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ضمن تشکر از جنابعالی جهت ارسال مقاله به دومین کنفرانس بین المللی مخاطرات محیطی که در روزهای ۷ و ۸ آبان ماه ۱۳۹۲ در دانشگاه خوارزمی برگزار گردید، بدینوسیله گواهی می شود مقاله جنابعالی با عنوان:

" CRITICAL SLOWING DOWN THEORY AND DESERTIFICATION MANAGEMENT"

در این کنفرانس ارائه شده است.

امید است با مشارکت و تلاش علمی بیشتر در پیشرفت و اعتلای کشور موفق باشید.

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دانشگاه خوارزمی
Kharazmi University

CRITICAL SLOWING DOWN THEORY AND DESERTIFICATION MANAGEMENT

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ABSTRACT

A new view to desertification phenomenon based on thermodynamics laws for open systems has been followed in this article. Desertification is defined as irreversible land degradation that is caused by human activity and climate fluctuations leads to deterioration of human well-being. Some ecosystems may occasionally change quite abruptly to a contrasting state. Shift may occur in ecosystems with alternative stable states in which the conditions change gradually toward a critical point, called a bifurcation, where the ecosystem becomes unstable and shifts to the alternative state. In any systems that are close to a critical transition, recovery upon small perturbations becomes slow, a phenomenon known as critical slowing down. In this article the desertification has been analyzed under this fact and considered a result of non-equilibrium point in ecosystem near to critical transition. The equilibrium thinking used in this research can be helpful for development of sustainable ecosystems and combating desertification.

KEYWORDS: Critical Slowing Down, Resilience, Desertification, Bifurcation, Equilibrium

Critical slowing down

The term ‘‘critical slowing down” refers to the fact that near threshold points (bifurcations) the return time to equilibrium upon a small perturbation increases strongly.

A simple way to understand critical transitions is to think of the behavior of a system as the motion of a ball in a landscape of valleys and hilltops (Figure 1). Ball represents the state of the ecosystem. Valley corresponds to the basins of attraction of the two alternative stable states of the ecosystem.

The width and the steepness of the basin of attraction determine the capacity of the ecosystem to absorb a perturbation without shifting to an alternative state, and reflect the resilience of the state of the system where vegetation density is in maximum.

As conditions bring the ecosystem close to a critical transition (*critical threshold)*, the basin of attraction of the current states of the ecosystem shrinks and so does its resilience: even a tiny perturbation is enough to shift the sphere to the alternative valley where slowing down occurred.

At the same time, the steepness of the basin of attraction becomes lower: this means that the same perturbation that may not tip the ecosystem, it will definitely take longer to dissipate due to the phenomenon of critical slowing down.

