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Original Article

A Conceptual Framework for Groundwater System Dynamics Evaluation by Combining Adaptive Cycle Theory and Social-Ecological System

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Abstract

Purpose- The groundwater system is subject to drastic changes. Nonlinear changes in the groundwater system and management have made it difficult. There has been no study on groundwater dynamics assessment and most studies have examined the variables of salinity control, pollution, water volume and water demand. In addition to filling the study gap, the difference of the research is that it has studied the capacity and the elements of the groundwater system as indicators in the groundwater dynamics.

Design/methodology/approach- In this study, using studies and literature on the groundwater Social-Ecological System (SES), a framework for evaluating groundwater SES dynamics by combining the groundwater adaptive cycle is presented. SES Groundwater consists of three subsystems: the aquifer, natural environment, and community. The elements of these three subsystems move in a four-stage adaptive cycle of exploitation, protection, release, and reorganization, in which potential change, connections, and adaptive capacity make the system dynamic.

Findings - In assessing the dynamics of the groundwater system, the threshold of concern is an important concept for indicators for which capacity can not be defined or when and where the indicators change.

Originality/value - The groundwater system dynamics assessment framework can be useful for proper management and timely actions to protect water and aquifer services in different areas.

Keywords: Adaptive Cycle, Groundwater, System Dynamics, Social-Ecological System, Evaluation.

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1. Introduction

The SES system is a relatively new framework for groundwater management. This system has different subsystems including aquifer, land surface ecosystem and above aquifer community (Bouchet & et al, 2019., Mathias & et al, 2020) socio-economic and political system, users, resource systems, governance systems. SES has been used by many researchers to study various issues (Petit & et al. 2017). SESs are constantly evolving. SES has the feature of nonlinear dynamics, resilience, and self-organization (Zhang & et al, 2021) which causes the dynamics and change of water services (Bouchet & et al, 2019).

The nonlinear dynamics of SES are rooted in the resilience and relationships of elements and groundwater subsystems. In many cases, the intervention and response of the groundwater system are not temporally and geographically consistent (Walkeret et al., 2004; Wycisk et al., 2008; Adobor, 2020). Intervention may take place in the short to medium term (5 to 7 years), but the system response includes self-regulation, adaptation, and immediate resistance, or it may take decades. Another issue in assessing the dynamics of the SES system is the spatial incompatibility of system intervention and system response. Interference may be at one particular geographical point and the system response in another place. The third problem is the existence of complex relationships between the actors and the elements of the groundwater system with each other (Zazueta & Garcia, 2021). The behavior of the elements of the system may be such that it causes damage to other elements because the elements of the system, in addition to internal relations, are also related to external factors of the system. We also refer here to the system's involvement and response to the behavior of different social groups. In most cases, especially the behavior of human elements is influenced by the external processes of the groundwater system. The response of the human elements of the groundwater system may not be appropriate to the goals of the aquifer, and this response may occur without considering the sustainability of the aquifer system, and certain social groups pursue their interests regardless of the interests of other social groups in the aquifer. These inconsistencies and non-compliance of the intervention with the system response at the time spatial scale and social groups, make it difficult to assess groundwater dynamics.

Regarding the evaluation of SES dynamics in various fields, many studies have been conducted to explore the tipping point route of natural systems, changes in urban sustainability, changes in the stability of lakes, oceans, forests, and other natural ecosystems of grassland systems, urban density (Walker et al., 2002., Mathias et al, 2020., Zhang & et al, 2021., Zazueta & Garcia, 2021). However, no study has been conducted to assess the dynamics of SES groundwater. To assess the dynamics of a groundwater SES, we need an effective method that not only assesses the long-term dynamics of groundwater stability but also identifies critical times and areas for improving groundwater management. In this paper, by combining SES with adaptive cycle theory, we seek to provide a framework for assessing groundwater SES dynamics.

The theory of the adaptive cycle was proposed by the French mathematician Ren´e Thom (Ekeland, 2002). Many researchers have used this theory in various fields (Li & et al, 2017., Zhang & et al, 2021., Adobor, 2020., Linnenluecke and Griffiths, 2010., Williams et al., 2019). The goal of adaptive cycle theory is to understand how systems change (Zhang & et al, 2021; Adobor, 2020). This cycle evaluates the movement of the system in three dimensions: potential, connectedness, and adaptive capacity (Holling, 2001) in four stages: exploitation, protection, release, and reorganization. At the exploitation stage, the system is in a state of rapid growth. In the protection phase (accumulation of resources and connectedness), the resilience of the system decreases. In the release phase, the connection between the various components of the system is weakened and the ability to adjust and control the system is reduced, which leads to system uncertainty. & et al, 2019). Moving the system from the exploitation phase to the protection phase increases resources and connections, but resilience decreases because too much connectedness causes cascading disturbances. In the context of assessing the dynamics of the ACSES (Adaptive cycle of Social and Ecological System), we have three sub-systems of aquifer, ecosystem, and community above the aquifer that a matrix with the components of the adaptive cycle creates and potential, connectedness and "adaptive capacity" changes in stages shows various exploitation, protection, release, and reorganization. To do this, we first detected the SES of groundwater, then defined the adaptive cycle about groundwater, next identified the indicators for assessing the potential, connections, and resilience of the dynamics of the SES of groundwater, and afterward presented the ACSES matrix. Finally, we stated the conclusions and lessons.

2. Research Theoretical Literature

2.1. Components of Groundwater SES

The main components of SES are groundwater exploiters, institutions, and natural resources. In the SES system, groundwater can be considered a complex resilient system (Bouchet & et al, 2019) in which there is a set of interventions and responses. Interference and response in SES occur in subsystems, and interference in a subsystem may take the form of harvesting, contamination, and salinization by operators, organizations, and other components of SES (Bouchet & et al, 2019). The response may occur in the operation of another subsystem and after years or decades in terms of time. This process reveals the complexity of groundwater system dynamics and the difficulty of assessing dynamics.

SES Groundwater consists of three subsystems of the aquifer, the natural environment, and the human community above the aquifer. The aquifer subsystem consists of layer elements (Blomquist, 2020), pores (Xu & et al, 2013), and underground faults that are subject to both interference and response capacity and resilience against the interference of factors outside the system. The upper aquifer environment also includes rivers (Boulton & Hancock, 2006), springs, rainfall, lakes and wetlands, and land cover, which are exposed to interference and response like aquifer elements. The response of these elements may be to slow and fast variables in the form of self-regulation, adaptation, and resistance. The third subsystem is human society which is likely to be the main interfering with aquifer elements and the natural environment above the aquifer. Key elements of this community also include exploiters, government agencies, NGOs, and companies. The forms of involvement of these elements are salinization, pollution, and harvesting, and their response to changing water services is adaptation and resistance.

2.2. Functionality and internal relationships of SES elements against change

The protection of groundwater services is the main objective of SES. The function of the elements of SES subsystems is to protect, store and treat water against the variables of salinity, pollution, harvesting, and water demand (Biggs & et al, 2015. Bouchet & et al, 2019). Aquifer layers in groundwater SES are responsible for purifying, protecting, and storing water flow in the aquifer. Underground pores also play a role in water protection for the system (Xu & et al, 2013). In-ground faults are responsible for supplying water to the aquifer. Of course, the quality of underground faults depends on how they elongated in relation to the course of rivers and surface water flows. If the elongation of the faults coincides with the direction of surface water flow, the feeding rate of the rivers decreases and vice versa.

