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# Anti-fragility, a new framework for groundwater social-ecological system management

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**ABSTRACT**

Groundwater management is of great importance for the sustainability of water services. Many approaches have been used for groundwater management. So far there has been no study conducted on the anti-fragility of the social-ecological system (SES) of groundwater. System anti-fragility refers to the process by which the system likes internal and external dynamics and events because it benefits from disruptions and improves its services. The aim of the present research is therefore to provide a conceptual framework for the social-ecological management of groundwater. The research method is as follows: First, the socio-ecological system of groundwater and fragility protection was defined based on the existing principles. The two models of Talib's anti-fragility and social ecology were then linked using the transfer concept. The results of the discussion on the relationship between the two models highlighted the weaknesses associated with the lack of accurate disclosure of the anti-fragility redundancy of groundwater to disturbances. Finally, an antifragile adaptive social-ecological model was constructed with one goal, three species, and three stages in the groundwater system. The purpose includes: eliminating the negative effects of disturbances and risks in the groundwater system, including methods; The energy transfer, function transfer, and element design steps included: (i) determining the effects of the disturbance rather than the disturbance and the risks themselves, (ii) formulating a transfer policy, and (iii) implementing the policy. This article not only expands the literature on groundwater management but also provides an appropriate framework for policymakers and water managers and can be helpful in groundwater planning and management.

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# ضد شکنندگی، چارچوبی جدید برای مدیریت سیستم اکولوژیکی اجتماعی آب‌های زیرزمینی

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**چکیده**

مدیریت آب زیرزمینی برای پایداری خدمات آب از اهمیت بالایی برخوردار است. روش های بسیاری برای مدیریت آب های زیرزمینی استفاده شده است. تاکنون هیچ مطالعه ای در مورد ضد شکنندگی سیستم اجتماعی-اکولوژیکی (SES) آب های زیرزمینی انجام نشده است. ضد شکنندگی سیستم به فرآیندی اطلاق می‌شود که سیستم از پویایی‌ها و رویدادهای داخلی و خارجی خوشش می‌آید زیرا از اختلالات بهره می‌برد و خدمات خود را بهبود می‌بخشد. بنابراین هدف پژوهش حاضر ارائه یک چارچوب مفهومی برای مدیریت اجتماعی-اکولوژیکی آب‌های زیرزمینی است. روش تحقیق بدین شرح است: ابتدا سیستم اجتماعی اکولوژیکی حفاظت از آبهای زیرزمینی و شکنندگی بر اساس اصول موجود تعریف شد. سپس دو مدل ضد شکنندگی و بوم‌شناسی اجتماعی طالب با استفاده از مفهوم انتقال به هم ارتباط داده شدند. نتایج بحث در مورد رابطه بین دو مدل، نقاط ضعف مرتبط با عدم افشای دقیق افزونگی ضد شکنندگی آب‌های زیرزمینی را در برابر اختلالات برجسته کرد. در نهایت، یک مدل سازگار اجتماعی-اکولوژیکی ضدشکننده با یک هدف، سه گونه و سه مرحله در سیستم آب زیرزمینی ساخته شد. هدف شامل: حذف اثرات منفی اختلالات و خطرات در سیستم آب زیرزمینی، از جمله روش‌ها. مراحل انتقال انرژی، انتقال عملکرد و طراحی عنصر شامل: (۱) تعیین اثرات اختلال به جای خود اختلال و خطرات، (۲) تدوین خط مشی انتقال، و (۳) اجرای خط مشی. این مقاله نه تنها ادبیات مدیریت آب های زیرزمینی را گسترش می دهد، بلکه چارچوب مناسبی را برای سیاست گذاران و مدیران آب فراهم می کند و می تواند در برنامه ریزی و مدیریت آب های زیرزمینی مفید باشد.

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## Introduction

Pollution, salinity, reduction of water volume, and increase in demand for underground water are slow variables that change over time and lead to changes in groundwater system services (Bouchet et al, 2019). Groundwater system services include the protection and storage of healthy water (Taghilou and Aftab, 2022).

In the stability of groundwater services, the control of slow variables is probably the main issue of management. Slow variables have internal and external origins and also occur at an indefinite time and place. Therefore, variables are unpredictable in this regard, and their management cannot be done accurately (Botjes et al, 2021). Climate change, the origin and volume of pollution in nearby places, operators with non-common interests, and possibly antonyms with groundwater operators are among disturbances, and the occurrence of them also occurs at unpredictable times. Therefore, the occurrence of events outside the system in an unknown place for an indefinite time has made the management of the groundwater system difficult.

In addition, the different and contrasting resilience of groundwater system elements against change, the nonlinear dynamics of community elements, ecosystems, and the aquifer system itself an important issues for groundwater managers to measure and evaluate performance in water management. Therefore, the groundwater system management approach is very important to solve these problems. Different approaches have been used in this field. Resistance approaches with technical tools through the establishment of different evaluation metrics (Foster & Van der Gun, 2016), resilience approaches with adaptation tools, resistance, and self-regulation through diversification and reduction of utilization, etc. have been used (Taghilou & Aftab, 2022; Wang et al, 2016). We argue that these approaches are not effective enough in the face of uncertainties in the sustainability and promotion of water services and sometimes fail. Therefore, it is necessary to adopt another approach in groundwater management and planning that not only does not seek to spend energy to control uncertainties but also can benefit from possible events with high uncertainties. Here we point out two new concepts in groundwater management in the presence of perturbations. Anti-fragility and transition management are two concepts that we combined with the social-ecological system (SES) and presented SES transition management of fragile groundwater.