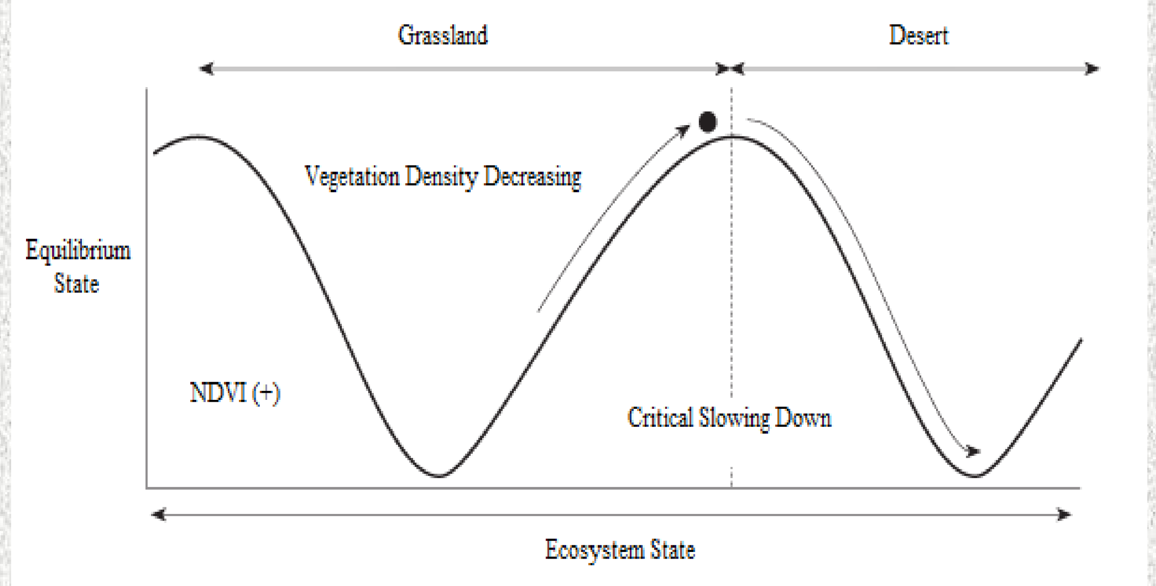

Fig. 1: The ecosystem state alterations pursing vegetation cover decreasing which change the view of ecosystem in consequence of equilibrium changes and a desert view will be output.

Case Study Position

To apply the methodology, the Khorasan Razavi (**KR**) province with second metropolitan of Iran, Mashhad, and one of the erosion and soil degradation centers has been considered. This area covers about 128430 Km^2 within longitude 55° 0 17" to 61° 0 15" East and between latitude 30° 0 24" to 38° 0 17" North approximately (Figure 2).

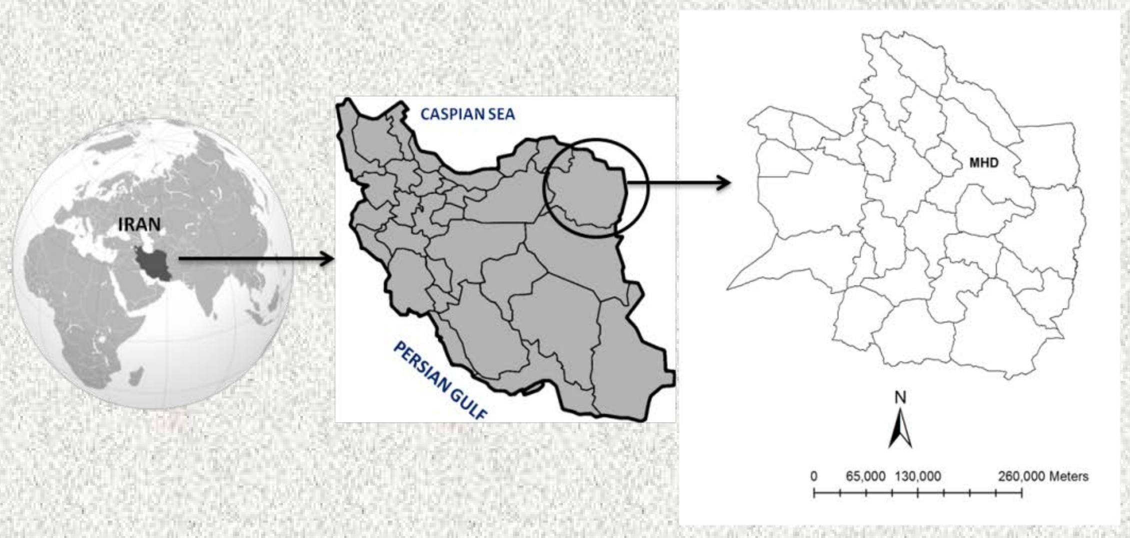

Fig. 2: The Khorasan Razavi (KR) geographical position, 4th widest province of Iran with 28 administrative zones and fragile ecosystem to desertification and degradation.

Methodology

To investigate resilience of ecosystem and non-linear responses to environmental perturbation, the vegetation cover dynamics was considered as an evidence for equilibrium changes. To determine these alteration a normalized difference vegetation index (NDVI) was calculated between 2000-2012 years by MODIS imagery data.