The function of the elements of the natural environment above the aquifer in groundwater services is to purify and nourish. Rivers play a role in water injection and treatment, but their relationship with groundwater is complex (Petit & et al, 2017). The flow of water in the course of rivers purifies possible polluted water and in the process of flowing water in the riverbed, it enters the aquifer. Of course, the rate of river water nutrition depends on tectonic factors and the width and slope of the riverbed (Allen & et al, 2004). The looseness of the riverbed and its wide width increase the amount of water feeding in the aquifer, but the slope of the river has an inverse role in feeding, in contrast to water treatment playing a constructive role in the sustainability of groundwater services.

The function of lakes and wetlands in the protection of water services is their nourishing role (Kløve & et al, 2011). These water levels store running water and inject it into aquifers over time. The role of these elements in the protection of water services depends on the quality of water and the proximity of its bed layers with adjacent aquifer layers. Ideally, the role of lakes and wetlands in feeding aquifers is to align aquifer layers with lake bed layers and their freshwater, which probably rarely come together - this largely determines the fragility of aquifers about these water sources. It shows. In the presence of these two conditions, lakes and wetlands have a very useful role in protecting groundwater services.

Precipitation is another element of the sub-environment system above the aquifers. The role of this element in water services is further determined by its nutrition (Earman & Dettinger, 2011). The amount of aquifer feeding by rainfall depends on the type (snow and rain) (Jasechko & et al, 2014), its amount (volume), and time.

Land use is involved in pollution, salinization, and groundwater demand. Rangeland, horticultural, agricultural and man-made land uses are effective in the amount of surface water infiltration and rainfall (Foster & et al, 2010). Intensive agricultural uses in water pollution and extraction hurt groundwater and the path to its involvement in water services is negative. Intensive agriculture using various chemical fertilizers and pesticides are the most important surface contaminants in groundwater (Popa & et al, 2019. Lerner & Harris, 2009). Man-made surfaces also hurt water storage, increasing the flow of water on the surface and reducing the permeability of the earth.

The role of the fountain in groundwater can be interesting. Fountains is effective in maintaining the balance of groundwater with surface water and reducing groundwater pollution. Groundwater outflow from fountains (in the absence of water extraction wells) leads to balanced use of groundwater. In addition to protecting groundwater, these natural phenomena make water available to users. In addition to protecting water, fountains play an important role in reducing salinity and groundwater pollution. The outflow of water from the fountain brings pollution and salinity to the surface of the earth and places it in a cycle of artificial treatment (treatment plants) and natural (combined with surface oxygen) and prepares the aquifer for the possible entry of safe water.

Human society is involved in adaptation and resistance to changing water services. In addition, the function of these elements in demand and harvest is debatable. Water abstraction and demand level are important as two control variables (Biggs & et al, 2015) in water services. In this regard, groundwater users are divided into three categories: Enthusiastic exploiters, moderate exploiters, and pro-environmental exploiters (Mathias & et al, 2020). Extremist exploiters prefer personal interests to collective interests and reinforce the tragedy of the masses. Moderate exploiters are those who are more adaptable to changing water and try to adapt to changes in strategy and activities. Pro-environmental exploiters play the role of resisting change and generally try to reduce demand and harvest. Their flexibility is more of a resistance type than an adaptation.

Exploiters' performance against water services is more affected by processes outside the system than changes within the system. Economic growth, population growth, and economic and livelihood policies in the performance of users against water services are very important to the processes and changes within the system (Bouchet & et al, 2019). This is due to the immediate effects of external processes on the livelihoods of users, as opposed to changes within the system, the effect of which occurs mainly in the long run.

The function of government agencies in protecting groundwater services is to protect public rights and the future. These institutions play a role in monitoring water harvesting and demand, pollution, and salinization (Bresci & Castelli, 2021). Their regulatory tools are laws that facilitate and restrict water use. These institutions determine the demand and withdrawal of water by direct exploiters in a way that maintains the balance of feeding and harvesting. This is done by preventing well drilling and over-harvesting of farmers' water rights. In addition to the above role, organizations are active in adapting activities, such as resistance measures to change activities, change livelihoods, artificial nutrition, water treatment and land-use change against pollution and salinity and water extraction (Habiba & et al, 2014).

Non-governmental and non-governmental organizations also have the role of supervising the water divider. These organizations distribute water based on the share of users. They also monitor and report on water pollution and salinization to protect public rights and the environment.

2.3. Groundwater Adaptive Cycle Background

The adaptive cycle was proposed by Holling (1986). This cycle operates in a three-dimensional space of potential, connection, and flexibility that has been considered in various studies (Sundstrom & Allen, 2019., Randle et al., 2014., Fath et al., 2015., Zhang & et al, 2021., Escamilla Nacher et al, 2021) In the adaptive cycle, the potential refers to the system's capacity to select options for resilience to change. The higher the system potential, the smaller the change capacity, but eventually it changes and moves to the next stage of the cycle (Figure 1).

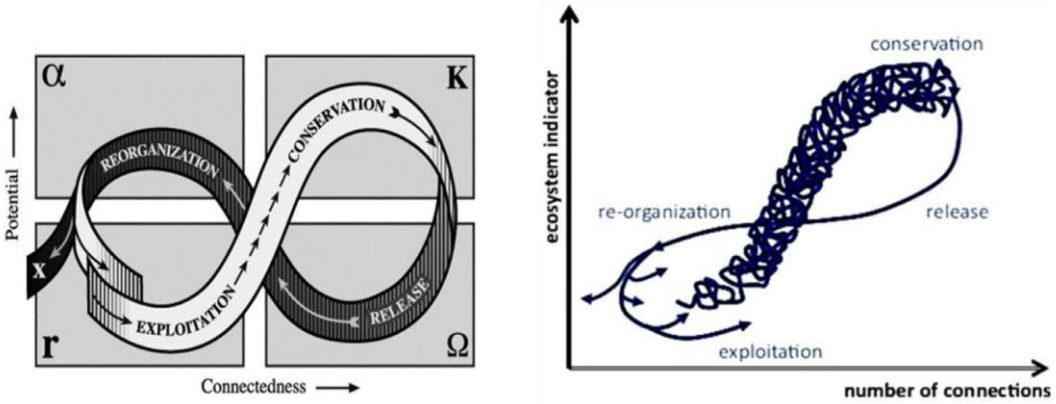

Figure 1. Adaptive cycle. Retrieved from: Sundstrom & Allen, 2019

The system resilience dimension shows the system's sustainability to change (Holling & Gunderson, 2002). Resilience includes the components of adaptation, self-regulation, and resistance (Bouchet & et al, 2019). The higher the degree of adaptation, resistance, and self-regulation of system elements, the lower the variability capacity of the system. The process and extent of potential change, connectedness, and adaptive capacity occur in four stages: 1- Exploitation (r) 2- Protection (k) 3- Release (Ω), and 4- Reorganization (α) (Holling & Gunderson, 2002). In the exploiter's phase, the potential of the system is very high and the growth capacity of the system is at a good level. At this stage, the connectedness is wide, but the intensity of resilience is minimal due to the absence of determinants and changes in system services (Grundmann & et al, 2012). With the expansion of use and consumption of resources, the growth potential of the system in the operation phase is minimized and the system is transferred to the protection phase. In this phase, the potential is high (Holling, 2001) but the high potential is increased through resilience and not through the inherent resources of the system. In the connectedness protection phase, it reaches its maximum (Sundstrom & et al, 2019) and the intensity of resilience, i.e., compatibility and resistance through high interventions and their high speed compared to the self-regulating speed, causes problems for the system. When the system in the protection phase reaches a point where the connectedness and connections are damaged and this connectedness is no longer constructive and useful in the system as a whole, an external disturbance transports the system to the release phase (Thapa & et al, 2016., Daedlow & et al, 2011) and at this stage, the system is freed from connectedness and connections.