Here, we will examine the groundwater system as an anti-fragility system and seek to answer the question; can the groundwater ecosystem be defined as an anti-fragile ecosystem? Anti-fragility in systems and objects was first proposed by Talib (2012). Since then, numerous researchers have used anti-fragility in various studies in areas such as urban management (Timashev, 2020; Blečić et al, 2017), diseases (Botjes et al, 2021), and others. However, no study has been done on the groundwater system. However, several studies have been conducted on groundwater as a resilient SES (Bouchet & et al, 2019; Rica & et al, 2017; Taghilou & Aftab, 2022; Mathias & et al, 2020; Foster & van der Gun, 2016). Anti-fragility system is an approach that is defined as resistance, robustness, fragility, and resilience but is not any of them (Aven, 2015; Taleb, 2012 Hespanhol, 2017). A strong and stable system is a system that is very resistant to shocks and stresses and does not break easily, but according to the law of nature, it has an end and disappears. A resilient system is a system that returns to its original state in the face of shocks with small changes and maintains its performance. Finally, a fragile system is a system that is very vulnerable to stress and mainly suffers from damage and loss. However, the anti-fragile system is not like the above concepts that avoid disturbances and stress. The meaning of this system is similar to the meaning of Nietzsche's idea that "everything that does not kill me makes me stronger". The fragile system is strengthened by internal and external disturbances and stresses, and they reap great benefits (Botjes et al, 2021; Taleb, 2012). In the anti-fragility system, we will also seek to introduce a pattern of redundancy that has not been mentioned in research. In this research, we have added the concept of "transition" in the form of resilience models to the anti-fragility system and based on that we have presented the anti-fragility SES transition management framework. We claim that in an anti-fragility system, high profits occur through three important transitions: (i) hard transition, (ii) functional transition, and (iii) energy transition. These transitions are very efficient in conditions of uncertainty and their use makes systems anti-fragile. In these systems, uncertainty conditions are not predicted and managed, and system management does not seek to control the perturbations of shocks, events, and dynamics (Botjes et al, 2021) but uses events and stresses to improve and strengthen the system through redundancy. Transition management is critical in an anti-fragility-based planning system; otherwise, anti-fragility cannot be applied to groundwater. In the anti-fragility system, management does not seek to prevent accidents and does not spend money on planning, but focuses costs on transitions. Therefore, in this study, the aim is to examine the following question: Can the groundwater ecosystem be defined as an anti-fragility system, and how can we define the groundwater system as an anti-fragility system?

To achieve goals, we defined groundwater at the beginning as an SES with the introduction of its subsystems and elements. We then introduced anti-fragility and then revealed the concept of transition. In the following, we have described the groundwater SES of anti-fragile and, in the continuation of the discussion, we have introduced the transition management framework in the groundwater SES of anti-fragile. Finally, we mentioned the conclusion of the discussions.

This research introduces a new lens for planners policymakers and managers to control crises and risks such as subsidence, pollution, and water reduction. Help many water brokers and managers how to plan anti-fracture for groundwater. It can also open another page in the development and expansion of the knowledge boundaries of the social-ecological system of underground water.

**SES Groundwater**

Groundwater SES framework has three characteristics of peak point, an ecological subsystem, a social subsystem (Mathias & et al, 2020), and aquifer subsystems (Bouchet & et al, 2019; Rica & et al, 2017; Taghilou & Aftab, 2022). This system performs three services protection, storage, and water health in the aquifer.

**Anti-fragility literature**

In defining anti-fragility, we take advantage of three concepts of "fragile", "resilient" and "resistance" and the four processes of "loss", "gain", "static" and "dynamic". Based on the existing literature, the concept of anti-fragility is defined in contrast to fragile, resistant, and resistant concepts (Hespanhol, 2017; Botjes et al, 2021; Taleb, 2012).

Fragile is a term that refers to a system or objects that are broken and destroyed in the face of disturbances and stimuli. In other words, fragile systems suffer from shocks and do not have the necessary power and capacity against disturbances (Blečić & Cecchini, 2022; Taleb, 2012). A resistant system is a system that has high power and strength against internal and external disturbances and stimuli and does not break easily.

A resistance system is also a system that adopts adaptation, resistance, and self-regulation modes against internal and external shocks (Li et al, 2020). These modes help the system not to be destroyed by shocks and the system can continue its previous process.

The anti-fragility system is not fragile, nor is it strong and durable, nor is it resilient, but beyond these characteristics. Anti-fragility is a system that likes dynamism and internal and external events because it benefits from disturbances and improves its services (Botjes et al, 2021).

