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Integrated Environmental Assessment of Unsustainable Exploitation and Pollution of Shared Water Resources in Transboundary Basins of Semi-arid and Arid Regions. Case Study: Tigris-Euphrates River Basin

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ABSTRACT

River basins perform the crucial role of providing water resources, especially in arid regions. Due to the nature of interconnection, human interventions and natural events will cause cumulative impacts on the downstream parts of river basins. The aim of this research is to identify and evaluate the impacts of interventions and changes occurring in the upstream of the Tigris-Euphrates River Basin on the downstream parts and provide strategies to reduce and control those effects. To achieve this purpose, multi-scaled investigation of the changes and dynamics of the land cover was performed and the causes and consequences of these changes were investigated using the Driving force-Pressure-Sate-Impact-Response (DPSIR) framework. The results displayed an increase in the area of artificial lakes and agricultural lands and a decline in the area of rangelands and natural wetlands, especially in the downstream of the basin. The state of the ecosystem was under the influence of Driving forces such as population and industrial growth and political competitions of the littoral states, which led to pressure on the limited water resources and development of water management and control projects. The overall trends of changes in the state of the environment had created impacts on the ecosystem and communities that required urgent responses from the riparian countries. Finally, to foster water cooperation instead of non-constructive completions in this region, a framework was developed with an emphasis on creating a union of riparian countries and using their scientific potentials to provide effective and impartial solutions.

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INTRODUCTION

Freshwater is considered as the primary factor in shaping all forms of life as well as human civilization on the planet. However, this life-giving substance is not distributed equally, and some regions suffer more from water scarcity (Gleick, 1993). In addition, parameters such as population growth and economic development have also increased the importance of access to safe, sufficient, and reliable water sources (Kucukmehmetoglu, 2012).

River basins are integrated natural units that perform the crucial service of providing water resources. Such inherent interconnectedness leads to the fact that water withdrawal and over exploitation can generate devastating impacts in the downstream areas of basins. The complexity and importance of these impacts are even more severe in transboundary watersheds where

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the downstream areas highly depend on the water flow from the upstream region located in neighboring states (Munia, et al., 2018) and the governments show a strong desire and tendency to restrict the international waters for themselves (Asaad, 2023). In the case of transboundary basins located in arid and semi-arid regions, access and control of the limited water resources is considered as one of the crucial factors in shaping the political relations between the neighboring countries. In such places which are controlled by different governments and actors (Eamen, et al., 2020) with divergent priorities (Ly, et al., 2022), allocating the limited water resources efficiently among competing demands is a highly complex issue.

Water performs a very substantial role in human security, which in recent years has been significantly undermined by the increasing severity of global water crises (Ismael, et al., 2020). The Middle East region is currently confronting one of the most significant crises related to the lack of water resources throughout its history. The occurrence of prolonged and intensifying droughts in this region (Rateb, et al., 2021) and the unsustainable exploitation of the limited water resources followed by the riparian countries (UN-ESCWA & BGR, 2013) have created intensified water stress in this region (World Bank, 2018).

Tigris-Euphrates River Basin (TERB) is a transboundary watershed located in the Middle East that provides the necessary water for the livelihood of 60 million people in addition to agricultural, industrial and energy production needs of the littoral states (Al-Ansari, 2016). Yet, this important basin is currently experiencing damages related to unsustainable water exploitation (Montazeri, et al., 2023). The downstream part of this basin is facing a serious water-stress due to natural and human induced pressure on the limited water resources, which makes this region vulnerable to water related conflicts (Rateb, et al., 2021). It is not surprising that the littoral countries have long been trying to control and manage the limited water resources of this region, especially through constructing large dams. In the shadow of lack of cooperation, these so called techno-political structures can serve to uphold the political ambitions (Tinti, 2023), which result in reduction of the river flow and political tensions and disputes which have become worsened in recent years (Dezfuli, et al., 2022). Among the most noteworthy examples are the completion of the major dams of Ataturk in 1990 on the Euphrates River (Cetin, et al., 2000) and Ilisu in 2019 on the Tigris River (Al-Madhhach, et al., 2020), which changed the water flow regime in the downstream (Dezfuli, et al., 2022) and the consequent water and energy crisis led to the violent protests in Iraq (Schulman, 2022).

Various studies have focused on the Tigris-Euphrates River Basin (TERB) status and environmental issues. The climatic condition with an emphasis on changes in precipitation patterns and droughts is one of the research topics worth mentioning. Bozkurt and Lutfi Sen (2013) examined the influential factors on climate change in this basin. Rateb et al. (2021) have examined the hydrological extremes in the basin and concluded that prolonged droughts and associated water scarcity are undeniable facts affecting the future of this region that need to be considered by the littoral states. The dust storm phenomenon is another critical issue in this region that has received attention from many researchers. Al-Ameri et al. (2019) investigated the occurrence of dust events in central Iraq and their relationship with climatic conditions and identified wind speed as the most influential factor in this issue. Darvishi et al. (2020) identified the location of dust storm formation susceptible areas. Hamidi (2020) highlights the importance of water resource management in controlling dust storm events in this basin. Salehi et al. (2021) uncovered that these particles could even cross the Zagros Mountains and reach the Northwest Iran Plateau. They highlighted the most probable mechanism of dust transfer from Mesopotamia to Iran.