In the release phase, the resources and the type of resilience against the disturbances and changes related to the protection phase are reduced. But another kind of resilience is formed in the face of new conditions. This resilience is related to the openness of the system about the new routine that is different from the previous system. In the reorganization phase, resources and connections increase (Holling & Gunderson, 2002) not the resources that were in the previous phases but new resources and connectedness that can be completely different from the previous system.

- Dimensions of the adaptive groundwater cycle

The adaptive cycle is a good way to evaluate the dynamics of ecological social systems. This theory has been used by various researchers in evaluating the dynamics of different systems (Grundmann & et al, 2012. Thapa & et al, 2016. Daedlow & et al, 2011. Zhang & et al., 2021., Escamilla Nacher et al., 2021). We have used this cycle here to evaluate the SES dynamics of groundwater. First, we introduce the dimensions of potential, connections, and adaptive capacity of the water adaptive cycle, then we would examine these dimensions in the stages of operation, protection, release, and reorganization.

2.4. Potential of the groundwater system

Potentials are indicators of tracking change and dynamism (Adobor, 2020). Groundwater system potentials include; Adjustment of aquifers, subterranean pores, lakes, wetlands, rivers, land use, temperate and ecological users, public institutions, good laws, springs, underground faults perpendicular to the surface water flow path. Aquifer nourishablity allows choosing to adapt and resist slow and fast variables. The porous layers of the pore also determine the feeding capacity and also play the role of purifying polluted and saline water. Basement layers and pores increase the suction power of surface water resources. Groundwater faults are an excellent source and potential for feeding and preventing aquifers from draining. These faults lead to more water infiltration into the ground and increase the capacity of the aquifer in the face of change (Behyari & et al, 2020). Lakes, ponds, and rivers also feed the aquifer. These water resources, provided they have healthy water conditions with less salinity and pH, prevent salinization, decrease the volume of aquifer water, and increase the capacity of aquifer resistance to change water services and interventions that change water services. The land cover also plays a role in protecting and destroying water resources. The positive role of land cover is to prevent evaporation and permeability of the land, which can play an important role in the resistance of the Trader aquifer to change.

Environmentalist exploiters have a very good capacity under the aquifer human society subsystem. These exploiters have high resilience and adaptability to conditions outside the system to protect water services (Mathias & et al, 2020). They also have a high capacity for participation in water management. Next to them, public institutions are an important resource in water conservation (López-Gunn, 2012). These institutions prevent excessive extraction by closely monitoring and dividing water by share, and increasing adaptive capacity and resistance to water discharge and salinization. In addition, good and efficient groundwater laws have great potential. Good laws play a role in preventing disruptions to water services (Foster & van der Gun, 2016; Molle & Closas, 2020) and also in building public trust and participation in adaptive measures and resistance to change.

3. Research Methodology

3.1. Groundwater connectedness

The groundwater system has sub-systems of the community, aquifers, and ecosystems that are interconnected (Bouchet & et al, 2019., Blomquist, 2020). The main form of communication for system stability is reciprocity. In interactions, energy is traded and transferred (Silberstein & Maser, 2013). The transaction and transfer of energy occur between the internal elements of the system with each other and with elements outside the system. The internal relations of the system are very important in the stability of system services and the connection of external elements can play the role of disturbance in the connections of the groundwater system, which leads to the confusion of the connections of internal elements and the balance of the system.

In the discussion of connections, traders of origin and destination, the subject and route of the transaction are discussed (Kernberg, 1988). Here, for traders, ie aquifers with society and the natural environment, the subject of the transaction and its results are important. Regarding the relationship between aquifer elements and the natural environment, the subject of the transaction is water, which plays an effective role in protecting aquifer services. The relationship between the two subsystems is largely positive (Lerner & Harris, 2009; Bishop & et al, 2017) and reinforces each other's role in water conservation. But the aquifer's relationship with society is debatable, and the issues they deal with are water and materials. In the relationship between these two subsystems, there is a negative effect on water services, which leads to a decrease in the capacity of the aquifer in providing safe water services and weakens the ability of the aquifer to resist and adapt to change (Table 1).

Table 1. Connectedness of aquifer elements with the community and natural environment above the aquifer

	Elements of the community subsystem and the upper aquifer environment	The subject of the relationship	Route of losses and gains for aquifers and protection of water services
Aquifer	River/Lake/ Wetland	Water	Mutual nourishment (+), water purifier (+)
	Land use/land cover	Water	Water pollution (+), water protection (+), evaporation reduction (+), high water extraction (-), increase in permeability intensity (+), water purification (+)
	The amount and type of rainfall	Water	Feeding with healthy water (+)
	Lakes and wetlands	Water	Feeding each other (+)
	beneficiaries	Water and materials	Extraction (-), Pollution (-), Salinity (-), Protection (+)
	government institutions	Water	Water treatment (+), transfer (-), protection (+), and artificial water feeding (+)
	Popular institutions	Water	Water protection (+), monitoring the division and extraction of water (+)
	Law	Water	Water protection (+), distribution and extraction monitoring (+), water pollution and salinity monitoring (+)

(+) A positive role in protecting water services and strengthening adaptive capacity, self-regulation, and aquifer resistance to change
(-) Negative role in protecting water services and strengthening adaptation capacity, self-regulation, and aquifer resistance to change

The community's relationship with the aquifer above the natural environment "probably" acts as a nuisance in the relationship between the aquifer and the environment. The word "probably" means that this relationship sometimes plays an important role in protecting groundwater services and leads to enhanced resistance, adaptation, and self-regulation of the aquifer and the natural environment above the aquifer against change. But most of the time it plays a destructive role in the relationship between aquifer and ecosystem, which is the result of the influence of elements outside the system such as population growth, urbanization, food security, and economic growth (Bouchet & et al, 2019) that the government seeks to respond to these processes.

In many cases, the interests of groundwater exploiters conflict with the interests of surface water users and prevent the protection and strengthening of the aquifer (Foster & van der Gun, 2016). The relationship of the aquifer with the elements of the natural environment above the aquifer is sometimes captured by the power relationship between surface water users, the government, or public institutions with groundwater users. Because surface water has higher benefits than groundwater for investors in transmission, canalization, and dam construction that does not exist in groundwater. This undermines government rules and practices in monitoring the rights of aquifers and groundwater users. So, what is meant here is the law, the public and government institutions that are effective in protecting water services (Foster & van der Gun, 2016), and nothing else.