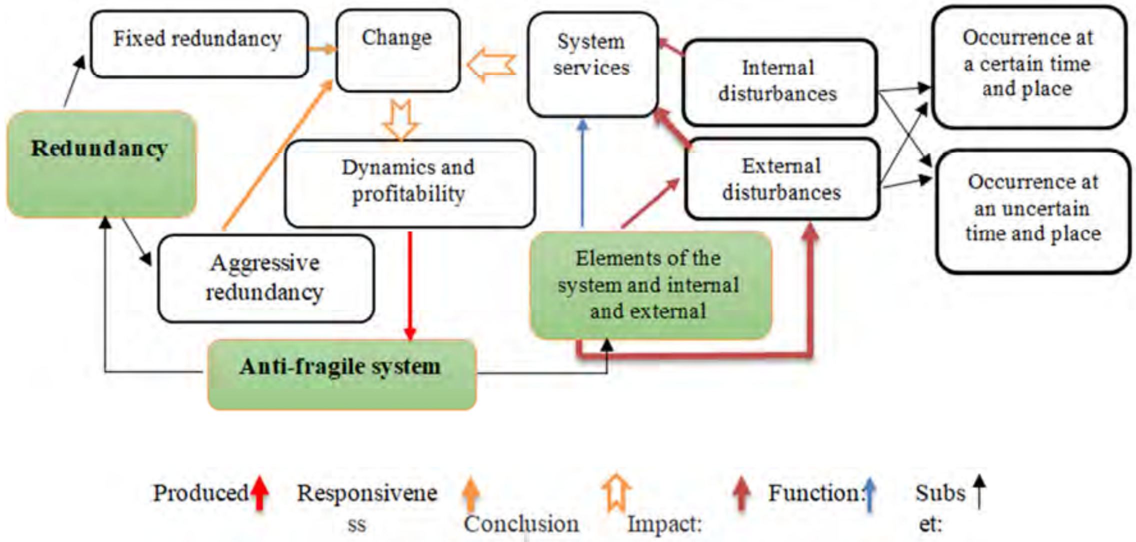



**Fig1: characteristics of the fragile system**

In a fragile system, the disturbances damage the weak parts of the system, leaving the strong parts and the strong parts multiplying. In this system, management loses its anti-fragility system if it has optimizing decisions and controls internal and external stimuli, and antibody capacity is not formed within the system. In a fragile system, management plans further to develop and respond to system redundancy (Fig 1). The redundancy of spare parts of the system is used to expand and upgrade whenever necessary. In natural-human systems, there are layers of redundancy and resources that are used to upgrade systems and strengthen elements against internal and external disturbances. Redundancy in systems is both fixed and aggressive. Fixed redundancy is used to compensate. Aggressive redundancy is fighting the system for the next war and building capacity (Taleb, 2012). In other words, the aggressive redundancy prepares this system for the next war against disturbances and is similar to maneuvers.

In Berkes et al.'s (2008) study, redundancies in the system are defined in various contexts, including component redundancies, in which when one element is absent, another element does function in the system. Function redundancy, in which a system element has multifunctional capacities uses the potential capacities for system stability in the event of disturbance and changing conditions without the element changing. In technical redundancy, programs and potential capacities for maintenance are embedded in the system. Social redundancy involves the awareness and understanding of tasks by individuals in society. Economic redundancy is the capacity and financial and capital support and budget in the system. In this study, we will point out three other types that have no research history in the studies, these supplements are; (i) Natural which redundancy includes the capacity of elements to self-regulate against disturbances and changes. (ii) Place which redundancy includes the capacity of physical and functional communication of places and (iii) Time which redundancy includes the ability of elements to the simultaneous relationship of changes in elements at the time of occurrence. This redundancy allows the system to define new redundancies such as creating a new element and a new function to respond to perturbations. This redundancy prevents the shock effect from spreading throughout the system and leads to the creation of new functions in the system.

Therefore, the anti-fragility, fragility, strength, and resilience of systems are measured through the possible responses of redundancy to factors and disturbances and their placement along the gain-loss and static dynamics (Table 1). So, we can define the following features for these systems:

* The system is resistant and fragile internally static but with different thresholds. Internal and external dynamics are harmful to them. They do not benefit from the change of interests.

* Resilience and anti-fragility systems are internally dynamic but with different potential advantages. For resilience, change has no benefits, but anti-fragility has many advantages. Anti-fragility likes external dynamics, but resilience is incompatible with external dynamics.

**Table 1: System Properties**

| System type | Damage from disturbances | Benefit from turmoil | Static | | Dynamics | |
|---|---|---|---|---|---|---|
| | | | External | Internal | External | Internal |
| Fragile | D | Non | P | P | N | N |
| Resistant | Pd | Non | P | P | N | N |
| Resilience | Non | Non | P | N | N | P |
| Anti-fragile | Non | B | N | N | P | P |

Adaptability: P., Incompatibility: N., Neutral: Non., Benefit: B., Damage: D., Possible Damage: Pd

## The concept of "Transition"

Redundancy in ecological and social systems is done naturally and intentionally. Therefore, transition management is very important in these systems. "Transition" has been used extensively in the political fields (Haxeltine et al., 2008; Kaplow, 2003; Wang & Lo, 2021) and physics. "Transition" means the transfer of responsibility, duty, and energy from one element to another. In an anti-fragile system, responses to disturbance occur in the form of transitions. The response of the system to perturbation is done in three ways: (i) "Hard transition", in this form of relationship in the event of loss of an element due to disturbance, a new redundancy is created by elements or other system redundancy to replace, or potentially existing elements are replaced, (ii) "Functional transition", the deleted function of an element due to shocks, other elements of its functional system perform and (iii) "Energy transition", (Transition tree pruning) in case of loss of elements and their current function, other elements and their function are strengthened (Fig 2). In transition management, cost and energy are used to improve the system, not to stabilize the status quo, the cost is to make a profit, not to prevent a loss. Second, targeting in the system is based on the type and effect of the disturbance and the type of damage to the element and function, and third, the plans and goals in managing the transfer of costs and energy are not to prevent, limit, and this is done compensate for the loss of accidents, which is done through various redundancy.

In the discussion of transition, two important redundancies cultivate other redundancies and make the transition possible: 1- place redundancy and 2- time redundancy (Patranabis et al, 2015; Yu et al, 2020). System disturbances occur in time and space and disrupt system operation. In the system, there is the place and time capacity that makes the system stronger against disturbances and causes the system to have the necessary opportunity and geographical space to build new capacities and turn the disturbance into an opportunity and usefulness. This is the case in the capitalist economic system.

System time redundancy means that the system performance does not disappear at the moment of disturbance or irreparable damage. Rather, the redundancy of the system postpones the crisis to the future, the redundant opportunity for the natural and social elements of the system to be able to create the necessary add-ons, strengthen them, or activate potential add-ons.

