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Research of the Impact of Climate Change on Ecosystem Services by Using Geospatial Information Technology – a Case Study of the Lan-Yang River Basin

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ABSTRACT:

Global warming is a common problem faced by countries around the world. In addition to the gradually rising temperature, there are also extreme climates and unstable rainfall patterns. All of the above phenomena may affect the ecosystem services.

In Taiwan, the hillsides are heavily developed by human activities. The soil and water conservation function of hillside is damaged by the torrential rain, especially during the season when tropical cyclones and monsoons prevail.

In this paper, the Lanyang River Basin is selected as the research area. In addition to its diverse topography, it is also the main area affected by monsoon and typhoon rainfall. If heavy rain occurs in the mountainous area, it often causes landslides or road collapse. Landslide not only endangers people's lives, but also causes the structure of the hillside to become fragmented and incomplete, thereby destroying the original ecosystem services.

This study aims to use multi-period satellite imageries and long-term temperature and rainfall data provided by the TCCIP to analyze ecosystem services in the Lan-Yang River Basin in order to observe whether there is a clear trend of degradation in the fragile hillside ecosystem.

Only after better understanding of the environmental conditions and climatic impacts of the site can help us plan preventive strategies for slope land conservation and disaster prevention, and jointly formulate a hillside land development and conservation plan with the goal of sustainable development.

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1. Introduction

1.1 Land Degradation Crisis

According to the Special Report on Climate Change and Land released by the Intergovernmental Panel on Climate Change (IPCC) in 2019, more than a quarter of land is affected by degradation crisis, how to protect land and restore forest function are the key solutions to solve this problem

For Taiwanese hillsides, monitoring and observing environmental changes over a long period of time will not only help us understand the impact of climate change on the ecosystem, but also help us to propose solutions that can effectively protect and strengthen the environmental problems we are currently facing.

We need to fully understand the trend of ecological environment change in the region, and whether global warming will have an impact on the hillside environment in Taiwan to produce a feasible plan for sustainability of the slope land.

1.2 Study Area

We take the Lan-Yang River Basin as an example. The Lan-Yang River is located in Yilan County and flows through mountains, hills and plains. There are obvious urban settlements in the downstream area. People were mainly engaged in agricultural production before.

While in recent years, many agricultural lands have been transformed into tourist farms and used for tourism purposes as a resting place for residents in the metropolitan area. Lan-Yang River serves as the main source of water supply to nurture the living needs of local residents.

Facing the humid northeast monsoon, Yilan County has a stable annual rainfall supply and occasional heavy rainfall brought by typhoons. It is always challenging the soil and water conservation function of the hillside area, and that is a serious threat to the development and protection of hillside resources. Based on topographic features and rainfall patterns, the Lan-yang River Basin is suitable as a representative area for the study of hillsides affected by climate change.

2. Materials & Methods

The purpose of this report is to determine whether there is landscape fragmentation in the Lan-Yang River Basin, and use satellite images of the study area and land use data to assist in the classification of features. Then evaluate the discrete situation of each feature by calculating the landscape index.

2.1 Satellite Image Database

The currently used satellite imagery is the Landsat series images, including images taken by four satellites at different times.

Before completing the analysis for this report, there were more than 300 cloud-filtered images in the database covering the period from 1984 to 2021. After removing the images with cloud-covered line of sight above the Yilan area, we selected 10 images and use to classify features.

Among them, the satellite images taken by Landsat 7 have been corrected for missing stripe data ( ) , so that the satellite data can be used for analysis.