Table 2. Connections of community elements with elements of the natural environment above the aquifer

	Elements of the upper aquifer environment	The subject of the relationship	Results route of losses and gains for aquifers and protection of water services
Exploiters	River	Water and materials	Extraction (-), water transfer (-), canalization (-), protection (+), pollution (-).
	Land use/land cover		Land-use change (-), cultivation of irrigated crops (-), land cover strengthening (+), degradation (-), pollution (-)
	The amount and type of rainfall	Water	Storing and directing water to storage facilities (+)
	Lakes and wetlands	Water and materials	Pollution, water rights protection (+), privacy (+)

	Elements of the upper aquifer environment	**The subject of the relationship**	**Results route of losses and gains for aquifers and protection of water services**
Efficient government institutions	River	Water and materials	Inter-basin transfer, water treatment (+), water distribution monitoring (+), protection (+), extraction and pollution monitoring (+)
	Land use/land cover		Protection and reinforcement of land cover (+), change monitoring (+)
	The amount and type of rainfall	Water	Storing and directing water to storage facilities (+)
	Lakes and wetlands	Water and materials	Privacy (+), pollution, and water rights (+)
NGO	River	Water and materials	Water sharing (+), consumption monitoring (+), protection (+)
	Land use/land cover		Protection and strengthening of land cover (+), change monitoring (+)
	The amount and type of rainfall	Water	Storing and directing water to storage facilities (+)
	Lakes and wetlands	Water and materials	Protection of privacy, pollution, and water rights (+)
Good law	River	Water and materials	Determining water rights (+), determining privacy (+), and determining the share of exploitation (+)
	Land use/land cover		Land cover protection (+)
	The amount and type of rainfall	-	-
	Lakes and wetlands	Water and materials	Protection of privacy, pollution, and water rights (+)

(+) A positive role in protecting water services and strengthening adaptive capacity, self-regulation, and aquifer resistance to change

(-) Negative role in protecting water services and strengthening adaptation capacity, self-regulation, and aquifer resistance to change

The transaction process takes place between the elements of the subsystems. In this transaction, most of the time, what is good for one element may not be good for other elements and may cause harm to other elements (Silberstein & Maser, 2013). This is where the debate over resilience comes into play. Because "loss" is considered as interference in the states of that element and this intervention has a self-regulatory response of adaptation and resistance, which is the third dimension of assessing the dynamics of the groundwater system.

- Resilience of groundwater system

Stability against groundwater control variables is achieved through compatibility, service, and resistance of system elements. In adapting the system to change variables, changing the type of groundwater use, changing the pattern of cultivation or transfer of water to valuable crops, reducing the volume of water use, reducing dependence on groundwater resources by changing the way of life by individuals, society and government It happens (Habiba & et al, 2014).

The use of natural treatment plants includes nutrient uses such as the conversion of arable land to forests and grasses, prevention of change of natural uses, prevention of encroachment on rivers (Lerner & Harris, 2009), change of irrigation system, and modification of harvesting rules, some of the Resistance is from human society (Bresci & Castelli, 2021). In addition, changes in the rules for wells and water abstraction (Liu & et al, 2006), and the issuance of pollution licenses to farmers, factory owners, and municipalities increase the sustainability of groundwater resistance to pollution.

Increasing the nourishment role of rivers, lakes, and wetlands in the presence of humid climates, and increasing suction by the aquifer (Sandwidi, 2007) are important self-regulatory processes against change. Artificial freshwater feeding (Molle & Closas, 2020), prevention of saline infiltration into the aquifer, saline water treatment, reduction of chemical fertilizer use in agriculture (Foster & et al, 2018., Pulido-Bosch & et al, 2018), amendment of laws The use of groundwater, the improvement of riverbeds can increase the amount of groundwater recharge and improve the quality of groundwater. Finally, the development of sustainable and organic agriculture and the use of treated saline water in the agricultural sector will prevent the change in groundwater services.

Purification of pollutants such as metals, organic matter, etc. by the earth's layers and its constituents when water enters the aquifer is one of the measures of self-regulation of the aquifer system. In addition, the riverbed with its constituents mainly prevents the entry of polluted water. Rivers engage the aquifer with oxygen before it enters the aquifer and reduces the amount of pollution in the water, which overall delays the change in water services and creates relative stability.

3.2. Groundwater SES Dynamic Evaluation Indicators

The resources and capacity of the system are an excellent guide for evaluating the dynamics of the system against the variables of slow salinity, pollution, water volume, and water demand, which are defined as the factors influencing the change in water services (safe and sufficient water). However, in selecting indicators based on sources for dynamic evaluation of groundwater systems in the comparative cycle, there can be several important issues: 1- The type of indicator that can determine the impact on dynamics 2- Data collection and information for indicators, 3 - Time to change index values and 4- Place to change index values.

Various indicators affect the dynamics of the groundwater system and it is difficult to determine the exact amount of their impact on the dynamics of the whole system. There is no specific standard that can recommend an "appropriate" index to assess the dynamics of SES in the adaptive cycle. Because the value of indicators is affected by a set of index relationships that are very difficult and sometimes impossible to abstract from each other, using all of them also faces another problem.

The independence of the index and the dependence of the index on other indicators determine the threshold of concern and the peak of the index and water services. Any independent variable is a good indicator to evaluate because it alone can affect system services. However, if the index is highly dependent, a "Threshold of concern" can be used for it, and this worry is the ratio of the number of changed indices to unchanged indices. The higher the value, the higher the Threshold of concern. But the choice of indicators does not depend only on the type and nature of the variable. Data collection for all of these indicators is another issue that makes dynamic evaluation difficult. The data either do not exist or are mainly available to various sources such as various governmental, non-governmental organizations, and private exploiters, which are not always possible to collect in most countries and regions, making it difficult to assess dynamics at any time and place. Another issue is that dynamic data is not always specific to a specific place and time that can be used to study SES change. It may be in adjacent places and aquifers that are located in the political sphere of other countries and other administrative regions, which make it difficult to access for evaluation at all times and therefore cannot be relied on.

In selecting the indicators in evaluating the dynamics, the type of indicator in terms of speed and volume of groundwater system change should be considered. Some indicators create high speed in dynamics and others may have low speed and their volume of change is very deep and wide. Changes in indicators may have social roots, some have natural roots, and some have human and natural roots. Therefore, paying attention to the roots of change can be important in selecting indicators to evaluate dynamics. Another issue in selecting indicators is whether the values of your indicators change internally and externally. SES change indicators may be rooted outside the water management location, which is very difficult to monitor and manage change. In the meantime, system resources are a good guide for selecting the index that has been used in this text.