Place redundancy of the system also means that it distributes the effect of the disturbance and transmits it to adjacent locations to prevent the accumulation of the effect and it allows placing it in other places to make the necessary redundancy for the stability and profitability of the system. As shown in the study by Tang et al. (2022), inter-basin water transfer is the redundancy of place that transmits the effects of various disturbances to adjacent locations and uses them for sustainability, which is a benefit to a particular location.

## Ant fragility in Aquifer System

**- Aquifer system dynamics:**

The aquifer subsystem consists of layer elements, pores, and water (Taghilou & Aftab, 2022). These elements are constantly exposed to dynamics in the face of internal and external disturbances and risks. Understanding the dynamics of the elements is important in anti-fragility planning.

Layers and pores are elements that are much more dynamic. The dynamics of layers and cavities refer to the decrease and increase in the volume of space and their internal filling. These spaces are stimulated by disturbances and shocks of water extraction, water inflow, and subsidence, and their volume decreases or increases. High demand for groundwater and reduced water nourishing increase vacancies and maximize the likelihood of land subsidence (Horvath et al, 2017), studies have shown (Tang et al., 2022) that subsidence contributes to the development and creation of function. It becomes the power of the system and becomes useful.

The volume and health of water (salinity and pollution) in the basement is a feature of the water element of the aquifer system. These characteristics are constantly exposed to salinity, pollution, and high demand due to population growth and community economy and are therefore more dynamic. Studies show that the dynamics of volume and health of the water in the basement tend to decrease over time, and its increase is likely to occur less than the decreasing trend (Qian et al, 2020; Kurwadkar et al, 2020; Li et al, 2021). How the groundwater volume and health decrease in the development and creation of function and capacity inside and outside the aquifer sub-system depends on the performance of the aquifer system redundancy.

**- Anti-fragility redundancy of the aquifer**

Aquifer subsystem redundancy includes form (Blomquist, 2020; Chala et al, 2022)، , underground flows, and underground pores (Kiernan et al, 2003). Aquifers are divided into two general categories in terms of the form egg cartons and integrated cartons. Aquifers are rarely dynamic in the short term, and their deformation and interdependence depend on the tectonic movements of the earth, which is beyond our discussion. Each form of the aquifer can be an important local redundancy that plays a role in creating new capacity and function of protection and production of safe water in the system during subsidence, salinity, pollution, and reduction of water volume.

Regarding the role of aquifers form in reducing pollution, salinity (Chala et al, 2022), and preventing or self-regulating water volume, no study has been done to show the geometric forms of aquifers as a place redundancy, compensate for pollution, salinity, volume reduction, and water inflow. However, it can be argued that the form of the aquifer's egg cartoon creates the capacity to compensate. Because, firstly; Aquifers egg cartoon protrusions prevent contamination and salinity from spreading to all cartoon chambers (Chala et al, 2022), and the flow of water between the chambers, purifies the walls separating salinity and water pollution, thereby compensating for pollution and salinity. Also, large amounts of withdrawals from one chamber do not spread to other chambers, which is a very important redundancy when it does not expose the entire groundwater to changing the entire aquifer and creates the opportunity to compensate by creating a "social redundancy". Any damage, including pollution, salinity, and reduction of water volume in each chamber creates social awareness for management and control, which is useful in defining activity for other chambers. This plays a role in the planning and management of aquifers in two ways: First; Learning in action (Bouchet & et al, 2019), and second; creating a public belief for operators that any disturbance in groundwater can be harmful. Expressing the role of integrated aquifer form in creating and developing aquifer capacity against water volume reduction, pollution, salinity, and reduced water inflow is more complex than egg cartons.

Due to the lack of study literature, its role cannot be accurately determined or defined. However, the form of the aquifer bathtub outperforms the egg carton form in creating another plug-in, which can enhance existing functionality and define new functionality in the system. This is a natural redundancy for "water flow in the basement". The flow of water between cavities and aquifers increases the amount of oxygen in the water and reduces the chance of contaminating bacteria multiplying (Barbaro et al, 1994). In addition, groundwater flows from the bed of wetlands, rivers, and lakes to the entire aquifer and reduces pollution and compensation. However, the role of the integrated aquifer form in the development and capacity building against salinity is not the same as the egg carton form that prevents the spread of salinity throughout the aquifer. However, the flow of water from healthy sources such as rivers, lakes, rain, and snow between all sections and spaces inside the aquifer reduces the salinity concentration in the aquifer and compensates for the damage. Integrated aquifers are generally fragile against salinity unless compensated by other aquifer elements and subsystems, which will be discussed below.

The volume and porosity of the land are another redundancy that can create underground dams (Ishida et al, 2011), which are very suitable for upstream and downstream users in terms of functionality and effectiveness in groundwater management with fewer negative effects. Evacuated pores are a good place to build underground dams. Aquifers or aquifers that form in environments with interdental porosity and most of the underground reservoirs that are more important in terms of exploitation are located in this series of reservoirs. In this complex, instead of a large and continuous aquifer, a set of related gaps is created after the passage of water flow and acts as a suitable place for water storage and further strengthening of the aquifer (Yilmaz, 2003).