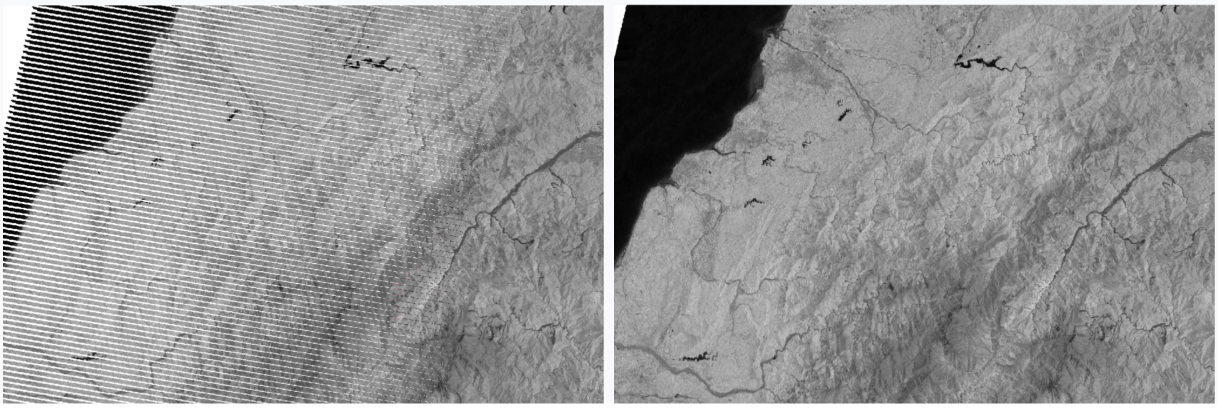


Figure 1: Landsat 7 SLC-off image comparison before and after calibration (Date:2008/5/12)

2.2 Landscape Classification

We used unsupervised classification tool in ArcGIS Pro and set the preset features into 15-20 different categories. In order to ensure the reliability of the classification results, we compared the preliminary results with the land use data in the same year, and reclassified the preliminary results into 6 different features.

2.3 Landscape Ecology

Major research topics in landscape ecology include calculating land use and land cover changes in landscape patches, linking landscape pattern analysis with ecosystem interactions.

From the review of relevant literature, landscape ecological analysis can calculate the size, distance, shape and distribution of patch. We can analyze whether the vegetation in the target area has changed from large patches to fine distribution.

we selected six indicators for this study:

a. Patch density, PD

$$PN = \sum_{i=1}^{n} P_i$$

$$PD = \frac{PN}{A} \times (10,000)\, {m^2}/{ha.} \times 100$$

P_i : the number of patches in the i-th land cover category
PN : the sum of the number of patches for the i-th land cover category
A : The total area of the study landscape (unit: m^2))

b. Euclidean Nearest-neighbor Distance, ENN_MN

$$ENN\_MN = \frac{\sum_{j=1}^{n} h_{ij}}{n_i}$$

h_{ij} : the nearest neighbor distance between patch j and patch i of the same type
n_i : the number of patches i in the landscape

c. AREA_MN

$$AREA\_MN = \frac{\sum_{j=1}^{n} a_{ij}}{n_i}$$

a_{ij} : Area of the j-th patch of the i-th category (unit: m^2)
n_i : the number of patches i in the landscape

d. Mean Fractal Dimension, FRAC_MN

$$FRAC\_MN = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} [\frac{2\ ln\, P_{ij}}{\ln a_{ij}}]}{N}$$

P_{ij} : perimeter of the j-th patch of the i-th class
a_{ij} : the area of the j-th patch of the i-th class

e. Connect Index, CONNECT

$$CONNECT = [\sum_{j=k}^{n} \frac{{c_{ijk}}/{n_i g}\,(n_i - 1)}{2}] * 100$$

c_{ijk} : the connection status of the patches j and k related to the category i in the i-th ground object category, and the degree of connectivity is equivalent to the connection point between this type of patch and other blocks

n_i : the number of patches i in the landscape

f. Normalize Landscape Shape Index, nLSI

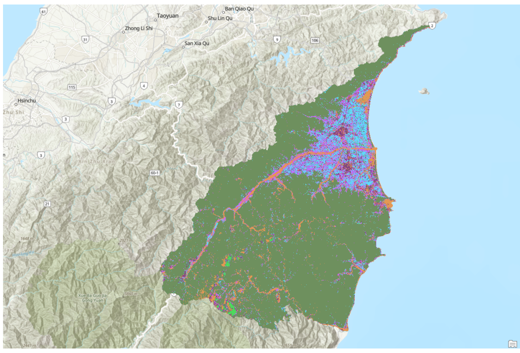
$$nLSI = \frac{e_i - min\ e_i}{max\ e_i - min\ e_i}$$

