應用多元空間資訊製作水里溪集水區崩塌潛勢圖

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研究背景目的

受到全球氣候變遷影響，使得極端氣象事件發生頻仍，分布於農林山村地區之不同土地利用型，暴露在颱風、暴雨及人為活動之影響下，容易發生**崩塌(landslide)**及土石流(debris flow)等危害，常造成當地生命及財產的損失。不僅增進了當地的生態與社會系統的脆弱度(vulnerability)，同時也減低了當地的生態服務功能之綜合資源承載量(carrying capacity)、進而提高山村經濟生產損失以及居民生活安全性的風險。因此如何蒐集各項環境影響與致災啟動因素之地理空間資訊，藉由先進的空間資訊分析技術，有效製作山村不同土地利用型之**崩塌潛勢(susceptibility)分析圖**，進而以不同時空尺度研究崩塌危險度(hazard)等級及危險區域(hazard zone)劃分，以及脆弱度估算(vulnerability estimation)，對崩塌災害風險行評估(risk assessment)，從評估結果提出因應的調適策略，作為有科學基礎的決策依據，為當前重要的課題。

本研究.選擇中尺度水里溪集水區為試驗地範圍，以過去10年為時間尺度，於不同空間及時間尺度下整合不同時期衛星遙測、各項土地利用調查、數值地形、氣象、天然災害、環境敏感區劃等多尺度空間及圖籍資料。應用空間統計分析技術，分析並製作極端氣象天然災害事件導向之集水區崩塌潛勢分區分級圖。期望本崩塌潛勢分級圖，可供後續結合各種土地利用型圖、社會經濟地理資訊，評估崩塌風險之用。

使用氣候變遷的資料

水里溪集水區6期無雲福衛二號影像、水里溪集水區2015.04.14法國法國太空公司Pléiades衛星影像、內政部水里溪集水區5m及1m數值高程及表面高圖層，水土保局申請取得2011年南投縣山坡地土地利用型圖。**由國家防災科技中心取得1km歷年月雨量資料**、農業試驗所提供的山坡地土壤圖，以及從內政部地理資訊圖資雲服務平台下載及申請有關水里溪集水區與崩塌潛勢分析相關的5萬分一地質圖、坡地土壤圖、崩塌地類型調查圖、順向坡區位圖、土石流潛勢溪、災害發生歷史圖資、地質敏感區位劃分等地理資訊圖資。

研究試區

以包含日月潭的水里集水區為試驗地範圍，以2004年至2015為時間尺度，選擇6期時期福衛二號衛星遙測、1期2015.04.14拍攝之法國Pléiades衛星影像(圖1)，應用影像分割技術之半自動崩裸地萃取程序完成7個時期試驗區域的崩塌地調查。