The change detection of NDVI has been considered for equilibrium change and resilience oscillation of ecosystem as an early warning signal to desertification process and emerging desertified ecosystem.

Based on the changes of NDVI value, the ecosystem behavior in the KR was analyzed. The critical slowing down for ecosystem close to critical transition where the NDVI value shows a significant change considered for desertification starting.

Results and Discussion

Stability properties of KR ecosystem showed that size of the attraction basin is changing between years 2000-2012 which refers to resilience oscillations under land use changes and environmental turbulences. Based on the figure 3, zone A, with a wide attraction basin indicated the maximal disturbance of ecosystem to absorb without shifting to another state. The recovery rate from vegetation cover decreasing as a small perturbation is a measure of local stability of equilibrium. As shown in the figure 3, such local recovery rates reflect the size of the basin of attraction even if the perturbation does not bring the system close to the border of the attraction basin.

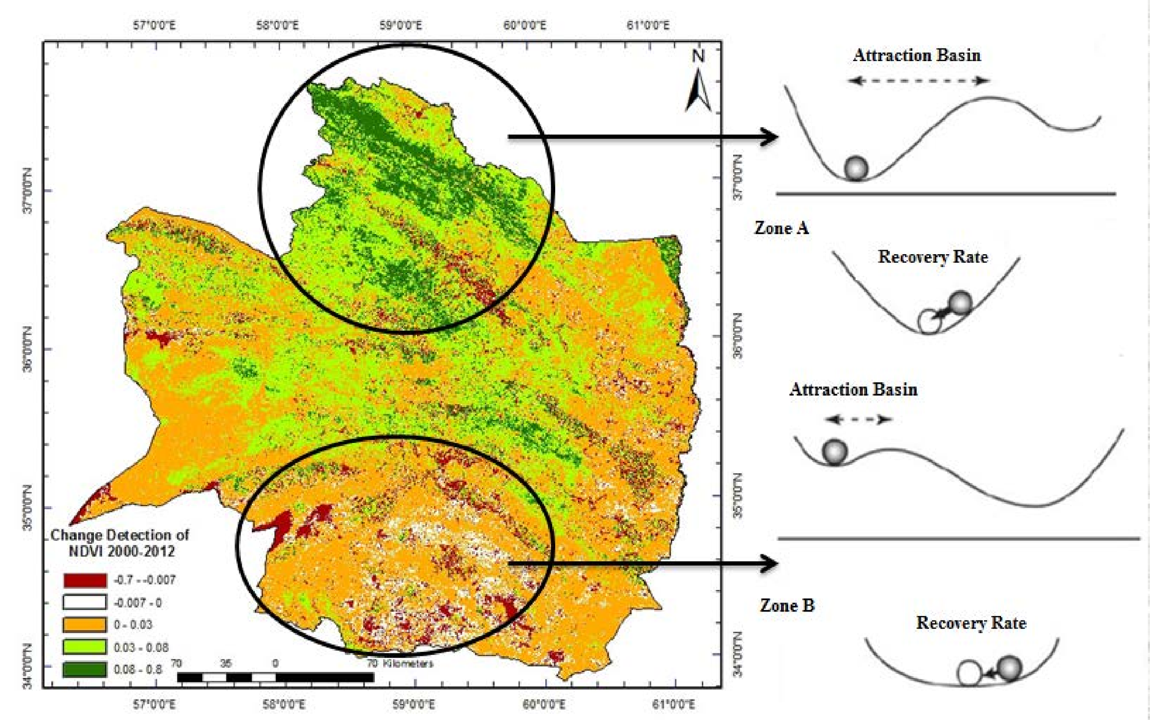

Fig. 3: The change detection of NDVI between 2000-2012 years is indicating resilience oscillations of KR ecosystem. The small attraction basin showed a low resilience in the ecosystem where a small perturbation, here vegetation density changes, caused a big effect, here emerging desertification.

According to the figure 4, with NDVI value increasing the attraction basin is developing which leads to high resilience and low recovery rate.