- Aquifer subsystem (AS) dynamics assessment indicators

The most important aquifer resources that extend the choice and resilience of aquifers to changing water services are pores, aquifer layers, aquifer shape, groundwater flows, and aquifer faults. The amount of space in the layers and pores of the aquifer is important in water treatment and the amount of water storage (Vrba & et al, 2007). According to the laws of physics, the amount of porosity in the aquifer is inversely related to the strength and resistance of the aquifer to the reduction of groundwater volume. The larger the pores of the earth, the greater the change in aquifer and groundwater services as soon as the volume of water decreases. Aquifer subsidence is the culmination and reorganization stage of this element of SES (Vrba & et al, 2007). Therefore, the root of change in this element depends on the nature of the element, the ratio of the amount of artificial natural nutrition to the amount of extraction, and the speed of artificial and natural nutrition to the extraction groundwater rate.

Another indicator of SES dynamics is groundwater flow (Henriksen & et al, 2008). The higher the groundwater flow, the faster the rate of change and passage through the climax and the occurrence of the release and reorganization phase in the adaptive cycle. Groundwater flow may be different in two administrative areas and may be challenging to manage because decisions in other locations for the aquifer are uncontrollable. Of course, the amount of water flow in the aquifer is strongly influenced by the shape of the aquifer. Therefore, another indicator in assessing the variability of groundwater flow is the ratio of the shape of the egg carton to the shape of the aquifer pool. In the form of an egg's carton, the underground flow of water is less than in the form of a pool, and therefore the speed and location of the change in the place of the eggs will be higher.

The basement faults' elongation stretch relative to the surface water flow path affects the rate at which the aquifer is fed. Therefore, the higher the angle of the faults relative to the surface water travel path, the closer the degree of change of SES water services to delay and the greater the flexibility of the aquifer against change. Because in this case, the power of the aquifer is at a good level.

The rate of spring water is another indicator that shows the rate of change and dynamism of SES (Vrba & et al, 2007). The amount of watering of fountains can be a threshold of concern and the tipping point of aquifer change. Of course, the location of the fountains relative to the height of the layers is the control indicator of the springs. The lower the location of the fountains relative to the pores and layers, the amount of discharge can be a good indicator to assess the threshold of concern and the tipping point or release stage of the adaptive cycle.

Table 3. Definition of variables and concepts

Variables	Indicators	index
Earth pores	The degree of porosity in the aquifer is inversely related to the strength and resistance of the aquifer to the reduction of groundwater volume	AS_1
Aquifer shape	The ratio of the area of the egg carton to the pool	AS_2
Groundwater flow	The ratio of aquifer area within the administrative area to aquifer area in the adjacent office area	AS_3
	The ratio of aquifer area in the administrative area to the total aquifer area	AS_4
Basement faults	The angle of the faults about the path of surface water movement is more than 45 degrees and close to 90 degrees.	AS_5
fountains	The rate of change of watering fountains in each year compared to the previous year	AS_6
	Average height of fountains to aquifer height	AS_7

4. Research Findings

4.1. Dynamics assessment indicators of Environmental Subsystem (ES)

The basic resources of the natural environment are in expanding the sustainable capacity of groundwater services, rivers, wells, lakes, wetlands, and rainfall. Changes in these resources indicate the capacity for change in groundwater systems and water services (Table 4).

River discharge (Vrba & et al, 2007), riverbed, and the number of days of water flow per year are among the indicators that are important in assessing the dynamics of groundwater SES. Changes in river discharges over the years determine the rate of aquifer feeding (Henriksen & et al, 2008.,., Gejl & et al, 2020). By changing the flow of rivers due to the transfer of water to other basins and creating a dam, the rate of feeding of aquifers decreases. The feeding rate of rivers also depends on the level of the riverbed. The higher the width of the riverbed due to the encroachment on the riverbed by the human community, the lower the width of the river and the less the river feeds.

In arid and semi-arid regions, the rivers that feed the aquifer are not permanent and are seasonal. In these areas, the number of days of water flow is a measure that determines the dynamics of the groundwater system. The number of days of water flow in the river varies in different years and depends on the amount of rainfall and the type of rainfall. The closer the ratio of the number of water days in the river to the number of days in the year, the higher the rate of river nutrition, and vice versa.

Groundwater wells, the density of water wells, average depth of wells, and average discharge of wells above aquifers are suitable indicators for assessing the dynamics of groundwater SES. The density of water wells can vary depending on the content of pores and soil layers, and the amount of rainwater fed and leaking from rivers. In places where there is naturally nourishing and leakage and the volume of layers and pores of the earth is high, higher density is not effective in rapid change, but in areas with low aquifer volume and low natural and artificial nutrition, well density increases the speed of water service change. Therefore, if the ratio of natural nourish to water depletion from the aquifer with good density, well depth, and well discharge, if changed together, will greatly change the water service and system dynamics and the adaptive groundwater cycle.

Water quality and level of lakes and wetlands; it is also an indicator of the SES dynamics of groundwater. Lakes and wetlands are important sources of groundwater recharge (Kopeć & et al, 2013. Gejl & et al, 2020). Pollution rate, salinity, and water level are very important in the dynamics of groundwater services. With the decrease of water in lakes and wetlands, their level of pollution and salinity will increase and the amount of polluted and saline water in the aquifer. Therefore, SES reduces the resilience of groundwater and increases the passage rate from the peak point and the protection phase of the adaptive cycle.

Changes in precipitation and type of precipitation; other indicators are very effective in groundwater dynamics. Rainfall is involved in the aquifer's natural nourishment. Therefore, reducing or increasing rainfall is important for the sustainability of groundwater services (Hund & et al, 2018). Rainfall and snowfall increase the SES 'resilience to salinity, pollution, water volume, and water demand, and reduce the transition velocity and stages of the adaptive water cycle.

Ground cover; is another effective indicator of groundwater dynamics (Foster & et al, 2010). Land cover density is directly related to natural nourishment (Kopeć & et al, 2013). The ratio of plant density of the aquifer to the total area of the aquifer determines the amount of aquifer nourishment. The higher the density of rangeland and agricultural vegetation, the higher the aquifer nourishment rate which increases the flexibility of the groundwater system and delays the passage of the peak point and the change of the adaptive cycle stage of the groundwater.

Table 4. Indicators of the natural environment subsystem above the aquifer

Variables	Indicator	index
River	Changing the width of the riverbed compared to a few years ago	ES_1
	Changing the ratio of the number of days of water flow to dehydration in the long run	ES_2
	Changes in river discharge over the long term	ES_3
Wells	Changing the density ratio of water wells at the top of the aquifer compared to a few years ago	ES_4
	Changes The average depth of water wells to a few years ago	ES_5
	Changes The average flow of wells from a few years ago	ES_6
Lakes and wetlands	Changing the water level of lakes and wetlands	ES_7
	Changes in the salinity of lakes and wetlands in the long term	ES_8
Rainfall	Change the rainfall every year to the long-term average	ES_9
	Changing the ratio of snow to rain in the long run	ES_{10}
Land cover	Changes in land vegetation density in the long run	ES_{11}

4.2. Social subsystem (SS) indicators to assess the dynamics of SES groundwater

Human indicators of groundwater systems are the performance of society regarding groundwater management. Environmental users, low water consumption cultivation pattern, deterrent laws, continuous monitoring, artificial groundwater recharge, government management institutions, public water distribution institutions, population density and per capita population, occupational dependence and income of human communities to groundwater, activity diversity, water transfer, water transfer canals are important social elements of SES groundwater (Table 5).