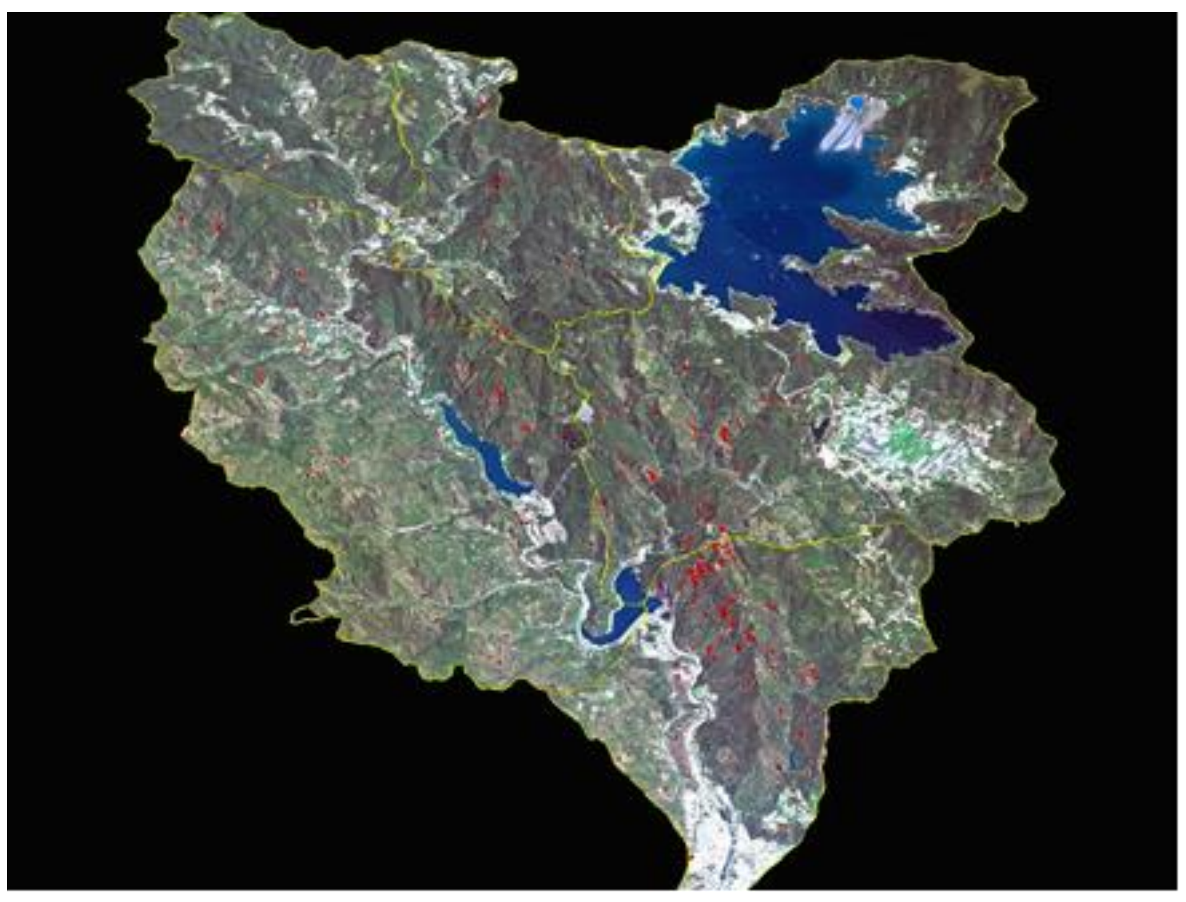

圖 1. 南投縣水里溪集水區(面積8,362公頃) 2015.04.14 法國 Pléiades 衛星全色融銳化融合影像，空間解析度50cm。結合數值地形模型(DTM)展示立體透視圖。應用影像分割技術萃取的紅色多邊形，代表坡度大於15度、面積大於0.04公頃的崩塌地及土壤裸露區塊。

崩塌潛勢分析

應用**不安定指數統計估計方(instability index method)**，Pléiades衛星影像判釋所得崩裸地、以水土保持局2011年調查的崩裸地，以及由國家防災資訊科技中心提供歷年地面調查所得的水里集水區崩屑滑動區塊及落石崩塌空間分布圖，聯集4個圖層的崩裸地區塊；以2004年至2015年為分析的時間尺度。藉由蒐集的各項地理資訊圖層，以地理資訊空間分析方法製作了水里溪集水區 15個，具有5m空間解析度之崩塌地發生空間指標圖層**:(1)平均降雨量分級圖(2)坡度分級圖(3)海拔高分級圖(4)坡向分級圖(5)地形粗糙度分級圖(6)NDVI分級圖(7)山坡地土壤分類圖(8土壤深度分級圖(9)五萬分一地質分類圖(10)離道路分級圖(11)距離主流分級圖(12)距離支流分級圖(13)距離活動斷成分級圖(14)距離順向坡分級圖(15)距離土石流潛勢溪分級圖**。

結果與討論

本研究充分運用從政府開放資料，綜合崩塌地有關土地利用調查、土壤、地質、數值地形、氣象及災害等的地理資訊圖層，進行空間分析。應用不安定指數統計分析方法，各項指標的各級面積崩塌比率之變異數(coefficient of variation) 大小，能選出有利於崩塌潛勢的分析的主要影響指標。**從15個相關指標(圖2)中選取了(1)地形粗糙度分級圖、(2)坡度分級圖、(3)山坡地土壤分類圖、(4)NDVI分級圖、(5)五萬分之一地質分類圖，以及(6)平均降雨量分級圖，共6個指標(圖3)。**

崩塌潛勢影響指標	變異數 V(%)	權重 W(%)
1.地形粗糙度	157.64	21.22
2.平均坡度	134.95	18.16
3.山坡地土壤分類圖	129.60	17.44
4. NDVI	123.53	16.63
5.五萬分之一地質分類圖	106.75	14.37
6.平均雨量	90.54	12.18
7.土壤深度	111.55	
8.距斷層距離	67.76	
9.海拔高	67.70	
10.距支流距離	57.84	
11.距主流距離	48.33	
12.坡向	46.52	
13.距土石流潛勢溪	44.22	
14.距道路距離	41.51	
15.距順向坡距離	27.01	