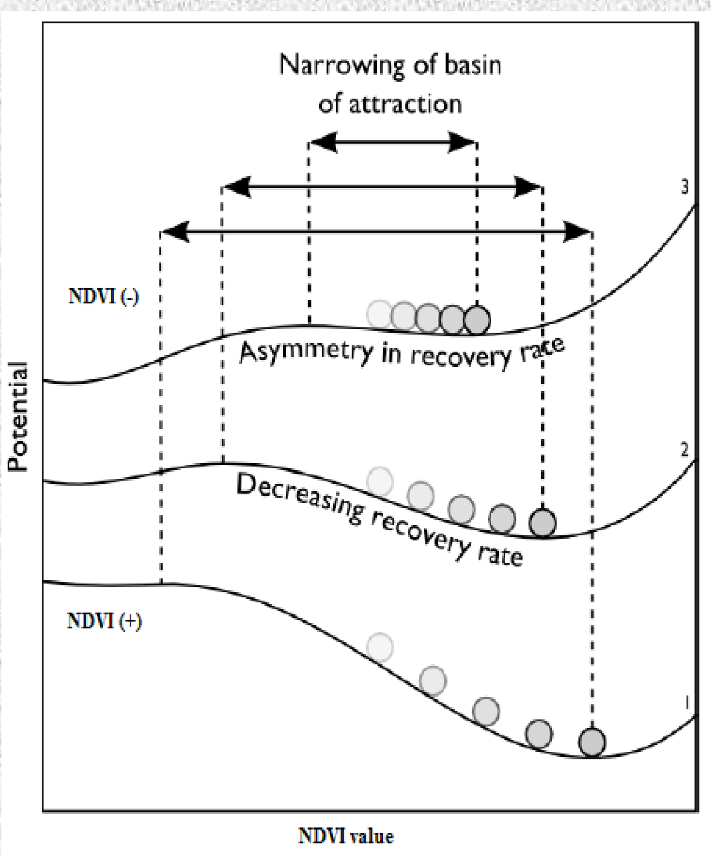

Fig. 4: The relationship between vegetation cover changes (NDVI) and resilience oscillations; vegetation degradation leads to increase recovery time and slowing down ecosystem.

Main References

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ABSTRACT:

A new view to desertification phenomenon based on thermodynamics laws for open systems has been followed in this article. Desertification is defined as irreversible land degradation that is caused by human activity and climate fluctuations leads to deterioration of human well-being. Some ecosystems may occasionally change quite abruptly to a contrasting state. Shift may occur in ecosystems with alternative stable states in which the conditions change gradually toward a critical point, called a bifurcation, where the ecosystem becomes unstable and shifts to the alternative state. In any systems that are close to a critical transition, recovery upon small perturbations becomes slow, a phenomenon known as critical slowing down. In this article the desertification has been analyzed under this fact and considered a result of non-equilibrium point in ecosystem near to critical transition. To investigate equilibrium oscillation, the land use alteration of Khorasan Razavi (KR) was monitored between years 2000-2012 by imagery data using NDVI changes. The descending trend of vegetation cover density was considered as tipping point in ecosystems near to critical transition and prone to desertification. Results indicated that vegetation cover decreasing shows a descending effect on ecosystem resilience to keep equilibrium. Also following these consequences was determined that in ecosystem with low resilience, a desert landscape is emerging. So increasing resilience can be an action to combat desertification. The equilibrium thinking used in this research can be helpful for development of sustainable ecosystems and combating desertification.

KEYWORDS: Critical Slowing Down, Resilience, Desertification, Bifurcation, Equilibrium

Introduction

Mathematically, critical slowing down is connected to the fact that close to the critical transition the dominant eigenvalue of the system at equilibrium vanishes. Practically, critical slowing down enables us to probe the ecosystem dynamics to assess its resilience and calculating the upcoming transition risk (Dakos et al, 2001: 154).
In physics, critical regimes are characterized by the divergence of the correlation length to infinity, by critical slowing down, which is the increase of the relaxation time of the system due to small perturbations, crossover regions, and the presence of an order parameter.