Upstream activities and land use changes in the area have also been a subject of investigation. Modelling the hydro-climatic implications of the land use and land cover changes in the upper segment of the Tigris-Euphrates basin on the water budget Yilmaz, et al. (2019) concluded that the changes in the land use and land cover in upstream of Tigris-Euphrates Basin could produce transboundary negative impacts on the water budget of the region. According to Montazeri et al. (2023) water allocation activities are one of the influential factors that are capable to adversely affect the water and soil resources in downstream parts of this basin.

Water crises and related conflicts and political challenges have captured the attention of many researchers (Freeman, 2007; Al-Muqdadi, 2019; Tinti, 2023). Kibaroglu and Maden (2014) investigated the water crises causes in the Euphrates-Tigris river basin through studying the hydro-political relations between the littoral countries and concluded that the water related developmental projects followed by the states crises were one of the reasons to fuel the crises. Rashid et al. (2022) believed that the water management projects followed by upstream countries in Tigris-Euphrates River Basin have violated the international low of equitable access to water and caused reduction in Iraqi water resources. Shahbaznezhadfard and Yousefi (2022) studied the strategic water conflict in Tigris-Euphrates basin by a developed dynamics-based model and concluded that the current trend of conflict would end in a destructive future.

Some researchers focused on providing water management solutions. Examining the upper part of the Euphrates basin as the case study, Muratoglu, et al. (2022) emphasized the importance of water footprint as an accounting framework for water resource management of basins located in semi-arid regions. They believe that agricultural sector is responsible for high water footprint in the region, and water footprint accounting could be a useful tool in water management of large scale transboundary basins of semi-arid areas.

The complication of the situation and the probable solutions to overcome the environmental problems of transboundary river basins have captured the attention of many researchers. Researchers have investigated the negative effects of the activities carried out in the upstream parts of international watersheds (Mubako, et al., 2018). Examining four transboundary basins with different political situations, Skoulikaris and Zafirakou (2019) emphasized that providing reliable data and river basin management schemes could help prevent past conflicts over water quantity and quality. Also, according to Ly, et al. (2022) as a result of the growing demand for energy, the land use changes related to hydropower development has taken place under extreme climatic conditions in arid transboundary basins and integrated water resource management under cooperative frameworks can help reduce their negative impacts. Yuan, et al. (2022) believe that water and environmental collaborations and coalitions are vital prerequisite for maintaining transboundary river basins as a system.

The review of the literature showed that in most cases, only one or few aspects of the environmental crises of the Tigris-Euphrates River Basin have been investigated and the complex relationship between environmental and human factors and political decisions in creating such an unsustainable situation have been unaddressed. The present study aims to conduct an Integrated Environmental Assessment through a multi-scale land use changes investigation combined with the Driving force-Pressure-State-Impact-Response model as a comprehensive causal framework to evaluate and demonstrate the causes and consequences of environmental crisis resulting from unsustainable water withdrawal and allocation by the TERB littoral states and to propose solutions.

MATERIALS AND METHODS

The Tigris-Euphrates River Basin (TERB) is considered as one of the most important transboundary basins in the Middle East from the natural, historical, socioeconomic, and political aspects. The Euphrates River originates from Turkey and flows through Syria to Iraq. In the case of the Tigris, the tributaries start from Turkey, and the course is shared between Iran and Iraq. Although the Tigris and Euphrates rivers are separated for most of their course, they join at the end of the basin into the Shatt Al Arab (Arvandrood) river. Therefore, they technically form one basin. Except for the mountainous areas, the climatic condition in most parts of this basin is classified as semi-arid to arid, and the amount of annual rainfall in some regions is even less than 50 mm (Rateb, et al., 2021).

This basin demonstrates a special geographical complexity; countries have territories in the twin rivers' upstream, middle, and downstream parts (Table 1). The location of the countries in the basin has created a superiority and dominance for the upstream states and the vulnerability of the downstream countries (Figure 1).

One of the most influencing factors in water availability of this region is the construction of water management infrastructures by the riparian states and the number of dams show a

Table 1. Statistical features of Euphrates-Tigris Basin (UN-ESCWA & BGR, 2013; UNEP, 2001)

Characteristics		**Tigris**	**Euphrates**
Total Area		221,000 km2	440,000 km2
River Length		1,800 km	2,786 km
Mean Annual Flow Volume		26 BCM (at Kut)	~25 BCM (after damming)
Riparian Countries		Iran, Iraq, Syria, Turkey	Iraq, Syria, Turkey
Main dams		14 (max. storage capacity 116.5 BCM)	>60 (max. storage capacity 144 BCM)
Main Tributaries		Feesh Khabour River, Greater Zab River, Lesser Zab River, Diyala River	Sajur River Jallab/Balikh River Khabour River
Area in Riparian Countries (km^2)	Turkey	53052	121787
	Syria	948	95405
	Iran	175386	-
	Iraq	142175	282533
	Saudi Arabia	-	77090