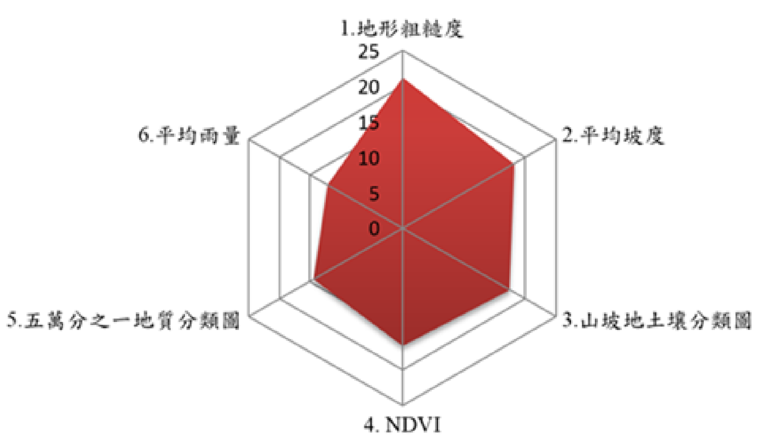

圖 2. 15個崩塌潛勢指標選取及前6個影響指標的權重

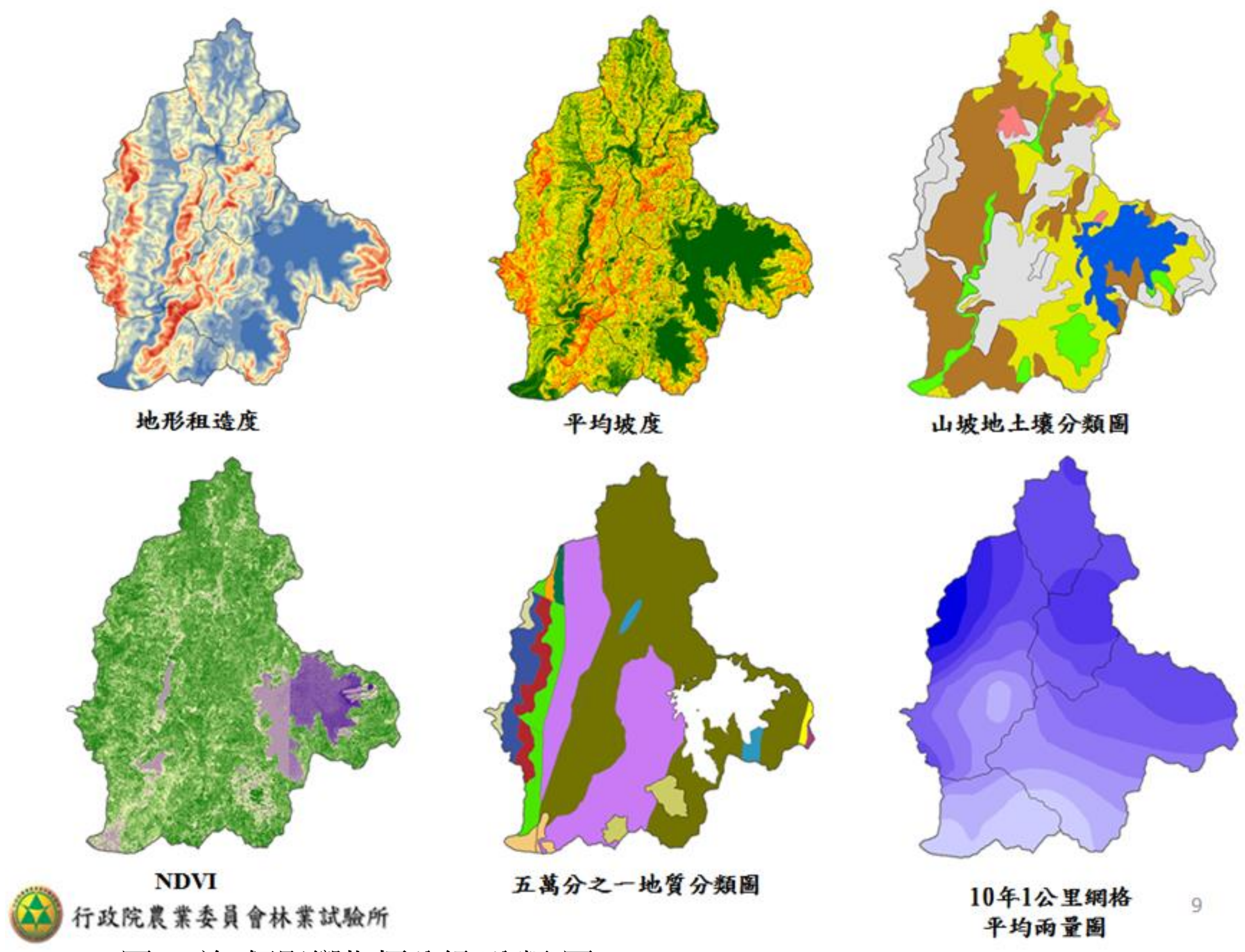

圖 3. 前6個影響指標分級(分類)圖

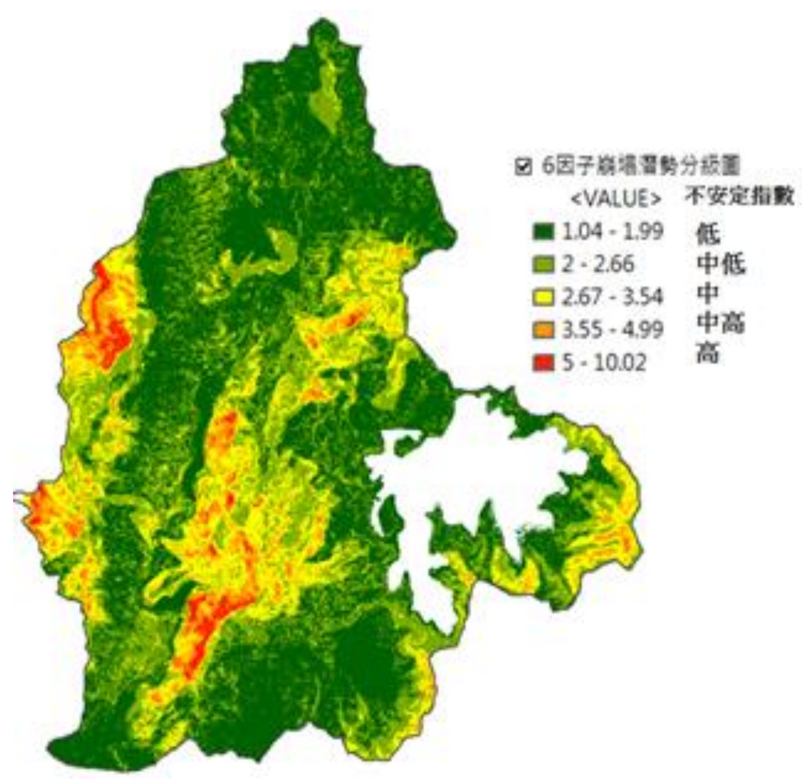

圖4. 崩塌潛勢機率5等分級圖

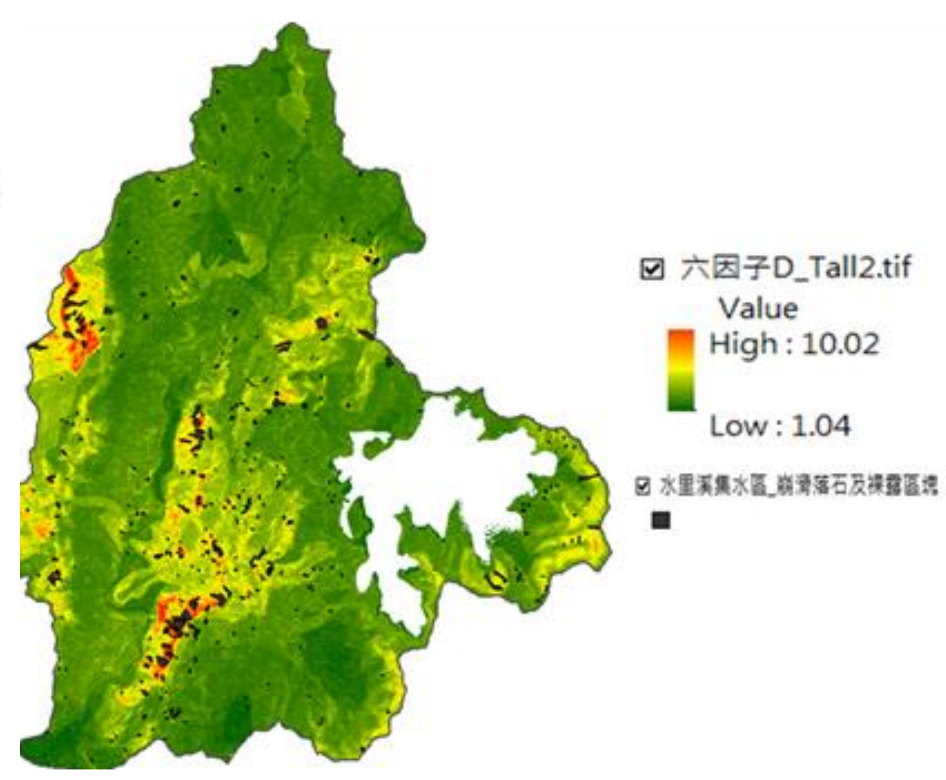

圖5. 崩塌潛勢機率圖與水里溪集水區歷年崩滑落石及裸露地區塊套疊圖

本方法可依據過區發生的崩塌地所在的位置進行個指標分級的不安定分數，並以變異數所佔權重當作不安定分數指數值，計算個別指標的權重，以各指標分級或分類的不安定評分分數，求得水里溪集水區崩塌潛勢機率圖，本圖示一個連續數值，將機率從1到10分顯示表達，將訓練用的聯合崩塌地圖層進行套疊分析，**發現有82%的崩塌地區塊落在機率大於5分的區位。再將水里溪集水區崩塌潛勢機率圖分成低、中低、中、中高、高5級(圖4)，其中處在第5級區位的崩塌發生機率值大於0.5以上，必須加以注意。**本崩塌潛勢分級圖可與其他地理資訊圖層相疊加以驗證，目地在於提供後續結合各種土地利用圖(圖5)、社會經濟地理資訊，評估崩塌風險之用。

Adjusting climate change adaptation strategies for upstream watershed using 30 years remote sensed data