Critical slowing down

Some ecosystems may occasionally change quite abruptly to a contrasting state (Scheffer et al, 2001: 591). Theoretical studies have suggested that such shift may occur in ecosystems with alternative stable states in which the conditions change gradually toward a critical point, called a bifurcation, where the ecosystem becomes unstable and shifts to the alternative state. It has been recently suggested that such shifts may be announced in advance by generic leading indicators for critical transitions (Scheffer, 2009: 96). This idea is based on the fact that systems tend to show a phenomenon known as ‘‘critical slowing down’’ as they approach bifurcation points (Wissel, 1984: 102; Strogatz, 1994: 23; Scheffer, 2009: 98) where a tiny change in conditions can lead to a marked qualitative change in the behavior of a system. The term ‘‘critical slowing down’’ refers to the fact that near these points the return time to equilibrium upon a small perturbation increases strongly. In the figure 1 has been showed the ecosystem responses to environmental changes (*vegetation degradation*) and equilibrium alterations.
A simple way to understand critical transitions is to think of the behavior of a system as the motion of a ball in a landscape of valleys and hilltops (Figure 1). Ball represents the state of the ecosystem. Valley corresponds to the *basins of attraction* of the two alternative stable states of the ecosystem. The width and the steepness of the basin of attraction determine the capacity of the ecosystem to absorb a perturbation without shifting to an alternative state, and reflect the *resilience* of the state of the system where vegetation density is in maximum. As conditions bring the ecosystem close to a critical transition (*critical threshold)*, the basin of attraction of the current states of the ecosystem shrinks and so does its resilience: even a tiny perturbation is enough to shift the sphere to the alternative valley where slowing down occurred. At the same time, the steepness of the basin of attraction becomes lower: this means that the same perturbation that may not tip the ecosystem, it will definitely take longer to dissipate due to the phenomenon of critical slowing down.

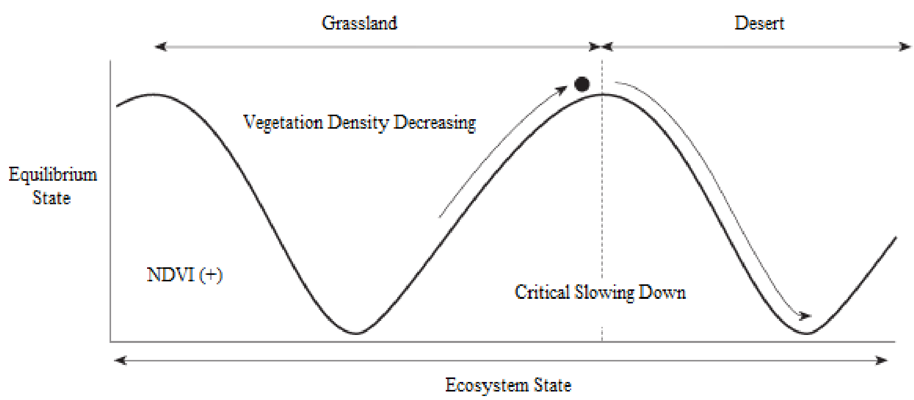

Fig. 1: The ecosystem state alterations pursing vegetation cover decreasing which change the view of ecosystem in consequence of equilibrium changes and a desert view will be output.

According to the figure 1, in some cases, ecosystem changes such as desertification or salinization of soils might be irreversible. In other word, desertified landscape could emerge consequence of human activity or climate fluctuations as environmental disturbances.

In summary, the critical slowing down phenomenon leads to three possible early warning signals in the dynamics of a system approaching a bifurcation: slower recovery from perturbations, increased autocorrelation and increased variance.

In this research a case study was done for ecosystems of Khorasan Razavi (KR) province located eastern north of Iran. The purpose is investigating ecosystem resilience for computing slowing down ecosystem and equilibrium alterations. Changing vegetation cover density was considered as an early warning sign to desertification for pursuing this purpose. The resilience oscillations, has been monitored between years of 2000-2012 by NDVI changes.