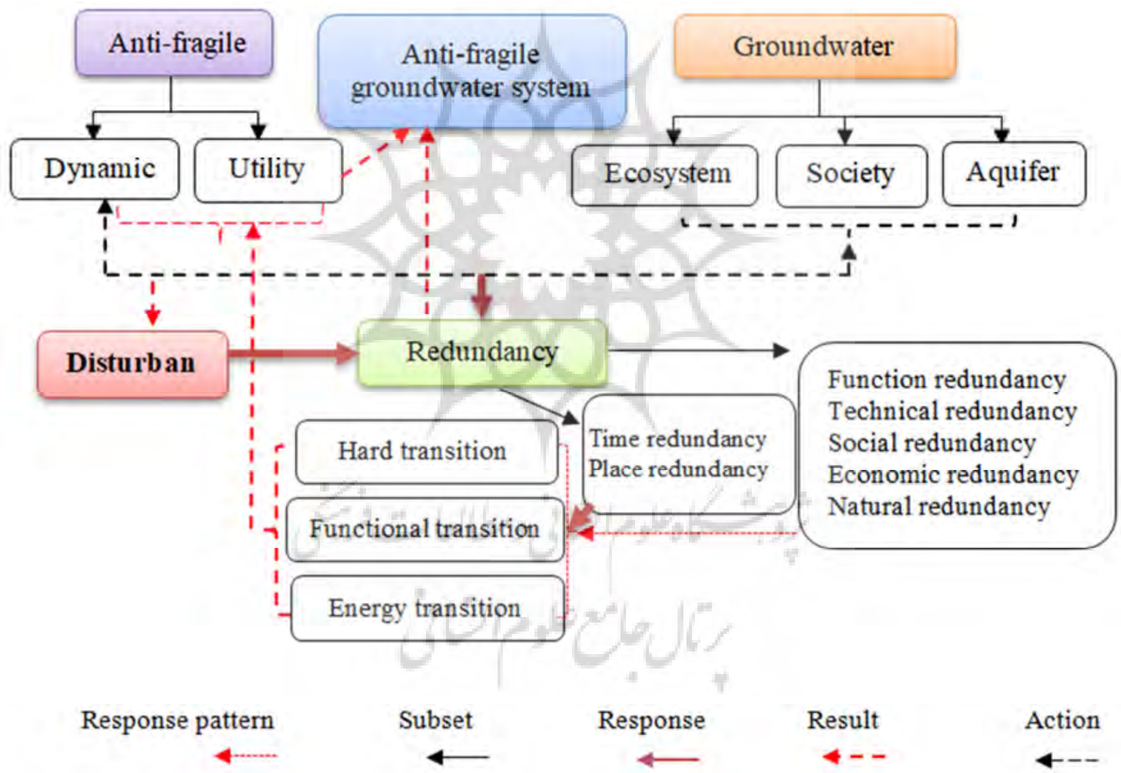



**Fig 2: Anti-fragile groundwater system**

## Anti-fragility in Ecosystems and Social Systems

*** Dynamics**

The upper aquifer ecosystem includes elements of rivers, lakes, wetlands, land cover, and rainfall in the SES groundwater. This dynamic creates and exacerbates the four shocks of salinity, pollution, high demand, and declining aquifers (Taghilou & Aftab, 2022). River dynamics are defined by the form and width of the route, the amount of water, and the health of the river water. Changing the width of the route, changing the bed of water transfer to farms, reducing the amount of water, and changing the water health of the river are the dynamics of the river ecosystem that disrupt groundwater services.

The riverbed is one of the main apertures for aquifers (Boulton et al, 2020). Any decrease in river width reduces the amount of aquifer feeding by the river. In many cases, the width of rivers is reduced for various reasons by natural and human factors, and in appearance acts as a negative stimulus to the sustainability of water services.

The volume of surface water is very dynamic and depends on the performance of the community and the climate of the region. Due to climate change and increasing demand, the volume of water in rivers has decreased sharply. The volume of river water has two main functions in the groundwater system: First, it determines the amount of aquifer nutrition, and second; plays a role in purifying and reducing environmental pollution entering the water (Singh et al, 2010). Therefore, if the river water is reduced, the treatment and feeding of aquifers will be minimized.

Another dynamic of rivers is their water hygiene. Today, with the spread of human and natural pollution, the water health of rivers changes drastically over time (Singh et al, 2010;) and this process intensifies when water is depleted, most likely with the entry of pollution into the aquifer of water services which in turn endangers the underground.

Lakes and wetlands are one of the most important sources of aquifer nutrition. These water resources are exposed to dynamics in terms of inlet water volume and water health (Kebede et al, 2021). The volume of incoming water depends on the volume of river water, the amount of rainfall in the area, and the adjacent area. Reducing rainfall and changing the type of rainfall and human performance concerning surface water has an effective role in the amount of water entering the lakes. Inter-basin water transfer, extraction, and high consumption reduce the volume of water entering the lakes and ultimately lead to poor performance and the role of lakes and wetlands in feeding the aquifer. On the other hand, evaporation from the surface of lakes and wetlands increases the salinity of lakes and the infiltration of lake water into aquifers increases the salinity and water pollution and reduces the quality of groundwater.

Rainfall is another element of the ecosystem. Rainfall varies greatly in terms of time, volume, intensity, and type of rainfall throughout the year, especially in arid and semi-arid regions. These changes make the role of this element in the groundwater system very likely and lead to reduced nourishing and reduced groundwater quality.

Land cover is another element of the ecosystem and this element has very high dynamics. Land cover and land use have several functions in the groundwater system (Scheurer et al, 2009): First, it plays a role in water nutrition. The higher the density of the land cover, the higher the aquifer nutrition, and vice versa. Second; Land cover prevents evaporation of moisture and high soil dryness, which is very effective in protecting water and its effect on irrigation Land temperature adjustment is also an important factor that should not be undermined.

Society is more dynamic and faster developing than ecosystems and aquifers. Population, welfare, urbanization, industrialization, and food security are factors in society that change a lot. Population growth, social welfare, poverty, growth, industrial development, and the level of food production are among the factors that expose society to many changes and cause disturbances in the groundwater system. High demand and water pollution and salinity, land-use changes, and aquifer drainage are important disturbances in the groundwater system.

*** Anti-fragility redundancy of ecosystem and social system**

The high ecosystem dynamics of the aquifers indicate that seven major disturbances threaten it, affecting groundwater quality, decreasing river width, changing riverbed structure (Galay, 1983), salinity and surface water pollution, decreasing rainfall, land cover change, and increasing water demand have been the main disturbances of the aquifer ecosystem.