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Introduction

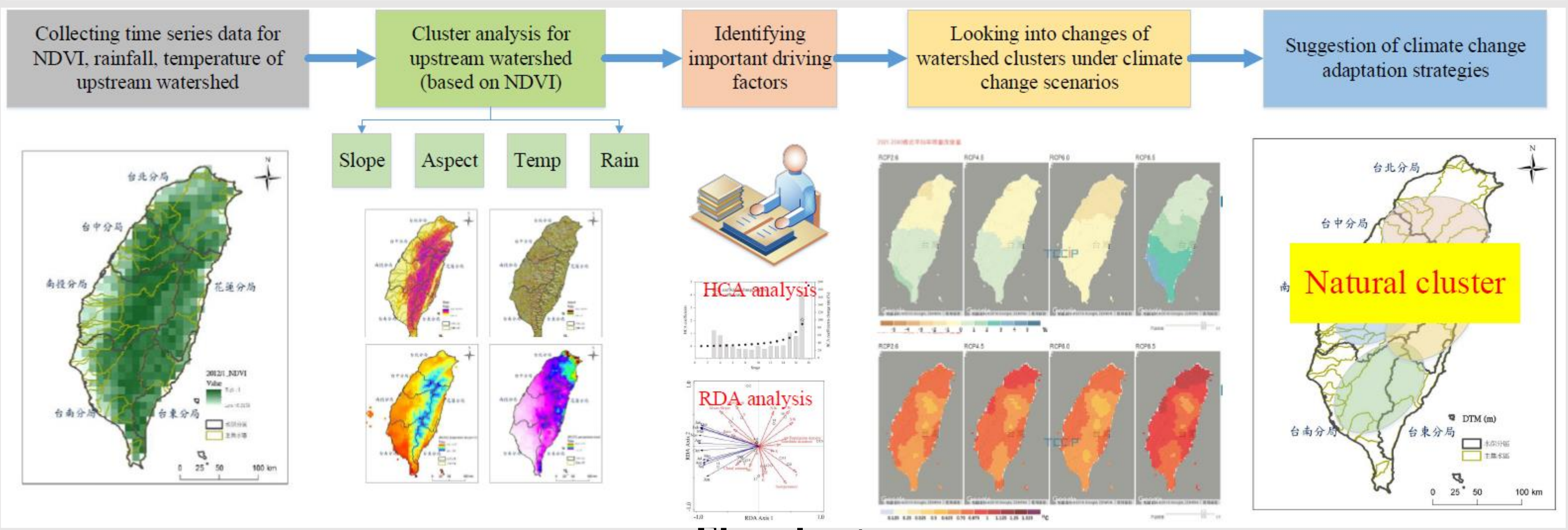
Under the influence of global climate change, Taiwan is facing many challenges such as extreme precipitation events, more collapses, landslides, and other disasters that are seriously affecting the safety of lives. Remote sensed data have been utilized to assist evaluating climate change influences on terrestrial ecosystems, especially on terrestrial vegetation. Therefore, the present study aims to identify natural clusters on Taiwan's terrestrial vegetation, especially for upstream watersheds, by using 30 years remote sensed data. Additionally, important factors for explaining the vegetation variance were analyzed. Moreover, we have put forward suggestions of climate change adaptation strategies according to future climate change scenarios of each upstream watershed group. Eventually, the results of the present study will benefit both the major management agency, the Soil and Water Conservation Bureau, and the sustainability of the ecosystems of Taiwan.

Research Questions

1. What are the long-term trends of upstream watersheds?
2. Do the upstream watersheds have natural clusters? What are the associated explanatory variables?
3. What are the future climate change scenarios situation for each cluster?

Materials and Flowchart

Materials	Source	Spatial resolution/pixel
Normalized Difference Vegetation Index (NDVI)	GIMMS NDVI3g dataset	8km
Temperature and Precipitation Climate Change Simulation Scenarios	Taiwan Climate Change Projection and Information Platform (TCCIP)	5km
Slope and Aspect	Taiwan Ministry of the Interior-Digital Terrain Model (DTM)	40m



Flowchart

Methods

1. **Hierarchical cluster analysis (HCA)**
   Agglomerative hierarchical cluster analysis (Huang *et al.* 2014)(Fig.1)and Wards Method were used.
2. **Redundancy analysis (RDA)**
   RDA is a method extending from multiple linear regression(MLR) which assumes that there are linear relationships between variables(Ter Braak 2002), with the following formula:

$$\left(S_{YX}S_{XX}^{-1}S'_{YX}-\lambda_k I\right)u_k=0$$

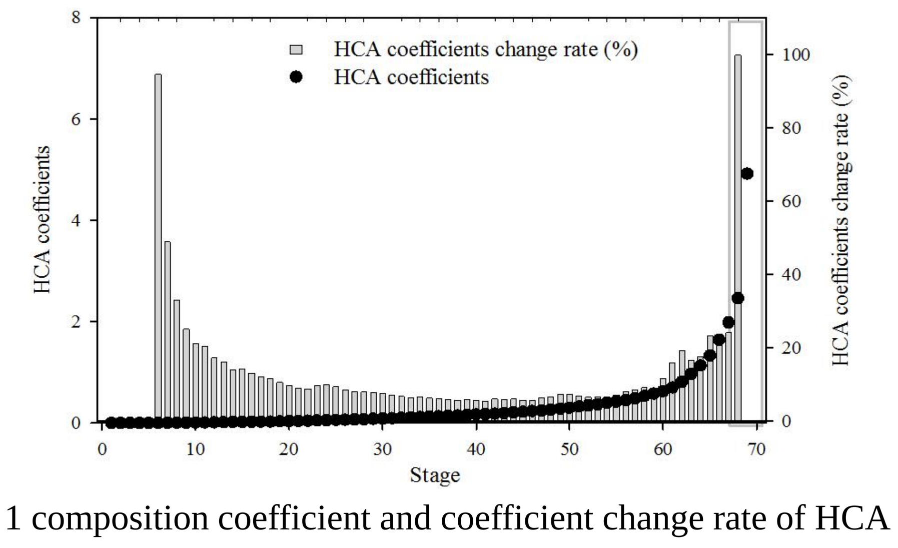


Fig. 1 composition coefficient and coefficient change rate of HCA

S_{YX} is a covariance matrix of dependent and the explanation of variance. S_{XX}^{-1} is the covariance matrix of the explanation of variance after normalizing. I is a unit matrix. λ_k is the eigenvalue of k axis. u_k is normalized canonical feature vectors (Legendre and Legendre 2012).