Material and Method:

Study Area Position:

To apply the methodology, the Khorasan Razavi (**KR**) province with second metropolitan of Iran, Mashhad, and one of the erosion and soil degradation centers has been considered. This area covers about 128430 Km^2 within longitude 55° 0 17" to 61° 0 15" East and between latitude 30° 0 24" to 38° 0 17" North approximately (Figure 2).

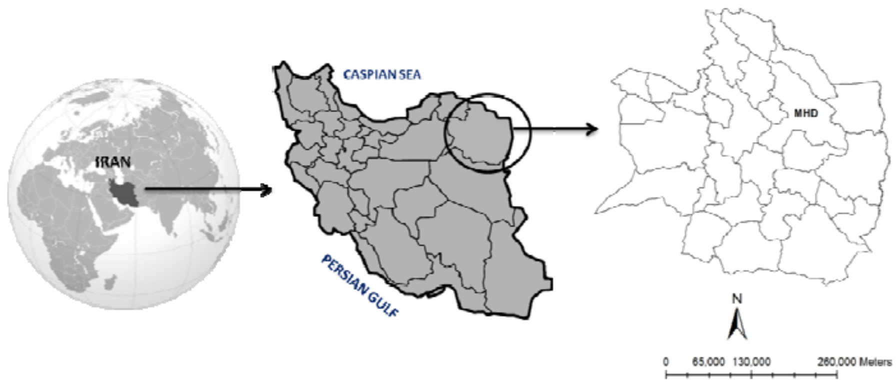

Fig. 2: The Khorasan Razavi (KR) geographical position, 4th widest province of Iran with 28 administrative zones and fragile ecosystem to desertification and degradation.

Methodology:

To investigate resilience of ecosystem and non-linear responses to environmental perturbation, the vegetation cover dynamics was considered as an evidence for equilibrium changes. To determine these alteration a normalized difference vegetation index (NDVI) was calculated between 2000-2012 years by MODIS imagery data under formula 1.

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad (1)$$

Where, RED and NIR reflect atmospheric reflection for red and near infrared electromagnetic spectrum. The change detection of NDVI in this research has been considered for equilibrium change and resilience oscillation of ecosystem as an early warning signal to desertification process and emerging desertified ecosystem.
Based on the changes of NDVI value, the ecosystem behavior in the KR was analyzed. The critical slowing down for ecosystem close to critical transition where the NDVI value shows a significant change considered for desertification starting.

Results and Discussion

Stability properties of KR ecosystem showed that size of the attraction basin is changing between years 2000-2012 which refers to resilience oscillations under land use changes and environmental turbulences. Based on the figure 3, zone A, with a wide attraction basin indicated the maximal disturbance of ecosystem to absorb without shifting to another state. The recovery rate from vegetation cover decreasing as a small perturbation is a measure of local stability of equilibrium. As shown in the figure 3, such local recovery rates reflect the size of the basin of

attraction even if the perturbation does not bring the system close to the border of the attraction basin.
In the dry regions of KR, self-organization can lead to particular spatial patterns under some conditions. Here the complete loss of vegetation is an important transition, as recovery from the barren state may require more rain than is needed to preserve the last patches. There is good evidence to support the idea that a regular pattern characterized by spots of vegetation signals the proximity of a threshold to such catastrophic desertification which approved the Rietkerk et al (2004: 1927) works.