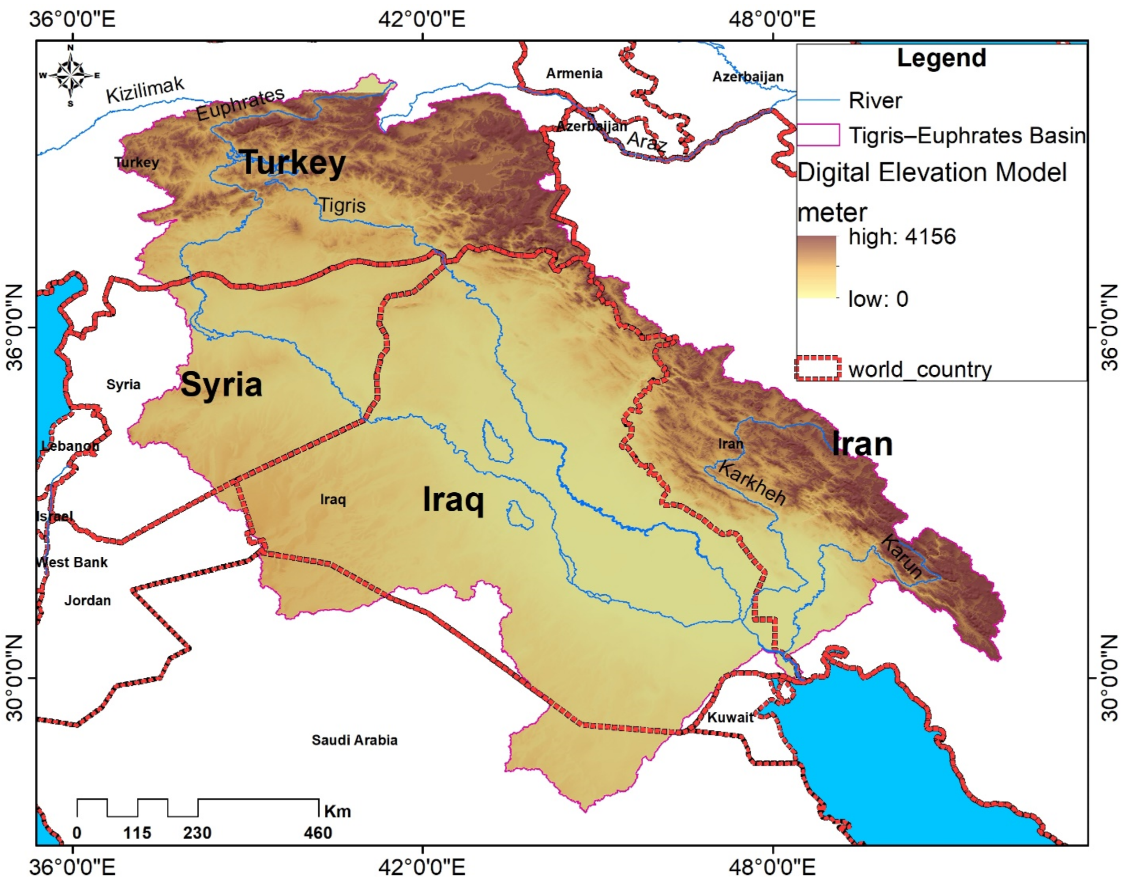

Fig. 1. Location of the Study Area

considerable increase in the region since the year 2000 (Rateb, et al., 2021). The Southeast Anatolia Project (Güneydoğu Anadolu Projesi, GAP), is one of the largest and most comprehensive developmental plans in this region (Bilgen, 2018), focusing on extracting water from the Tigris and Euphrates rivers to irrigate vast agricultural lands and generate hydroelectric power. Covering an area of more than 75,000 square kilometers (9.7% of Turkey's territory) and containing 22 different dams (Altinbilek & Tortajada, 2012); this mega project aims to manage the water resources of the Tigris and Euphrates rivers in order to produce electricity, irrigation and regional development of Southeast of Turkey and sets out to increase the area of irrigated agricultural land several times in the upstream segment of TERB (Yilmaz, et al., 2019).

These developments are taking place in this arid region, despite the fact that Syria and Iraq have already been suffering from the decline in the amount of their water resources (Al-Muqdadi, 2019), which has already brought about implications on their natural and socio-economic situation. About 80 percent or even more of the population of Iraq, Syria and Iran currently live in areas with high and very high degrees of water stress, while the global average of this index is about 40 percent (World Bank, 2018). In addition to reducing the available water, the gradual decrease in the quality of water resources is considered as a key factor in increasing water stress in the region (Mueller, et al., 2021).

- Water pollution and reduced quality

It can be reasonably concluded that the extraction of water resources in the upstream and the hot and dry climate of the region, along with the changes in land use, leads to decreased water quality in the downstream parts and increasing the water salinity of the natural ecosystems (Bijnens, 2021). A degraded water quality has been reported from Tigris river in Basrah Province in southern part of Iraq (Qurnah) and also in Aziziyah station (Chabuk, et al., 2020). Increased salinity is a problem that both Tigris and Euphrates rivers are facing in the downstream section after crossing Iraqi border, which for example in downstream of Kufa city, can reach to 1500ppm (Al-Ansari, et al., 2019).

Integrated Environmental Assessment is a holistic evaluation of environmental and socio-economic aspects that takes into account different dimensions of the issue. This integration can happen about disciplines, processes, stakeholders, scale of investigation, and side effects of management strategies (Kelly, et al., 2013).

The vast area of the TERB and the complexity of the current water-related environmental issues made it necessary to apply a comprehensive and multi-dimensional method for performing an integrated assessment of the environmental and socio-economic impacts related to water shortage. Therefore, in this study the Driving force-Pressure-State-Impact-Response (DPSIR) framework was applied for an integrated and strategic-level environmental assessment through interpreting the causes and possible consequences of the environmental changes and providing management solutions.