Results

1. What are the long-term trends of upstream watersheds?

The present study selected 70 upstream watersheds to conduct monthly time series analysis from 1982 to 2012 (Fig.2). Although not significantly, slight increasing trends were detected from the NDVI, precipitation, and temperature time series data for the year 2001-2012(Fig. 2).

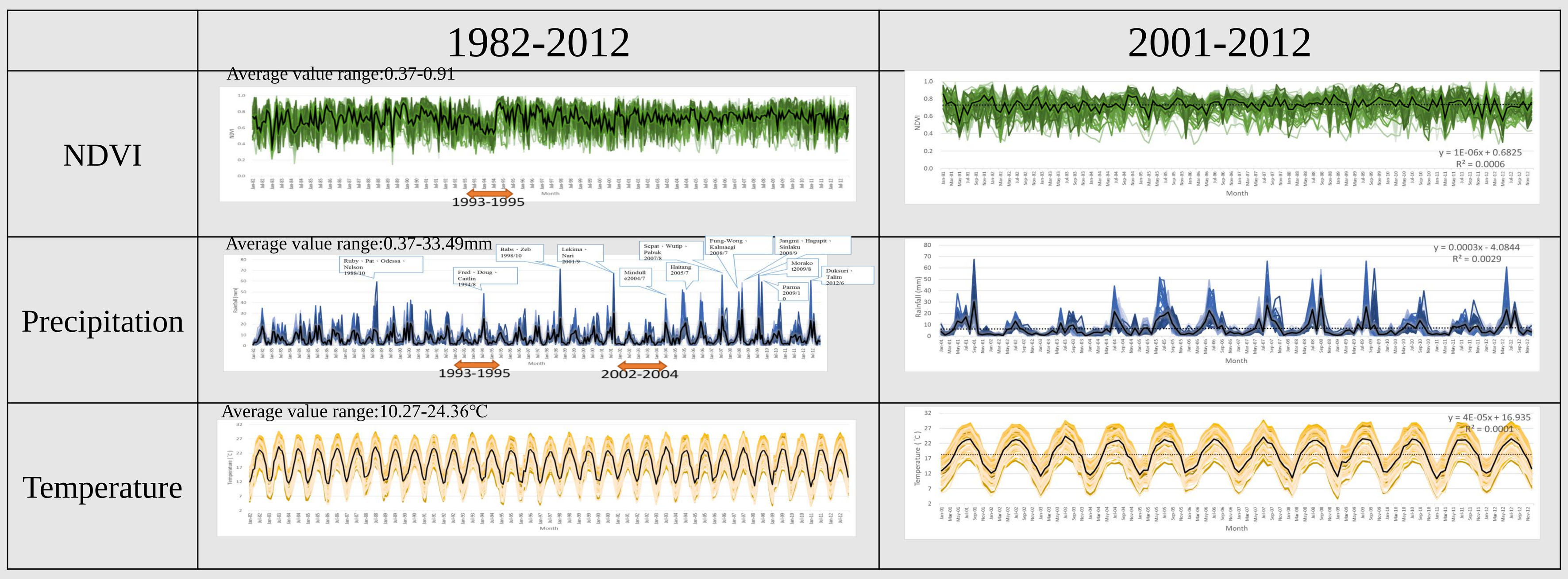


Fig. 2 Long-term trends of the selected 70 upstream watersheds

2. Do the upstream watersheds have natural clusters? What are the associated explanatory variables?

The results show that the upstream watersheds in Taiwan can be divided into 6 clusters (Fig 3). Nine significant explanatory variables, namely slope, temperature, flat slope, NE-facing slope, rainfall, East-facing slope, SE-facing slope, West-facing slope and NW-facing slope were contributing to the variance of NDVI (Fig. 4-5）。

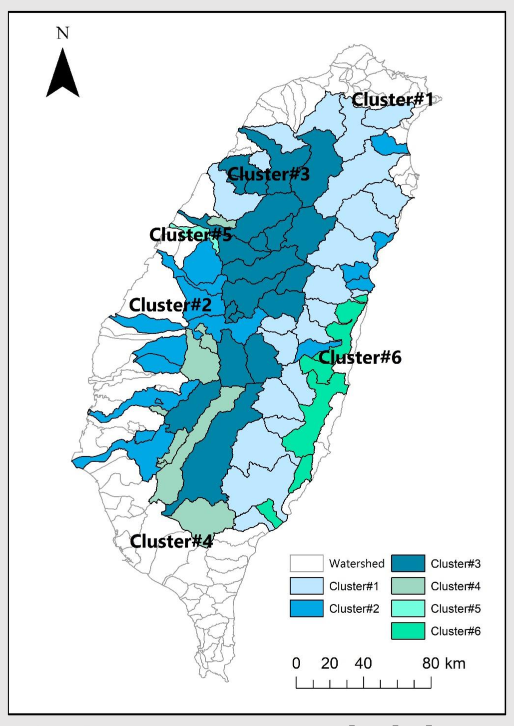


Fig. 3 Upstream watershed clusters

Name of variable	Explains %
Slope	35.2****
Temp	27.8****
Flat	17.2****
NE	11.2****
Rain	10.6****
E	5.9**
SE	5.7**
W	5.2**
NW	3.6*
SW	2.7
N	2.5
S	0.3