Reducing the width of rivers is a major issue considering the origin and destination of rivers, especially in plains. Narrowing the width and bed of rivers has one disadvantage and two benefits: it feeds aquifers. Reducing the width and creating a structural bed reduces the feed holes, which disrupts the groundwater system. However, the system's response to this disturbance is to increase water velocity and reduce evaporation, which is beneficial to the groundwater system. Increasing the velocity of water flow due to the accumulation of water in one path which minimizes the amount of water thrown through the evaporation and lag in the path for lakes and wetlands, more water accumulation for these water resources. In addition, it enhances the water health of lakes and wetlands by treating them through flow velocities. This process creates two types of benefits for groundwater in general, one, increased nutrition through lakes and wetlands; and two, increased capacity of water treatment in the groundwater system.

The relationship between concrete transition path disturbance and groundwater systems is a complex one. Replacement of concrete water transfer routes with natural and traditional routes reduces the volume of river water supply by 50%, thus it is a disturbance to the aquifer (Meijer et al, 2008). But this disturbance creates a huge benefit for the aquifer. Reducing groundwater extraction is an important benefit to the aquifer. Concrete paths increase the speed of water transfer to farms, improve water efficiency and productivity, and create capacity in the water exploitation system. Reduces dependence on groundwater resources among exploiters and strengthens water storage in aquifers. Of course, it should not be forgotten that this is an advantage when the proportion of water volume and land status is maintained, but if water storage is used in the development of new lands, this issue can complicate the relationship between concrete paths and aquifers. If the stored water is used in sloping areas and rain-fed lands for the agricultural sector, it will expand the aquifer feeding holes, which is a very important benefit for the aquifer. In sloping areas, terraced and seedlings are planted, and if drylands are planted, the volume of land cover will be denser This is very important in feeding the aquifer. In addition, the density of the land cover also reduces the level of evaporation, which is generally beneficial to the groundwater system.

Changing the width and bed of rivers creates another redundancy. The distribution of water in earthen streams is in a large part of the plain surface. This redundancy transforms the river's linear feeder into a large plain surface feeder (Zeng & Cai, 2014; Rodríguez et al, 2006) and is particularly useful for aquifers of egg-carton form. This is because some egg houses may or may not be fed less by rivers, but distributing water in earthen streams at the upper level of the aquifer, creates a benefit for the entire aquifer. Economic redundancy is another redundancy of the groundwater system against the reduction of nutrition from the riverbed. It causes the purification of groundwater from the saline water supply of lakes. Reducing the width of rivers accelerates the flow of water and increases the amount of water stored in the lake, which brings saline water into the aquifer. Saline water supply to the aquifer creates a cost for saline water purification, which subsequently creates this capacity in community-level budgeting in favor of the groundwater system.

Salinity and pollution are other disorders of the groundwater system in the ecosystem. Increased salinity and pollution in surface water sources pollute saline groundwater (Cho, 2000). This is a disturbance. Changing the type of consumption, developing activities compatible with saline water, surface water purification, and artificial feeding resulting from this disturbance creates redundancy that is created in the groundwater system and this disruption becomes beneficial.

Reducing the volume of surface water causes two types of disturbance in groundwater. First, it minimizes the aquifer nutrition level, and second, it increases the groundwater extraction rate. Inter-basin water transfer redundancy (Tang et al, 2022) is another benefit of surface water disturbance in the aquifer. This redundancy distributes the effect of disturbances to nearby places and leads to the strengthening of surface and groundwater in the disturbed area.

Creating social awareness about water status due to the visibility of water scarcity (Bouchet & et al, 2019) and the withdrawal of some consumers from the consumption cycle is another benefit that arises from the disturbance of surface water reduction in the groundwater system. As a result of this disorder, the double pressure on groundwater is reduced, which is a very important benefit for groundwater.

Climate change or change in the type and amount of rainfall is a natural shock imposed on the groundwater system. This perturbation reduces the rate of aquifer feeding and the accumulation of water in the aquifer (Green et al, 2011; Earman & Dettinger, 2011). Groundwater system responds to this shock by reducing the number of consumers and allocating costs to import virtual water from adjacent areas. It is an important redundancy of this disturbance. Also in the social field, due to the visible decrease in rainfall and surface water, public awareness of water status and social responsibility is created in the social system of groundwater It is a very important capacity for groundwater management.

Land-use change is another case of disturbance in the groundwater system. Reducing natural land means reducing water supply holes (Foster & Cherlet, 2014). But an important point to note is that land-use change in favor of human use expands the volume and velocity of runoff and reduces evaporation. This happens through floods. Floods transfer places of nourishing to other surfaces such as riverbeds, dams, lagoons, lakes, and dams. The system utilizes this perturbation through place redundancy. Land-use change in favor of man-made structures creates water accumulation. Water accumulation reduces evaporation levels and creates an opportunity to feed the aquifer.

Increasing groundwater demand is a very valid and disturbing disturbance in the groundwater system. This disturbance endangers the protection and storage of water in the aquifer (Awadh, 2021). There are capacities in the groundwater system that make the high groundwater extraction into process useful in the system. The growth of technology and its application in water conservation and consumption, the growth of water productivity, wastewater treatment, inter-basin transfer, and artificial feeding are the capacities that are created in the groundwater system. These capacities are beneficial to the groundwater system.

There is an important point in the dynamics of the groundwater system, the incompatibility of perturbations with each other in time and place, which is a very important opportunity to create different redundancies and benefits for the groundwater system. This temporal and spatial inconsistency of disturbance creates the opportunity for functional transfer, hard transfer, and energy transfer for the groundwater system and puts the system in a fragile state.