Table 5. Indicators of the social subsystem above the aquifer

Variables	Indicators	index
Exploiters	Changing the ratio of environmentally oriented farmers to moderate farmers compared to previous years	SS_1
	Change in the ratio of moderate exploiters to extremist exploiters compared to previous years	SS_2
	Changing the ratio of environmentally oriented exploiters to extremist exploiters compared to previous years	SS_3
	Changing the level of satisfaction of groundwater users from the decisions of surface water users	SS_4
Cultivation pattern	The ratio of low water consumption cultivated land area to high consumption land area	SS_5
Deterrent rules	Changing stakeholder satisfaction with water laws	SS_6
Continuous monitoring	Changing the level of stakeholder satisfaction with the supervision of public and governmental institutions regarding the operation and the rate of evacuation	SS_7
Artificial groundwater recharge	The ratio of the amount of artificially charged water to the amount of discharge	SS_8
Government management institutions	Change the number of managerial and decision-making institutions to non-decision-making institutions	SS_9
	Satisfaction with the political will of government institutions in groundwater management	SS_{10}
NGOs distributing water	Changing the ratio of public institutions to government institutions involved in groundwater	SS_{11}
Population density and population per capita	Change in population density above the aquifer	SS_{12}
Off-farm inputs	Changing the ratio of fertilizer and pesticide use to organic inputs	SS_{13}
Variety of activities	Changing the degree of job dependence and income of human communities to groundwater compared to the long term	SS_{14}
transferring water	Changing the ratio of water transfer to total renewable groundwater over the long term	SS_{15}

Source; (Molle & Closas, 2020., Foster & et al, 2010., Foster & van der Gun,2016., Konikow, 2013., Dietz et al. 2003., Vrba & et al, 2007., Henriksen & et al, 2008., Majidipour & et al, 2021)

4.3. The framework of the adaptive cycle of the ecological-social system

The framework for assessing the dynamics of the adaptive cycle of the ecosystem system (ACSES) of groundwater is as follows. In this model, SES is divided into three AS aquifer subsystems, ES natural environment subsystem, and the community (SS) subsystem. The characteristic of the framework for assessing the dynamics of the adaptive cycle of the ecosystem-social system (ACSES) of groundwater is as follows. First: In this SES model, it is divided into three sub-systems AS aquifer, ES natural environment subsystem, and community subsystem (SoS). Second: the adaptive cycle of these three subsystems in four operating processes (R), protection (K), Release (Ω), and reorganization (α) are evaluated based on changes in potential, connections, and adaptive capacity with groundwater SES indices. Third: Index values are in the range of zero to 100%. Based on dividing a cycle (possibly a complete cycle) into four quadrants, each quarter accounts for 25 percent of the total cycle, and changes to the entire system per quadrant will be 25 percent. Therefore, if we divide the distance from zero to 100 into four parts in the cycle, then the rate of change of variables will show up to 25% of the change capacity (Figure 2).

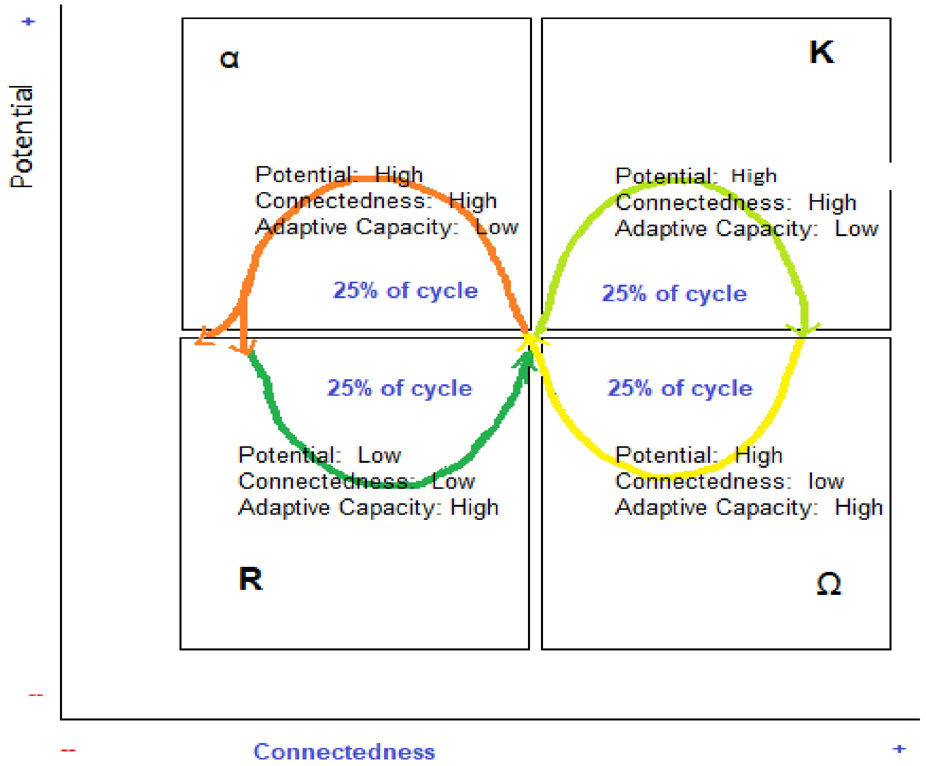

Figure 2. Adaptive groundwater cycle and the amount of change in each stage

Fourth: The important point here is that for some indicators the capacity from zero to 100 cannot be determined. Therefore, we considered low capacity less than 25% and high capacity between 25 and 100. The speed of change of elements is also different from each other some of them may go to the next stage and others may remain in the previous stage. Here we will use the concern threshold and the climax to assess change because of the difference in the speed of change.

Two important aspects help us determine system dynamics: the number of elements and the capacity of the elements that represent change (Table 6).

Table 6. How to change the elements of subsystems in the stages of the adaptive cycle based on resources, connections, and adaptive capacity

SES	Adaptive Cycle	Exploitation	protection	Release	Reorganization
Aquifer subsystem	Indicators AS_1 AS_2 $.AS_7$	–Changing potential indicators is less than 25% of resource capacity / 25% of resources used. Connections are less than 25% of capacity / 25% of elements are associated with elements outside the system	Between 25 and 100% of resources are used / the rate of change between 25 to 100% occurs in resources. 25 to 50% of the elements are connectedness	The potential is destroyed and only less than 25% of the capacity remains. / 25% of resources remain. Between 25 and 100% of the elements are connectedness to elements outside the system. The	New resources and capacity are formed / 25 to 100% of the system elements are changed and new elements are formed. Connectedness is minimal / Less than 25% of new elements are related to elements outside the system
Natural environment subsystem	ES_1 ES_2 $.ES_{11}$				

SES	Adaptive Cycle	Exploitation	protection	Release	Reorganization
The subsystem of human society	SS_1 SS_2 . . . SS_{15}	The rate of compatibility/resistance and self-regulation of the indicators is 25 to 100 resilience capacity of the elements	to elements outside the system / the relationship between elements inside and outside the system varies between 25 to 100. Compatibility, resistance, and self-regulation capacity reaches less than 25% of capacity.	relationship of the elements with the external elements has changed from 25 to 100. Adaptability, resistance, and self-regulation capacity reach less than 25% of capacity.	Adaptability, resilience, and self-regulation capacity are at a high level. Between 25 and 100% capacity is used for resilience / 25 to 100% elements have resilience capacity.