****p<0.001; ***p<0.01; **p<0.05; *p<0.10

Fig. 4 Explanatory factors

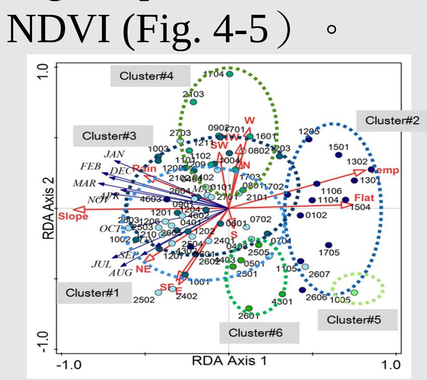


Fig. 5 RDA results

3. What are the future climate change scenarios situation for each cluster?

The HadGEM2-AO model was used to analyze four situations of climate change scenarios, RCP2.6, RCP4.5, RCP6.0, and RCP8.5, in 2021-2040, 2041-2060, 2061- 2080 and 2081-2100 (only 2021-2040 was shown in Fig. 6 for illustration purpose). Decreased precipitation patterns were seen in winter, spring, and summer, especially in winter (11-51% decrease). Increased Temperature patterns were seen for all seasons by 0.4 to 2° C(Fig. 7).

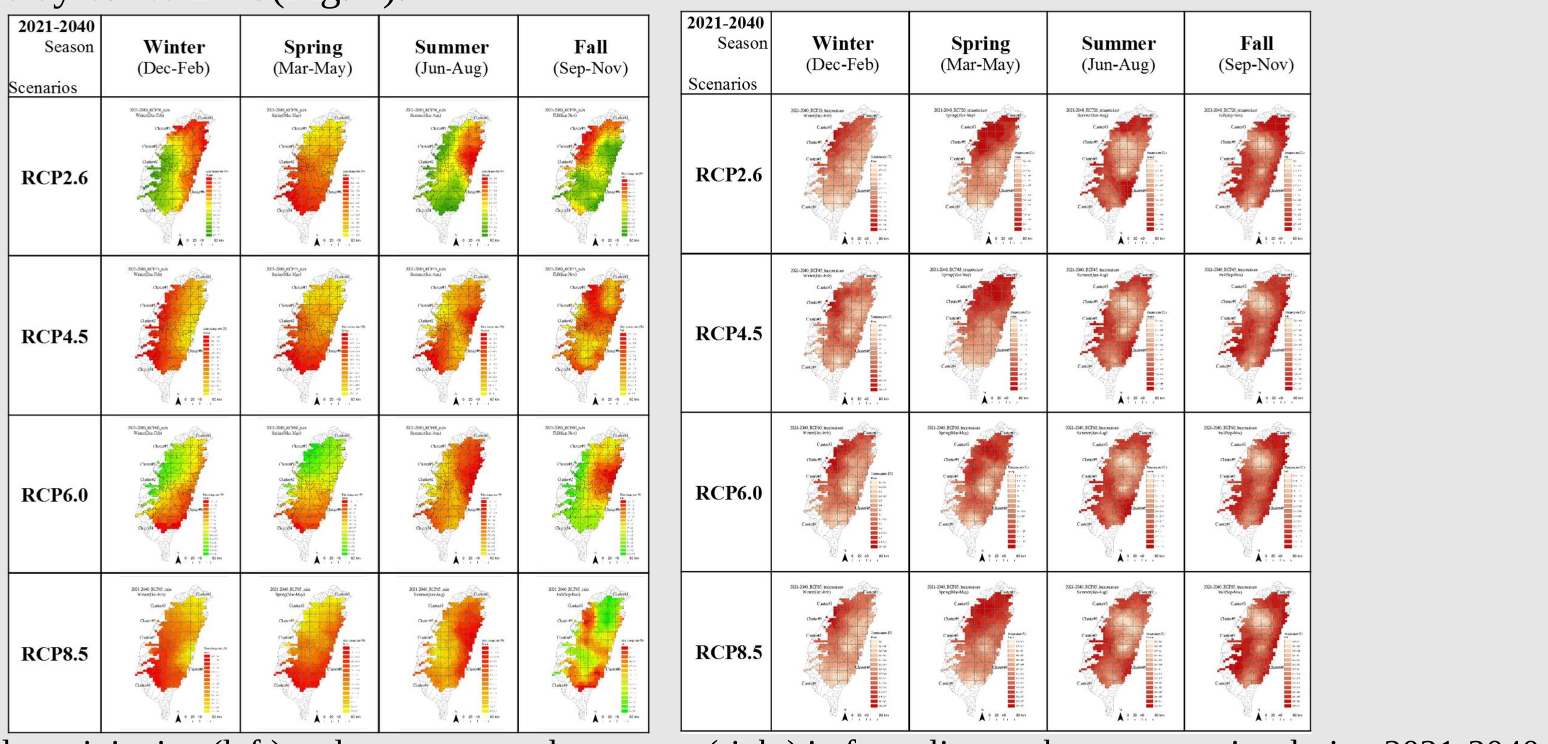


Fig. 6 Seasonal precipitation (left) and temperature change rate (right) in four climate change scenarios during 2021-2040