Recognized as a holistic tool capable of clarifying and developing causal links and connections between different aspects of a problem (Quevedo, et al., 2023), the DPSIR framework is able to bridge scientific aspects and indicators and policy through presenting strategic responses to the policy makers (Tscherning, et al., 2012). This framework is based on a causal chain that starts with Driving forces (typically related to political and socio-economic factors) that leads to excessive Pressures over natural resources and pollution production. The continuation of this trend ends in changes in the environmental State (physical, chemical, and biological environmental parameters) and results in negative Impacts on ecosystem function and human health. Eventually, such adverse conditions cause Responses in the forms of legislation or mitigation measures at local, regional, or international scales (Kristensen, 2004) (Figure 2).

To develop the DPSIR framework, it was necessary to obtain and organize the information related to the environmental, economic, socio-cultural, and political aspects of the study area

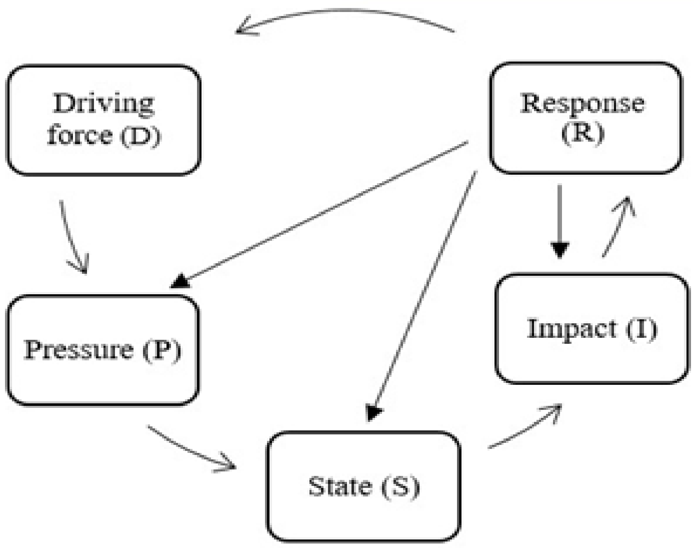

Fig. 2. Driving Force-Pressure-State-Impact-Response Causal Framework (Kristensen, 2004)

in the five components of the model. Therefore, the "State" of the ecosystem was first analyzed and the probable causes (Pressure and Driving force) and consequences (Impacts) were later derived and developed into the model

-State

To demonstrate the "State" of the ecosystem in TERB, the NDVI index was used to identify the changes in the area of different land cover types that presented the status of the ecosystem i.e. water bodies, tree covers and vegetation. To examine the changes more precisely, a multi-scale land cover analysis was conducted at three different spatial scales in which the whole basin was analyzed at the macro level, parts of the main countries located inside the basin were examined at the mesoscale and the areas with higher changes in the upstream, midstream, and downstream were investigated at the microscale.

Because one of the primary purposes of this research was to identify the ecosystem changes and their possible causes over time, more than one timescale should have been analyzed. To achieve this goal, initially the available information and images of the region were in different years were carefully studied. The image of 2021 was selected to show the conditions of the area after the operation of large-scale water storage and control projects in the upstream section of the basin. In addition, to better examine and achieve a scale to compare the changes, two images before this date with almost ten-year intervals (2002 and 2011) were also selected.

-Driving forces and Pressure

In order to continue the evaluation process, after preparing the land cover maps in different spatio-temporal scales, it was necessary to investigate the primary and secondary causes of those changes. Thus, in-depth literature review was elaborated to construct the "Driving force" and "Pressure" sections of the DPSIR causal chain.

-Impact

The "Impacts" were partly concluded by further analysis of the ecosystem degradations as the potential consequences of the changes in the "State" and the causal relationships discovered through the literature review.

- *Responses*

After finalizing and structuring the model, solutions and strategies were presented based on the components of the DPSIR causal framework. The purpose of these mitigation measures was to propose solutions to reduce the destructive effects on the natural and economic-social-cultural environment in the region. The proposed responses and strategies addressed all of the components of the DPSIR framework.

The different stages of conducting this research are demonstrated in Figure 3.

RESULTS & DISCUSSION

Figure 4 shows the numerical values of the land cover types of the selected land cover