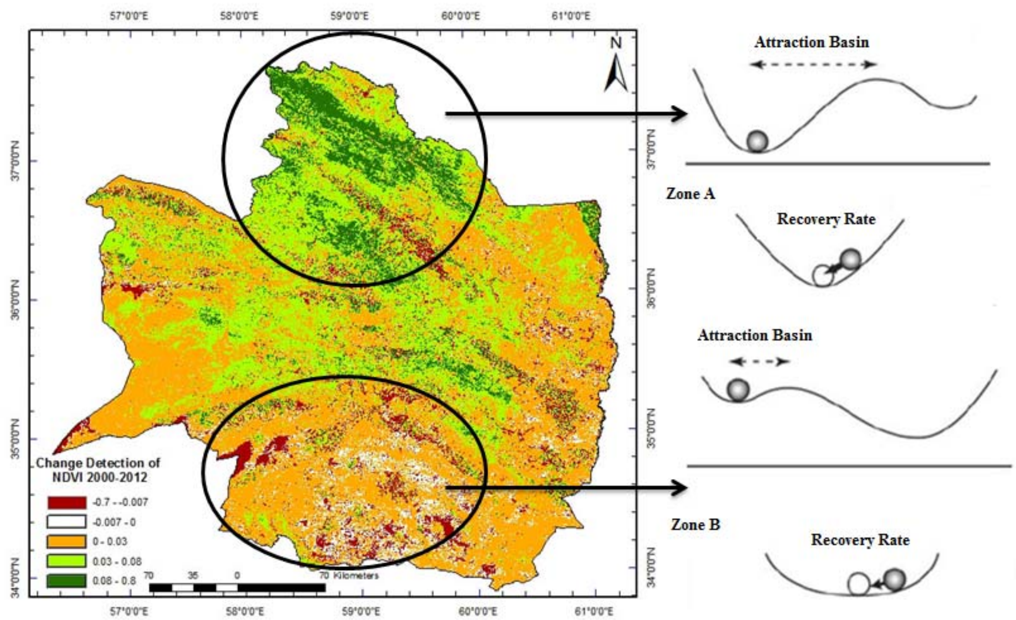

Fig. 3: The change detection of NDVI between 2000-2012 years is indicating resilience oscillations of KR ecosystem. The small attraction basin showed a low resilience in the ecosystem where a small perturbation, here vegetation density changes, caused a big effect, here emerging desertification.

In general, the descending process of NDVI value has been occurred in the regions with high susceptibility to desertification process which magnify by resilience potential of these ecosystems. The management of desertification refers to determine critical points where ecosystem close to a tipping point and a slowing down could be an ecosystem response.
According to the figure 4, with NDVI value increasing the attraction basin is developing which leads to high resilience and low recovery rate.

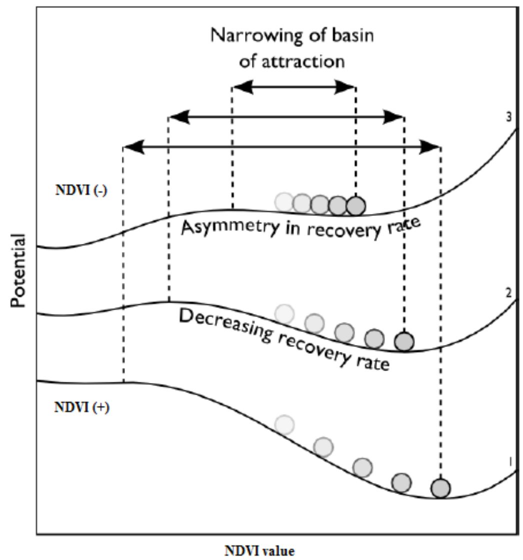

Fig. 4: The relationship between vegetation cover changes (NDVI) and resilience oscillations; vegetation degradation leads to increase recovery time and slowing down ecosystem.

In the state 1, with positive values of NDVI, the ecosystem shows a suitable attraction basin with high resilience where located in the northern ecosystems of KR. In the state 2 and 3 with decreasing trend of NDVI pursuing vegetation degradation by climate fluctuations and mismanagement of land use, the attraction basin shows an asymmetry condition where a small perturbation leads to big results, emerging a desert landscape of ecosystems. These states usually will occur in the southern regions of KR province where low resilience increase the ecosystem susceptibility to desertification. Therefore, to combat desertification and actions to prevent this process, attention to the resilience potential of ecosystem is important whereas actions should be concentrated in ecosystem close to critical points where a slowing down is expectable. For KR ecosystems, major actions should focus in the southern regions where recovery rate is low and strategies should increase this rate.

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