e_i : the sum of the perimeters of the i-type features

$max/min\ e_i$: maximum and minimum perimeters of the i-th category

3. Results

3.1 Classify Results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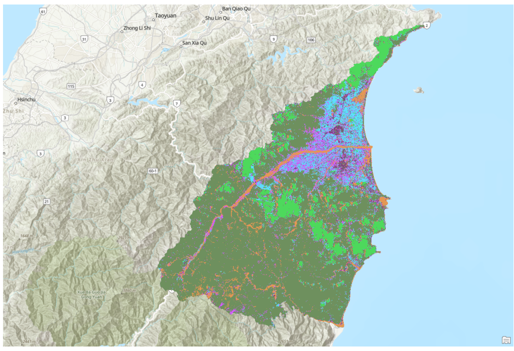
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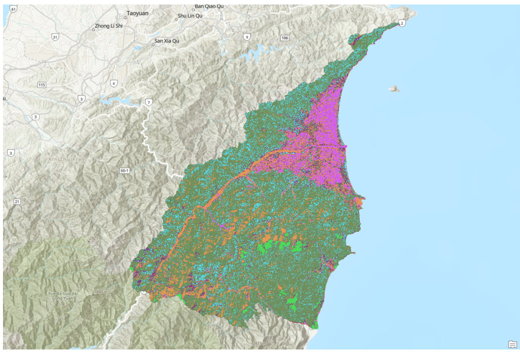
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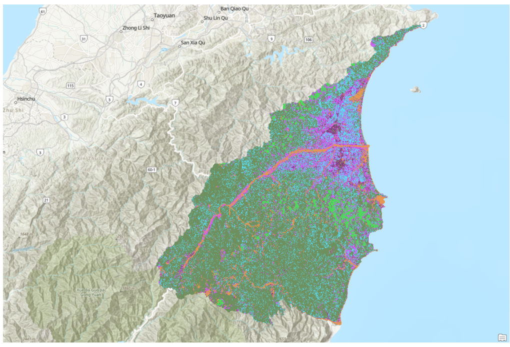
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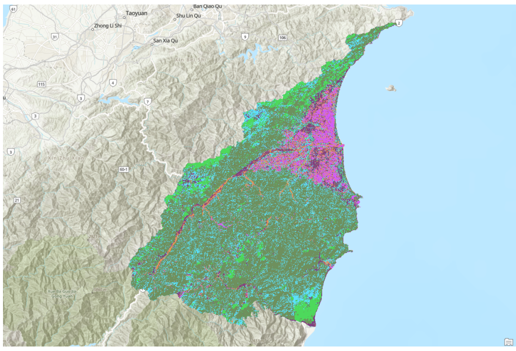
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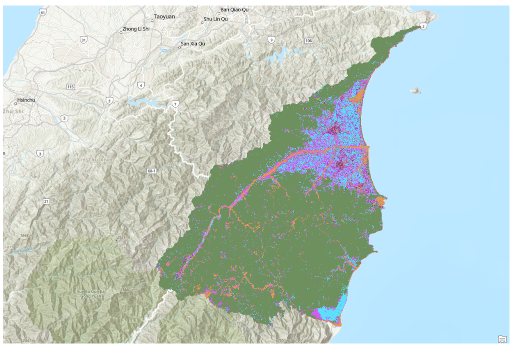
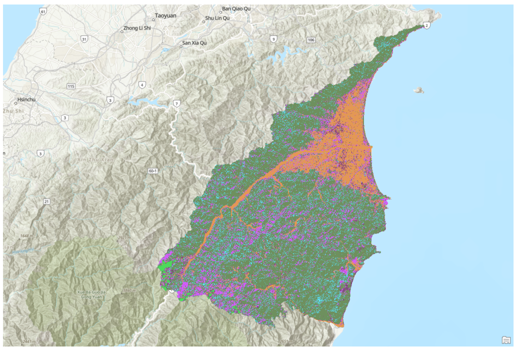