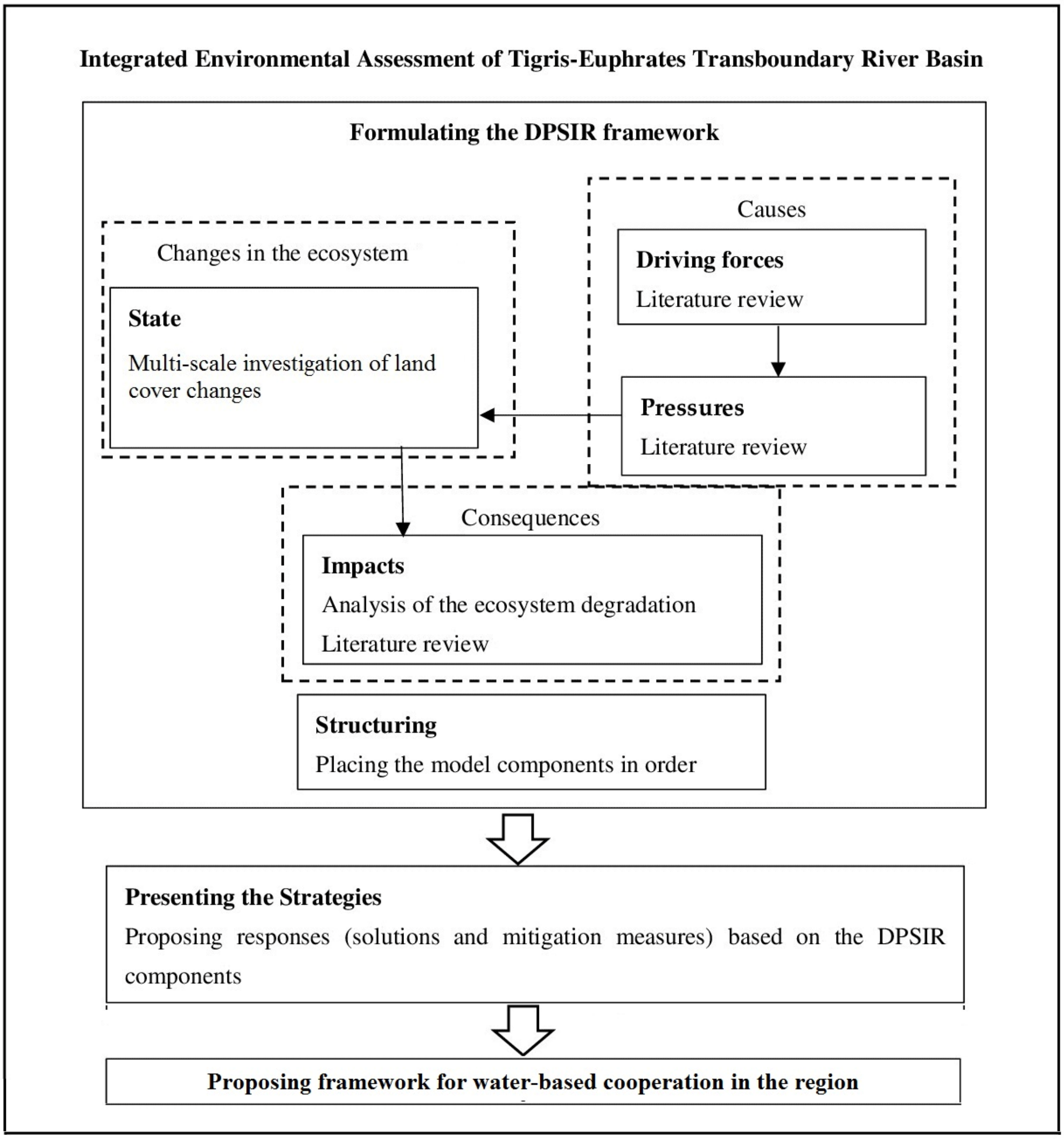

Fig. 3. The flow diagram of the research process

types for the period of investigation (2002, 2011 and 2021). According to the results, the trend of changes in the selected land covers in 2002-2011 is different from 2011-2021. In the first decade, water bodies (including the artificial lakes) show a slight increase; however, in the second time scale, this change is way more and reaches 27%. Moreover, it is witnessed that the green land cover in the second decade has considerably decreased. Also the land cover maps are presented in Figures 6, 7 and 8.

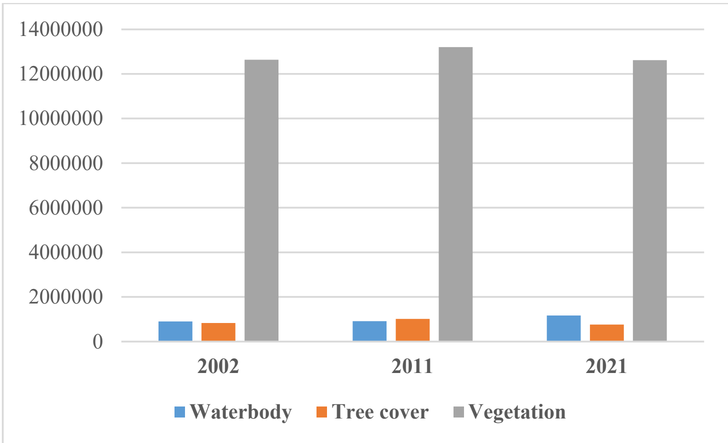

Fig. 4. The area of different land cover types in the whole basin (macroscale) in 2002, 2011 and 2021