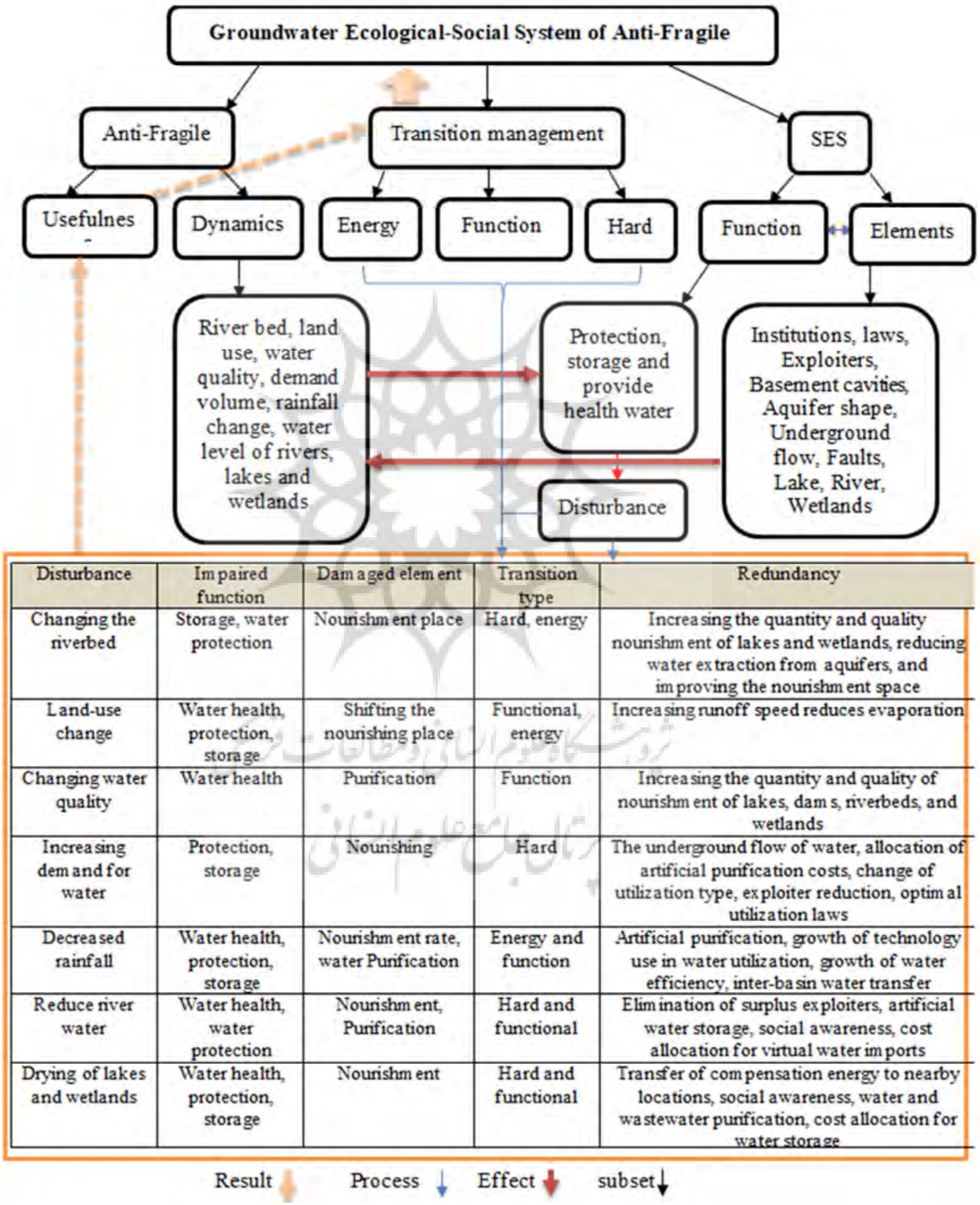
**Presenting the ant-fragile SES model using the transition concept**

Time and space are very important in transfer management. The relationships of the system elements are done in the framework of two redundancies and make the system anti-fragile through internal transitions. Time redundancy establishes the relationship of elements inside and outside the system in a time path (time interval). This redundancy helps to ensure that a defect in one element and its function does not have an effect on other elements and that the system has ample opportunity to respond appropriately to disturbances at the scale of the same element and does not alter or compromise the system as a whole. Place capacity creates two capacities of learning in practice and distribution of effect in geographical space and delays the accumulation of undesirable effects in one place. In this way, the system will provide the response power against disturbance or get help from nearby places and turn the adverse effect into a useful one.

In the groundwater system, these two redundancies help the groundwater management to respond appropriately to pollution disturbances, water volume reduction, river bed change, high water demand, change of land use above the aquifer, rainfall reduction, and surface water volume. Also, pollution and the negative effects of disturbances should not be transferred to the aquifer immediately or the so-called "transfer management" should be done.

As Figure 3 shows, inspired by the concept of strategic adaptive management (Van der Voorn et al., 2012; Bouchet et al, 2019), the “transfer management” framework is drawn with one goal, three paths, and three stages. The purpose of transfer management is to utilize the negative effects of groundwater system disturbances in three ways: energy transfer, function transfer, and element construction. This goal and method occur in three stages. (i) Identifying the effect of perturbation, not perturbation itself, (ii) Developing a transfer policy, and (iii) Implementing the policy.