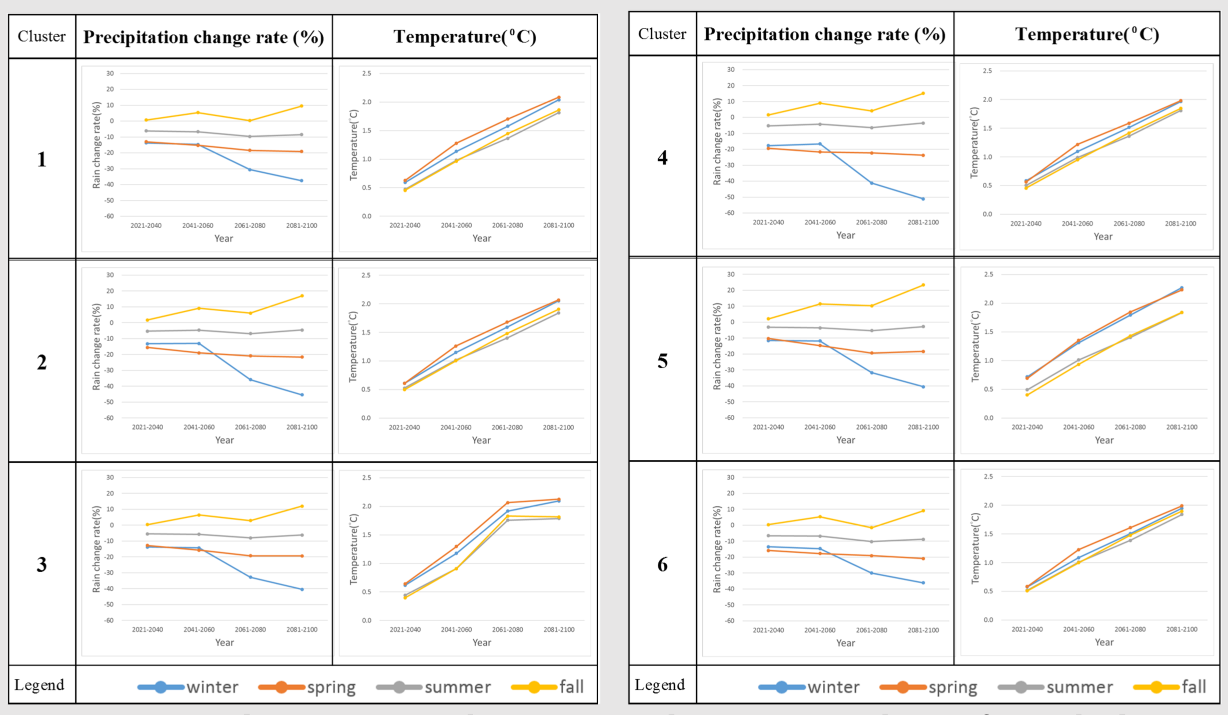


Fig. 7 Averaged precipitation change rate and temperature change for each cluster

Conclusion

1. The upstream watersheds in Taiwan can be divided into 6 groups. In the future, this group can served as management units.
2. Nine explanatory variables including slope, temperature, flat slope, NE-facing slope, rainfall, East-facing slope, SE-facing slope, West-facing slope and NW-facing slope were identified significantly for the NDVI variation explanation.
3. Decreased precipitation patterns were seen during the winter, spring and summer months, especially in winter (11-51% decrease). Increased Temperature patterns were seen for all seasons from 0.4 to 2° C.
4. Suggested climate change adaptation strategies are as follows:
   Cluster#1：the effects of precipitation pattern change on high-altitude tree species, associate carbon sequestration capacity, and ecological functions of forests.
   Cluster#2：the effects of predicted less precipitation and higher temperature on agriculture; consideration of natural disaster relief subsidy policies, agricultural insurance, hotspot/vulnerability assessment, timely adjustment of cropping, and crop rotation systems.
   Cluster#3： biodiversity of the conservation focal area (as a focal area connection the Central Mountain, south-to-north greenbelt conservation areas, and east-west forest greenbelt networks); predicted increased summer precipitation on slope erosion and landslides.
   Cluster#4：the suitability and the impact assessment of agricultural land; disasters of slope failure caused by typhoon and short-term heavy rain.
   Cluster#5： the effects of changes in precipitation on water resources deployment and agricultural irrigation needs.
   Cluster#6：strengthen the prevention, preparation, and adaptability works on large-scale slope failures and potential collapses.

Acknowledgments

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