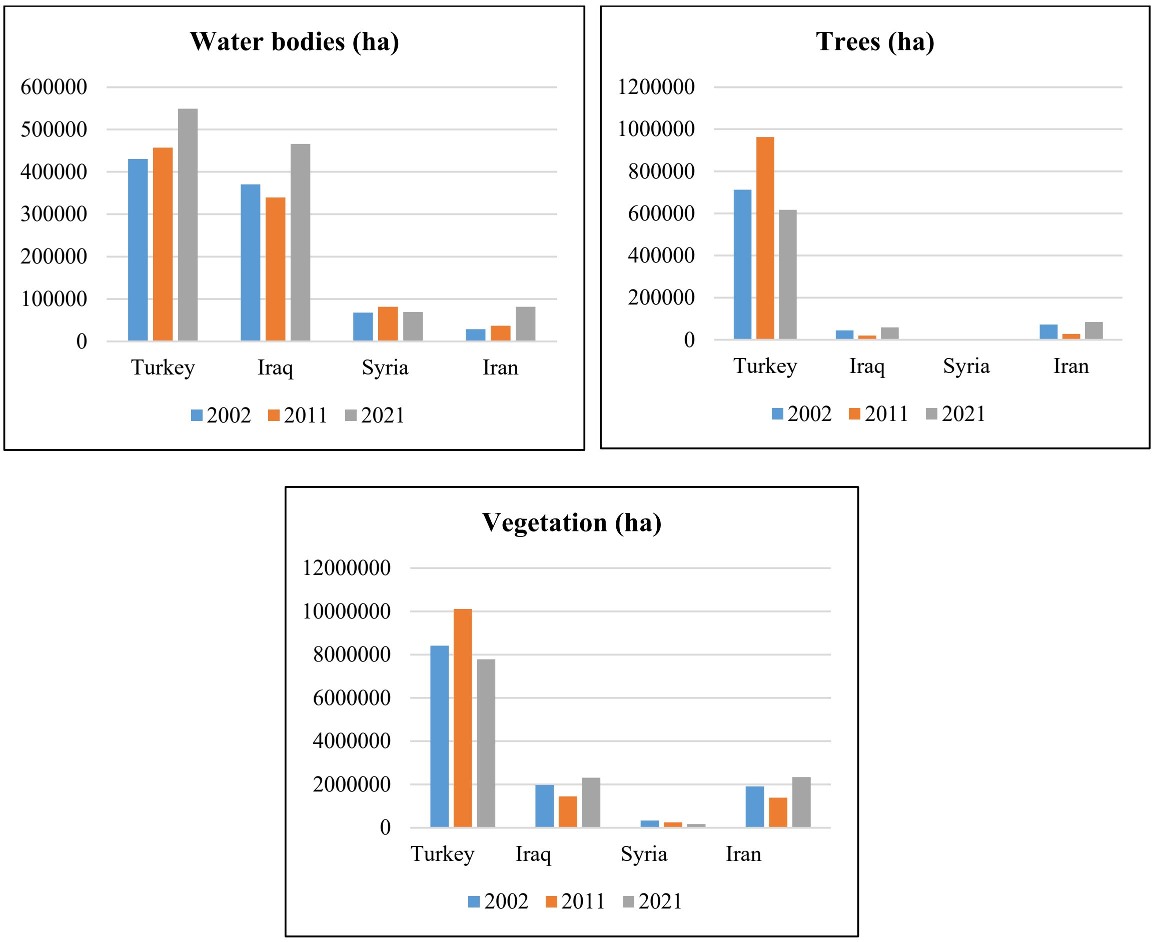

Fig. 5. Changes in the area of different land cover types of TERB based on the countries (only for the areas inside the basin) in 2002, 2011 and 2021

In Figure 5, the changes of the area of the selected land cover types in the period of investigation are demonstrated for the main countries of the basin. As it can be seen, Turkey possesses the largest amount of surface water resources in the basin, and Iraq ranks second in this regard. In both cases, the area of water bodies has increased in the period of investigation. Turkey also is a richer country in terms of the amount of tree and vegetation covers. Iran and