Fifth: There can be two types of dynamics in the system: 1- change in the number of system elements, possibly the elements of the system in the process of interactions are completely changed due to connectedness and transferred to the next stage of the adaptive cycle, and 2- possibly, the potential of the element Increase or decrease. For example, the pores of the earth are an asset of the aquifer system. It is possible that due to the discharge of water with subsidence of a few centimeters to a few meters, its capacity will decrease or it will be completely blinded and destroyed due to discharge. Another example; the volume of groundwater is another source in the aquifer. There are two types of change in this element; first, the volume of water is likely to decrease, and second, the quality and salinity of water may change. In any case, if the change of all elements of the system reaches more than 25% of capacity, number, quality, and volume, the system will be transferred to the next stage. In the next stage, the amount of change will be more than 25% compared to the previous stage. This theorem can be applied to all elements of the system and the dynamics and changes of the groundwater system can be measured.

Sixth: There is an important point in measuring the change of elements of the groundwater system: not all qualitative and quantitative capacities of the system are the same in all elements and do not change at the same time or place (Walkeret al., 2004; Wycisk et al., 2008. Adobor, 2020). Some quantitative and qualitative features of the system are likely to change in the long run and others in the short term. Some characteristics also change in places outside the jurisdiction (Zazueta & Garcia, 2021). In addition, some elements may be transferred to another stage of the adaptive cycle but others may remain in the previous stage. In this case, it will be difficult to measure the change in system and transfer it to the new phase of the adaptive cycle. For these conditions, we propose a threshold of concern for managing system change. The threshold of concern has been used by various people in their research (Bouchet & et al, 2019). Concern thresholds are used to assess resource dynamics, connections, and adaptive capacity at different stages. The threshold of concern is used when there is a change in the elements in a region and the time and amount of change can not be accurately measured. The threshold of concern is the capacity at which the maximum quantitative and qualitative change of elements for each stage is considered up to 25%, after which the change reaches its tipping point and the stage change occurs.

The threshold of concern in the connectedness dimension is the maximum capacity at which up to 25% of the elements of each system communicate bilaterally or multilaterally with elements outside the system. If more than 25% of the system elements are connected outside the system, the system is transferred from one stage to the next of the adaptive cycle. In the adaptive cycle, the duration of quantitative and qualitative change of elements depends on the degree of resilience of the elements and the system (Ajjur & Baalousha, 2020). The threshold of concern in the flexibility dimension is the reverse point of connectedness. The closer the cycle is to the connectedness, the less resilience the capacity is (Figure 3). At each stage of the adaptive cycle, if the flexibility of each element is reduced to 25% of their total capacity for adaptation, resistance, and self-regulation, the likelihood of change is greater. This change reaches 50% in the second stage of the adaptive cycle. Because the amount of quantitative and qualitative change of elements increases during the cycles, it causes more fragility to the system and increases the speed of change.

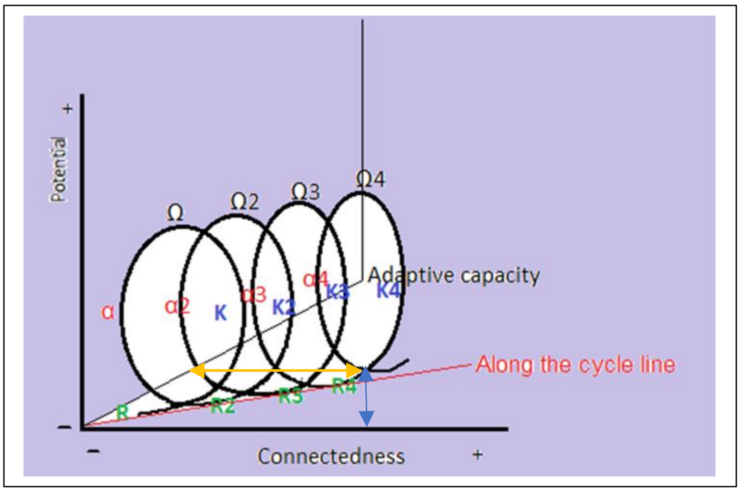

Figure 3. Adaptive groundwater cycle concerning resilience line and connectedness

Adaptive cycle line distance with connectedness axis Adaptive cycle line distance with resilience axis

Seventh: Determining the tipping point of each element is also important in the adaptive cycle to evaluate the dynamics. The tipping point probably cannot be used in the stages of the adaptive cycle because the tipping point is where the element changes completely, and this will probably be the destruction or complete change of the element. Thus, a series of repetitions of the threshold of concern moves the element to the peak point and the system reaches the stage of reorganization. At that time, the system is no longer the previous system and a new system has been formed. In other words, the stage of exploitation (R2), protection (K2), liberation (Ω2), and reorganization (α2) are formed and a new cycle is created in which the elements will probably be created with a new function (Figure. 3).

5. Discussion and Conclusion

The purpose of this paper provides a framework for assessing the dynamics of the groundwater system. According to the review of sources in this regard, little or no studies have been done. In this framework, we defined SES for groundwater and constructed its components. We also defined the SES framework based on the adaptive cycle theory and answered the question: How do the elements of the groundwater system change at different stages of the adaptive cycle and cause the system to move from one stage to another?

In this paper, based on the SES literature, we identify three subsystems of the aquifer, the natural environment, and the human community, and explain how they change in the process of exploitation, conservation, liberation, and reorganization using the concept of potential, connectedness, and adaptive capacity. And we showed that connections and flexibility are very important in system stability and their relationships are inverse in the cycle. The results of the study show that the model presented in this research is compatible with the comparative models of Holling & Gunderson (2002), Thapa & et al (2016) Daedlow & et al (2011).

As Walkeret et al (2004) and Adobor (2020) showed that the intervention and response of the groundwater system is not consistent in terms of time and geography and there is a need for a study in this field that this research can cover that gap.

Given the various issues regarding water in different geographical areas, this paper can be useful in assessing the dynamics of the groundwater system for proper management and timely action to protect water and aquifer services. It also helps to develop the concept of SES. The research work that can contribute to the ACSES framework is empirical research in this framework, evaluating water management based on the dynamics of the groundwater system, as well as evaluating and determining the capacities of the elements of each system.

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Authors′ contributions

The authors equally contributed to the preparation of this article.

Conflict of interest

The authors declare no conflict of interest.