Date:2020/6/22



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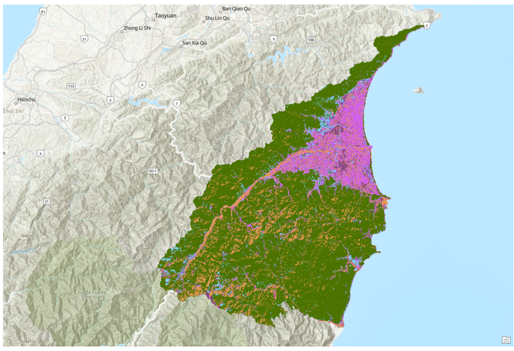
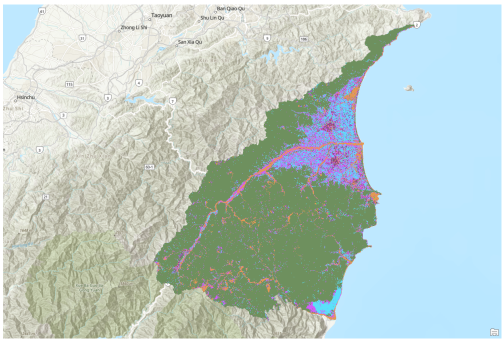


Date:2014/12/31



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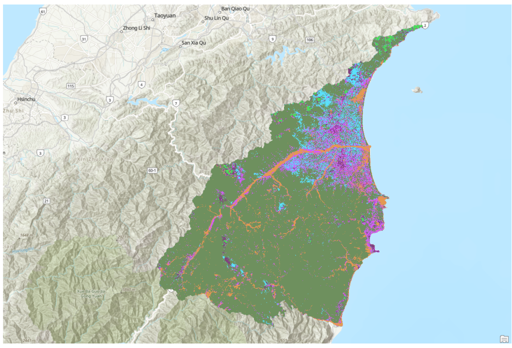

Date:2013/6/19

Figure 2: Reclassify results of Landsat images

summer	building	farmland	waterbodies	plant	soil
2013.6	**2.571543**	**5.854496**	**6.368065**	**75.47259**	**8.477039**
2015.6	**2.664514**	**16.62319**	**5.516892**	**58.30624**	**12.1712**
2016.6	**2.749748**	**8.740038**	**6.851026**	**62.15426**	**7.742355**
2020.6	**1.43844**	**8.542478**	**5.409528**	**74.89546**	**9.496209**
2021.6	**2.901019**	**7.354156**	**6.280948**	**75.76607**	**7.141575**

winter	**building**	**farmland**	**waterbodies**	**plant**	**soil**
2014.12	**3.115312**	**4.129166**	**13.83625**	**68.64847**	**10.2708**
2015.11	**3.759593**	**4.121435**	**10.60535**	**71.49217**	**10.02145**
2016.12	**2.254396**	**9.377104**	**13.4397**	**61.94713**	**12.08316**
2017.1	**6.479321**	**19.07936**	**5.239811**	**55.92451**	**4.559489**
2019.1	**6.617742**	**12.4344**	**13.64258**	**58.57849**	**6.291789**

Table 1: Landcover percentage (unit : %)

3.2 Landscape Ecology Index

Year	**2013.6**	**2015.6**	**2016.6**	**2020.6**	**2021.6**	**2014.12**	**2015.11**	**2016.12**	**2017.1**	**2019.1**
PD	1.4416	2.2212	1.3383	1.1507	0.9167	0.7155	0.517	1.2131	1.2063	1.4648
ENN_MN	76.58	79.434	93.213	97.772	102.523	103.496	109.777	93.214	92.021	86.186
AREA_MN	21.63	10.847	19.192	26.897	34.1553	39.647	57.146	21.094	19.158	16.526
CONNECT	0.26	0.1613	0.1596	0.2291	0.2643	0.2331	0.2885	0.1802	0.1272	0.1538
FRAC_MN	1.048	1.040	1.040	1.034	1.037	1.034	1.037	1.035	1.038	1.037

Table 2: Plant cover landscape patch index

Comparing the changes in the average area of patch in summer and winter, the area in summer gradually increases, while the area in winter tends to shrink gradually. This result shows that the vegetation in winter is mainly distributed in small patch with the rising patch density, which means that the vegetation fragmentation in winter has become more serious in recent years.