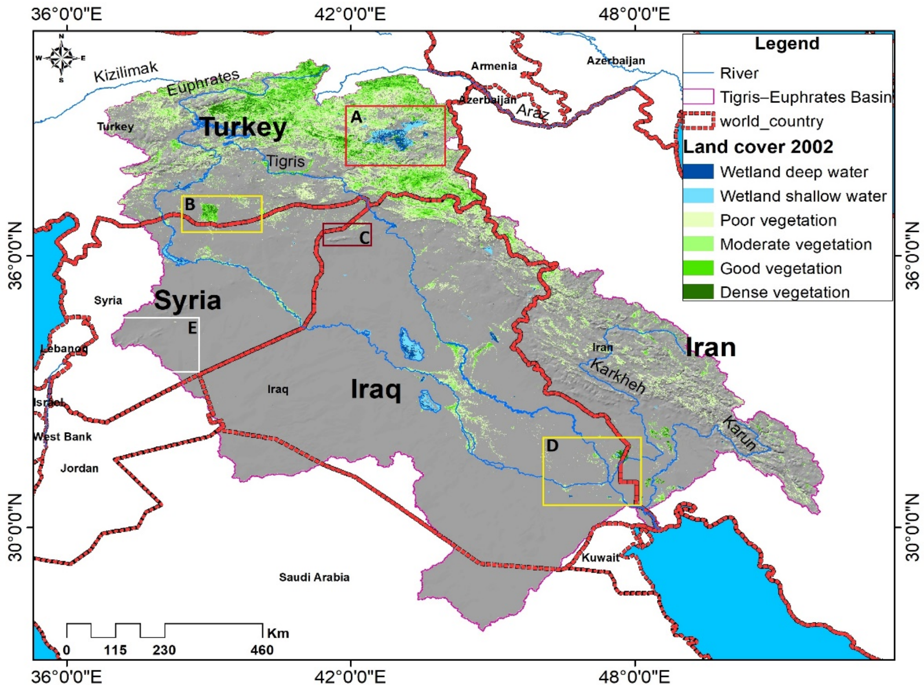

Fig. 6. Land cover state of TERB in 2002

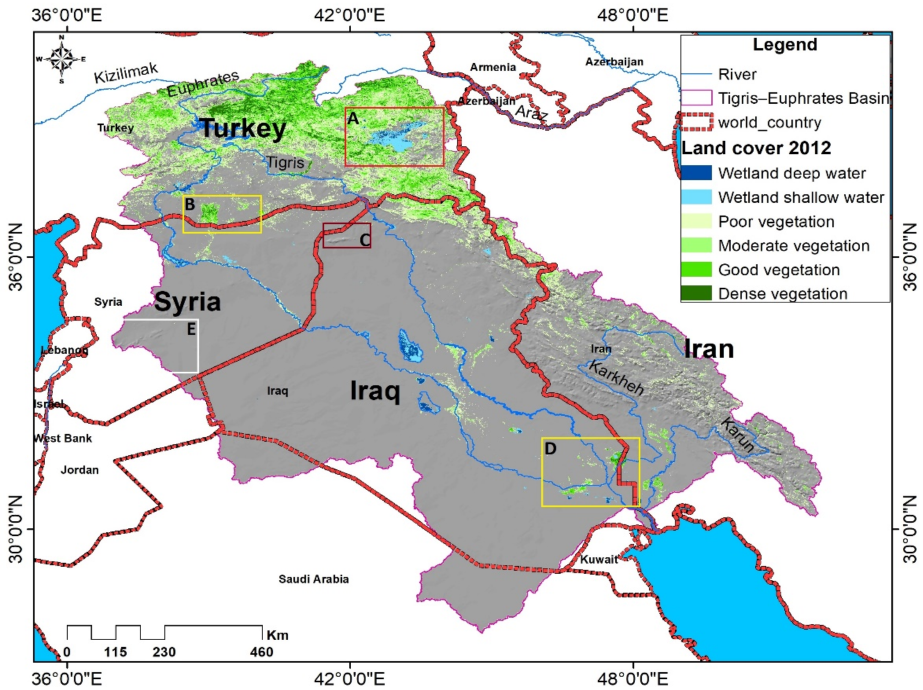

Fig. 7. Land cover state of TERB in 2012

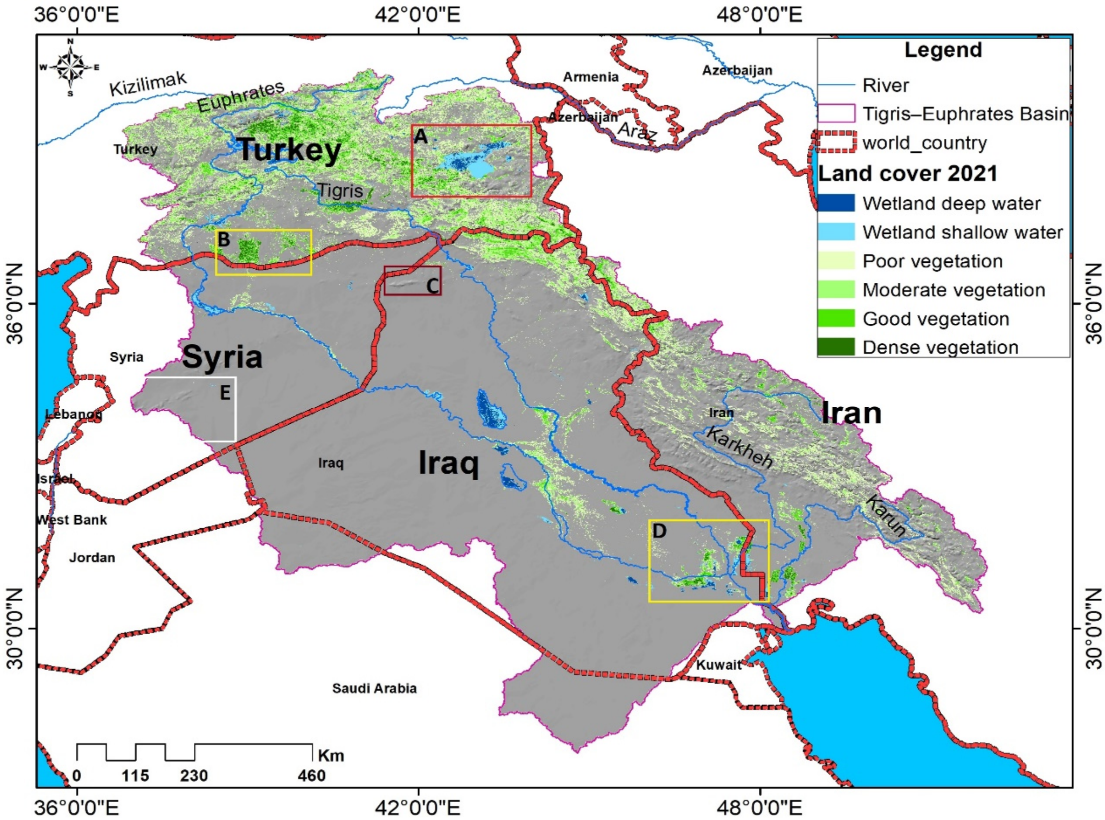

Fig. 8. Land cover state of TERB in 2021

Iraq are almost similar in terms of their share of these two types of cover in the basin while Syria has a very small share of vegetation in this basin.

Figure 6 demonstrates the changes in selected parts of TERB from upstream, middle and downstream of the basin. In the first section, the areas around Lake Van (A) are demonstrated, for which the status of the NDVI index shows a significant drop. The reason for this phenomenon can be climate change and decreased rainfall in the region, as well as excessive livestock grazing and unsustainable exploitation of the pastures.

The second section shows the downstream areas of the Atatürk Dam and the lands around the Turkey-Syria border (B). This region has undergone significant growth and development of horticulture and irrigated agriculture between the cities of Ayn al-Arab (Kobani) and Nusaybin. Before the construction of the Atatürk Dam and water transfer through the canal for agriculture expansion, there existed limited agricultural lands in this area.