In the first stage, transition management seeks to recognize the negative effects and consequences of perturbation in the form of elimination of the function and element of the groundwater system. This step must be done carefully. Because without accurate knowledge of the negative consequences management cannot use the necessary plugin. Transition management should identify deleted elements, malfunctioning elements, and additional or hidden idle elements with ecological footprints at this stage, reinforce the alternatives, create new elements, or activate the potential element. In the first stage, instead of spending money and energy to prevent disturbance, management uses energy and costs to benefit from the negative effects and consequences of disturbance through the transition.




| Disturbance | Impaired function | Damaged element | Transition type | Redundancy |
|---|---|---|---|---|
| Changing the riverbed | Storage, water protection | Nourishment place | Hard, energy | Increasing the quantity and quality nourishment of lakes and wetlands, reducing water extraction from aquifers, and improving the nourishment space |
| Land-use change | Water health, protection, storage | Shifting the nourishing place | Functional, energy | Increasing runoff speed reduces evaporation |
| Changing water quality | Water health | Purification | Function | Increasing the quantity and quality of nourishment of lakes, dams, riverbeds, and wetlands |
| Increasing demand for water | Protection, storage | Nourishing | Hard | The underground flow of water, allocation of artificial purification costs, change of utilization type, exploiter reduction, optimal utilization laws |
| Decreased rainfall | Water health, protection, storage | Nourishment rate, water Purification | Energy and function | Artificial purification, growth of technology use in water utilization, growth of water efficiency, inter-basin water transfer |
| Reduce river water | Water health, water protection | Nourishment, Purification | Hard and functional | Elimination of surplus exploiters, artificial water storage, social awareness, cost allocation for virtual water imports |
| Drying of lakes and wetlands | Water health, protection, storage | Nourishment | Hard and functional | Transfer of compensation energy to nearby locations, social awareness, water and wastewater purification, cost allocation for water storage |

**Fig. 3: Transition management framework and SES of groundwater anti-fragile**

In the groundwater system, disturbances are divided into three types according to the effect. (i) Disturbances that cause the destruction and destruction of the system element; land use, reduction of bed width, and change of river bed quality are disturbances that destroy the place element of feeding and purifying water of the aquifer. These disturbances reduce feeding and water treatment spaces and endanger the conservation, storage, and safe water services of aquifers (Fig 3). In the first stage of transfer management, it is important to know the volume and type of effect because creating the necessary redundancy to turn the damage into a useful one is effective.

(ii) Disturbances that undermine the functioning of the system element include reduced rainfall, reduced river water, and pollution. These disturbances weaken the purification function of the natural system (Balke & Zhu, 2008), storage, water protection, and the provision of safe water.

(iii) Tree pruning disturbances, as a result of this disturbance, one element is removed and the other element is strengthened. Pruning of trees means that pruning of extra branches increases the amount of energy received from other plants and gives higher quality products. In this type of disturbance, the system management identifies the elements that are hidden idle cuts off the energy and input costs to it, and directs them to the elements with potential capacity. These disturbances include; interfering with the responsibilities of governmental and non-governmental organizations, organizations, and institutions with parallel responsibilities, and changing the structure of riverbeds that transfer the pressure of water extraction from groundwater sources to surface water.

Second, in the second stage of policy formulation, we do not seek to manage the disturbance and we do not seek to prevent the occurrence of the disturbance, but how we make a profit from the disturbance. For example, changes in land use, unauthorized wells drilled in aquifers, extraction with illegal volumes, etc., are probably not solvable on a large complete scale. In transfer management, we do not seek to resolve these issues and seek compensation. Therefore, in utilizing disturbance, creating and strengthening the capacity of redundancy of the type of disturbance is an important principle in policy formulation. There can be three policies: The first is hard transfer. In this policy, the management of destroyed elements is replaced with a new or potential element of the system. System management must carefully construct these elements or identify potential elements. Change of use and transfer of water from concrete streams are disturbances that remove the spatial-place element of nourishing groundwater supply. Building or strengthening groundwater supply elements artificially and naturally is a hard transfer policy that turns disturbance into it is a benefit.

In the second policy, the function of the damaged elements is transferred to other elements in the system. In this policy, the system transfers the function of the affected agent to elements that can increase responsibility. Water transfer from concrete canals challenges aquifer supply but shifts the function of groundwater supply to surface water sources by increasing water efficiency.

Policy 3: Using the damaged element in the groundwater system. In the system, if the efficiency of the element is low, the element is removed and its function is transferred to another element without creating redundancy, costs, and double energy consumption. Also, the energy consumed by the damaged element is transferred with the minimum amount to the existing element with the same amount of function or more. In policy formulation, elements, energy, and function from natural to human elements may occur and vice versa.

Third: Implement the policy. In implementing the policy of the private sector, and the public sector, the capacities of the law, tools, and methods are used. At this stage, a new legal framework, private and public, tools, and methods are created, productivity is increased and new responsibilities are defined.

## Conclusion

On the one hand, the groundwater system is constantly exposed to the disturbances of climate change, over-extraction, land-use change, surface water depletion, lakes, wetlands, and increasing demand for water. On the other hand, its subsystems, and protection services are very dynamic. They change the storage and health of the water.

The turbulence and dynamics of the groundwater system are likely to be out of control. Therefore, the cost of time and capital to control, limit, and prevent the occurrence of disturbances is not effective.

Therefore, the creation of new elements, the transfer of the function of the damaged member to other members, and the transfer of energy of the damaged member to new and potential members make the groundwater system anti-fragile and disturbances make it useful.

This research has weaknesses. Redundancy has not accurately clarified against disruption. For example, it does not which redundancy should be used to turn unauthorized wells into useful ones. These topics could open the way for future groundwater writers and researchers.

This paper presents a framework for groundwater management by combining the concepts of groundwater SES with the concept of anti-fragility and transition, which is very important in groundwater planning, management, and water policies. The framework also states that the anti-fragility system of water does not occur naturally, but through management and governance, the groundwater system becomes anti-fragile.

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