FRAC_MN remained stable at around 1.038 from 2013 to 2021, indicating that the vegetation distribution in this area was seriously affected by human activities, and the patch shape was relatively simple, which was not conducive to maintaining ecological diversity.

For connectivity change, there is no special seasonal change, and it is not related to the vegetation area and block distribution density. Its value ranges from 0.28 to 0.15, and the overall distribution is low and close to 0, which is not conducive to the formation of biological corridors.

Year	2013.6	2015.6	2016.6	2020.6	2021.6	2014.12	2015.11	2016.12	2017.1	2019.1
PD	1.416	1.4599	1.5817	1.642	1.6824	3.9121	3.2601	1.2527	2.1524	2.799
ENN_MN	125.23	130.39	130.03	119.04	121.83	87.63	93.81	125.74	101.16	94.60
AREA_MN	1.8585	1.5616	1.7899	1.3614	1.5428	1.4615	1.3443	4.4319	1.006	2.014
FRAC_MN	1.0434	1.041	1.0423	1.0403	1.0432	1.056	1.0574	1.0447	1.0573	1.056

Table 3: Waterbody landscape patch index

The Lan-Yang River Basin is significantly affected by monsoon rainfall, so unlike the barren stream-type rivers in the central and southern regions, the Lan-Yang River Basin has the largest rainfall in autumn and winter (from August to November).

We can see that value of patch density in winter is higher than summer (about 40% growth).

The waterbody in the study area is dominated by continuous rivers, so the patch density represents the area expansion of the waterbody rather than landscape fragmentation.

From the lower ENN_MN in winter, that mean the runoff in winter is more concentrated, and it overlap with the period of high vegetation fragmentation, which may cause the danger of landslides and collapses in areas with bad soil and water conservation functions.

Year	2013.6	2015.6	2016.6	2020.6	2021.6	2014.12	2015.11	2016.12	2017.1	2019.1
plantcover	0.0454	0.1558	0.0528	0.0352	0.0304	0.0562	0.0467	0.1433	0.1261	0.1357
framland	0.3797	0.5088	0.3449	0.3731	0.3514	0.4699	0.4717	0.633	0.404	0.4726
soil	0.388	0.3976	0.4628	0.4359	0.4486	0.3645	0.3698	0.3797	0.2547	0.2368
waterbody	0.2396	0.2589	0.2432	0.2811	0.2684	0.328	0.3569	0.1671	0.4558	0.3105
building	0.393	0.46	0.4862	0.4921	0.3956	0.4119	0.3503	0.4709	0.2965	0.4004

Table 4: nLSI of each feature

From the nLSI performance of the five types of features, we can see that the nLSI of vegetation has been maintained at a value close to 0. Compared with other features, it lacks a complex shape. Combined with the former analysis of vegetation CONNECT index, the functionality of the vegetation in the study area as a biological habitat should be assessed to determine whether the vegetation in the area is experiencing a decline in habitat quality and an increased risk.

4. Discussion

From the analysis results of the vegetation landscape index, the vegetation distribution in Yilan area has been fragmented in recent years, and there is a tendency to become more serious.

And there are significant seasonal differences in such phenomena, but it is still unknown whether the fragmentation of vegetation will affect the ecosystem services in the study area.

To understand the impact of environmental changes on ecosystem services, we will analyze the vegetation functions in the study area, including its soil and water conservation functions, habitat quality and risk assessment.

Observe whether there is a trend of land degradation in the Lan-Yang River Basin under the greenhouse effect and landscape fragmentation.