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Original Article

ارائه چارچوب مفهومی ارزیابی پویایی سیستم آب زیرزمینی با ترکیب تئوری چرخه تطبیقی و SES انعطاف پذیر

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چکیده مبسوط

۱. مقدمه

چرخه تطبیقی حرکت سیستم را در سه بعد پتانسیل، اتصال و انعطاف پذیری در چهار مرحله: بهره‌برداری، حفاظت، انتشار، و سازمان‌دهی مجدد ارزیابی می کند. در مرحله بهره برداری سیستم در حالت رشد سریع قرار دارد. در مرحله حفاظت (انباشتگی منابع و روابط)، انعطاف پذیری سیستم کاهش می یابد. در فاز رهاسازی ارتباط بین اجزای مختلف سیستم ضعیف می‌شود و توانایی تنظیم و کنترل سیستم کاهش می‌یابد که باعث عدم اطمینان سیستم می‌شود، در مرحله سازماندهی مجدد، عدم قطعیت ناشی از فاز رهاسازی به تنظیم مجدد مواد کمک می کند. حرکت سیستم از فاز بهره برداری به فاز حفاظت منجر به افزایش منابع و اتصالات می شود اما انعطاف پذیری کاهش می یابد زیرا ارتباط زیاد باعث آبشاری شدن اختلالات می گردد. در مرحله رهاسازی ازادسازی منابع و پتانسیل انباشته شده اتفاق می افتد و منجر به گذار از نقطه اوج در سیستم می شود.

۲. مبانی نظری تحقیق

چرخه تطبیقی توسط هللینگ (۱۹۸۶) مطرح شد. این چرخه در یک فضای سه بعدی پتانسیل، اتصال و انعطاف پذیری عمل می کند که در مطالعات مختلف این سه بعدی مورد توجه قرار گرفته است. در چرخه تطبیقی بعده پتانسیل به ظرفیت سیستم در انتخاب گزینه ها برای پایداری در برابر تغییر اشاره دارد هرچه پتانسیل سیستم بالاتر باشد ظرفیت تغییر آن به حداقل می رسد ولی در نهایت تغییر یافته و به مرحله بعدی چرخه منتقل می شود.

بعد اتصال در چرخه تطبیقی به شبکه روابط عناصر در درون سیستم و بیرون سیستم اشاره دارد هر چه میزان اتصال و پیوستگی عناصر سیستم با عناصر خارج از سیستم بیشتر باشد ظرفیت تغییر پذیری سیستم را بالا می‌برد زیرا سیستم و عناصر آن در برابر آبشاری است اختلالات قرار می گیرد انعطاف پذیری سیستم را تضعیف می‌کند. بعد انعطاف پذیری سیستم نیز ظرفیت پایداری سیستم را در برابر تغییر نشان می دهد. انعطاف پذیری شامل مولفه های سازگاری، خود تنظیمی و مقاومت است. هر چه میزان سازگاری، مقاومت و خودتنظیمی عناصر سیستم بالاتر باشد ظرفیت تغییر پذیری سیستم کاهش پیدا می‌کند.

۳. روش تحقیق

در این تحقیق ابتدا مدلهای SES و چرخه تطبیقی بازخوانی گردید و سپس براساس کانکشنها و شاخصهای آب زیر زمینی مدل جدید ارائه گردید. شاخصهای چرخه تطبیقی عبارت‌اند از: منابع و ظرفیت سیستم راهنمای بسیار خوبی برای ارزیابی پویایی سیستم در برابر متغیرهای کند شوری، آلودگی، حجم آب و تقاضای آب است که در مجموع عوامل موثر در تغییر خدمات آب(آب سالم و کافی) تعریف می شود. اما در انتخاب شاخصها بر مبنای منابع برای ارزیابی پویای سیستم اب زیرزمینی در چرخه تطبیقی چند مسئله مهم می تواند وجود داشته باشد:۱ – نوع شاخص که بتوان میزان تاثیر آن را در پویایی تعیین کرد ۲- جمع آوری داده و اطلاعات برای شاخصها، ۳- زمان تغییر مقادیر شاخص و ۴- مکان تغییر مقادیر شاخص.

۴. یافته‌های تحقیق

ویژگی چارچوب ارزیابی پویایی چرخه تطبیقی سیستم اکولوژیکی-اجتماعی (ACSES) آب زیرزمینی به شکل زیر است. اول: در این مدل SES به سه زیر سیستم آبخوان AS، زیرسیستم محیط طبیعی ES و زیر سیستم جامعه(SoS) تقسیم شده است، دوم: چرخه تطبیقی این سه زیر سیستم در چهار فرایند بهره برداری(R)، حفاظت(K)، رهایی (Ω) و سازماندهی مجدد(α) بر اساس تغییرات پتانسیل، اتصالات و انعطاف پذیری با شاخصهای SES آب زیرزمینی ارزیابی می شود، سوم: مقادیر شاخص

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۱. نویسنده مسئول:
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در بازه صفر تا ۱۰۰ درصد قرار دارند. براساس تقسیم یک چرخه(احتمالا چرخه کامل) به چهار ربع، هر ربع ۲۵ درصد کل چرخه را شامل می شود و تغییرات در کل سیستم در هر ربع به اندازه ۲۵ درصد خواهد بود. بنابراین اگر فاصله صفر تا ۱۰۰ را به چهار قسمت در چرخه تقسیم کنیم آن وقت میزان تغییر متغیرهای تا ۲۵ درصد ظرفیت تغییر را نشان خواهد داد چهارم: نکته مهمی که در اینجا وجود دارد برای برخی از شاخصها ظرفیت صفر تا ۱۰۰ را نمی توان تعیین نمود. به همین جهت ما ظرفیت پایین را کمتر ۲۵ درصد و ظرفیت بالا را بین ۲۵ تا ۱۰۰ در نظر گرفتیم. پنجم: در سیستم دو نوع پویایی می تواند وجود داشته باشد: ۱- تغییر در تعداد عناصر سیستم، احتمالا عناصر سیستم در فرایند فعل انفعالات بر اثر اتصالات کاملا تغییر پیدا کند و به مرحله بعدی چرخه تطبیقی انتقال یابد و ۲- ممکن است ظرفیت یا پتانسیل عنصر کم یا زیاد شود. ششم: در تغییر و اندازه گیری تغییر عناصر سیستم اب زیر زمینی یک نکته مهمی وجود دارد: همه ظرفیت کیفی و کمی سیستم در تمام عناصر یکسان و در یک زمان و یا مکان تغییر پیدا نمی کند. هفتم: تعیین نقطه اوج هر عنصر

نیز در چرخه تطبیقی برای ارزیابی پویایی دارای اهمیت است. نقطه اوج را احتمالا نمی توان در مراحل چرخه تطبیقی بکار برد زیرا نقطه اوج جایی است که عنصر تغییر کامل پیدا می کند و این احتمالا نابودی و یا تغییر کامل عنصر خواهد بود.

۵. بحث و نتیجه گیری

با توجه به مسائل مختلف در خصوص آب در مناطق مختلف جغرافیایی، این نوشتار می تواند در ارزیابی پویایی سیستم آب زیر زمینی برای مدیریت صحیح و انجام اقدامات به موقع در راستای حفاظت از خدمات اب و آبخوان در مناطق مختلف مفید باشد. همچنین در توسعه مفهوم SES کمک نماید. کارهای تحقیقی که می تواند برای چارچوب ACSES کمک کند، تحقیقات تجربی در این چارچوب، ارزیابی مدیریت آب براساس پویایی سیستم اب زیر زمینی و همچنین ارزیابی و تعیین ظرفیتهای عناصر هر سیستم است.

کلیدواژه‌ها: چرخه تطبیقی، آب‌های زیرزمینی، دینامیک سیستم، سیستم اجتماعی-اکولوژیکی، ارزیابی.

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