expensive and out of my budget hence, I opted to use open-source data.

Some satellite images had excessive clouds which were more than 20% hence I had to look for the image of the same area of different month for the same year. This could have resulted to an inconsistency issue while detecting change in the area.

CONCLUSION

Based on the analysis done, the following conclusion were made:

1. Analysis of NDVI and EVI values from 2000 to 2024 indicates that both mining sites have shown a gradual increase in vegetation, suggesting some degree of successful ecological restoration. The improvements in NDVI and EVI reflect enhanced vegetation cover and health over time, with both sites demonstrating positive trends. However, the rate of improvement is different between the two sites, likely due to variations in restoration practices and local conditions.

2. Both sites have seen an increase in forest cover, which is indicative of successful reforestation efforts. The gradual increase in forested areas suggests that the restoration methods employed are contributing to the recovery of natural habitats.

3. The area classified as reclaimed land has increased significantly, particularly after 2015, reflecting the implementation of reclamation projects aimed at rehabilitating mined areas.

4. The area under mining pits increased rapidly up to 2015 but began to decline as reclamation efforts intensified. This decline is a positive indicator of effective rehabilitation strategies.

5. The area covered by bare ground increased slowly but steadily, which could be attributed to ongoing mining operations and the slow pace of restoration in some areas.

6. The settlement areas have increased slowly, reflecting gradual urban expansion or infrastructure development around the mining sites.

RECOMMENDATION

Based on the findings, the following are recommended:

1 Frequent Monitoring with Higher Resolution Imagery:

The use of continuous and higher-resolution satellite imagery is essential to provide more detailed insights into vegetation recovery and land use changes. This will help track restoration progress more effectively and identify areas requiring further intervention.

2 Increasing Ground Truth Points:

Expanding the number of ground truth points during field validation can improve the accuracy of classification and enhance the reliability of remote sensing analyses. This is particularly important for detecting subtle changes in vegetation cover and land use.

3 Tailoring Restoration Practices to Site-Specific Conditions:

The differences in vegetation recovery rates between Pingshuo and Fushun suggest that site-specific conditions, such as restoration practices, soil quality, and climate, significantly influence outcomes. Future restoration strategies should be tailored to these conditions to optimize ecological restoration efforts.

Declarations

“All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors”

Data Availability Statement

Dataset is not publicly available. Dataset however available from the authors upon reasonable request and with permission of Author.

Authors’ Contributions

Gill Ammara, Abaid Ur Rehman Nasir & Hongwei Zhang: Conceptualization, Methodology, Data curation, Writing- Original draft preparation, Investigation, Validation, Chang-hua LIU & Xiaojun NIE Visualization, Writing.

Disclosure of potential conflicts of interest

There is no conflict of interest

Ethical Approval

“Not Applicable”

Funding

No funding

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ABBREVIATIONS AND ACRONYMS

NDVI – Normalized Vegetation Index

USGS – United States Geological Survey

EVI – Enhanced Vegetation Indexing

LULC – Land Use Land Cover

AOI – Area of Interest

LIST OF FIGURES AND TABLES