In the third section, the region of Mount Sinjar (C) and the border areas between Iraq and Syria are shown, in which the Doqirat Dam on the Al-Hasakah River in the west of Mount Sinjar exists. Even though the NDVI index should have increased as a result of the microclimate change caused by this dam and its effect on the natural vegetation cover, this index has declined.

The fourth section of the figure belongs to the Nasiriyah region (D). This area generally has many wetlands surrounded by agricultural lands. With the construction of new dams in this region and the implementation of agricultural expansion plans by Iraq, the NDVI index has grown throughout the investigation time. Also, recently, wetlands restoration plans have been implemented in this area.

Finally, in the fifth section, the southwestern region of the Euphrates basin (E) is shown where the city of Damascus is located in the west of this area. This place is a desert with the least vegetation and its changes can only be limited to the fluctuations in the moisture condition on a very small scale. The NDVI index shows very small changes in this area.

In general, a considerable portion of the Tigris-Euphrates River Basin (about 50%) comprises barren lands without vegetation, most of which are located in Syria, west, and southwest of Iraq, Eastern Jordan, and Northern Saudi Arabia.

Also, about 21% of the area of the TERB, mostly located in the north, east, and northeast of the region (Zagros Mountains), is rangeland. With about 17% of coverage, irrigated agricultural lands rank third in terms of land cover in this basin after rangelands. This figure shows that despite being located in an arid region, irrigated agriculture in this area forms a relatively large portion of land covers. Most of these farms have been developed in recent years, relying on dams and water transfer infrastructures.

The drying of wetlands and natural lakes is one of the important phenomena in this region. The reduction of surface and groundwater in TERB has significantly affected these fragile ecosystems, which are mainly located at the end of the watersheds. Among these cases, the drying out of the wetlands located in Mesopotamia, including the Qarnah and Al-Hammar wetlands and the Hawizeh Marshes, is worth mentioning.

One of the most influential factors affecting the water demands in this region is the population size and growth. The most significant number of the total population of about 65 million people living in this area belongs to Iraq (about 44 %), followed by Iran (19.5 %), Turkey (18 %) and Syria (18 %). In addition to possessing the largest share of the basin's population, Iraq also has the highest population growth rate (2.93%) among other littoral states (GEF TWAP, 2020). Water production capacity in the TERB, which has been dramatically impacted by the anthropogenic causes (Montazeri, et al., 2023) and climate change (Adamo, et al., 2020) especially in the downstream parts is limited and may not meet the needs of the growing population of this region (Issa, et al., 2014).

-Agricultural development

The agricultural sector development is followed by all of the countries of TERB. In this case, planting high water demanding crops, especially cotton, is believed to have the potential to create water scarcity (Saysel, et al., 2002).

-Industrial development

Turkey is in the top 10 most important exporters of textiles in the world. The GAP area is assumed to carry out a considerable role in the increase of the country's cotton production (a high water demanding crop) and it is estimated that the production area for this crop will reach one million ha after the completion of this project (Basal, et al., 2019). Also hydropower industry development, which is one of the primary purposes of constructing numerous dams upstream of the basin, is pursued by the TERB countries.

The oil fields in the southern part of this basin (Iran and Iraq) are considered to be among the most critical factors of environmental pollution (Odthar & Salman, 2022) and especially the destruction of wetland ecosystems in the region. In addition to the destruction of water resources and the rich biodiversity, dried wetlands are one of the important sources of dust production.

-Tourism development

Tourism is an economic activity with high water needs. Turkey plays the role of a tourism hub in the region and seeks to further develop its tourism sector (Akadiri, et al., 2019).

In Iraq, pilgrimage tourism has received much more attention in recent years and millions of people travel to this country, especially during the Day of Arbaeen of Imam Hussain (AS) days, to visit religious places (Rokhbin, et al., 2020).

-Political instability

The history of conflicts and political instability are among the distinctive features of the Middle East region. The most significant of these incidents was the war between Iran and Iraq, which took eight years. The civil wars, violence, and unrest in Syria and Iraq are also significant and influential cases of political instability in this region, which has caused issues related to the shared water rights of the countries to be neglected and given less priority.

- Using water as a political leverage

Political rivalries of the TERB riparian states have caused these countries to utilize water as a political lever wherever possible and pursue ambitious development plans and policies that will eventually lead to further reduction of the water and destruction of land and environmental assets of the region (Ayboga, 2019).

PRESSURES

-Water control projects

Implementation of water resource control projects (dam construction) is considered to be one of the most important pressures in the region on the limited water resources. Unfortunately, there has been a competition of construction of large-scale water controlling infrastructures by the riparian countries since 1960s (Kibaroglu, 2017) disregarding the sustainability and coordination of these projects and less attention has been paid to sustainable water management which is only possible through cooperation between the countries.

- Consumption of the limited water resources

Consuming the limited water resources in the upstream section in the agricultural activities and producing crops with high water footprint are witnessed in the area (Muratoglu, et al., 2022).

-Climate change

Climate change is one of the key natural pressures on water resources and the environmental condition in the TERB region, which, even setting aside human interventions, has the potential to increase the aridity of the region as a result of decrease in rainfall and declined the natural water flow in the rivers (Bozkurt & Lutfi Sen, 2013) and increased the temperature (Adamo, et al., 2020). In the last four decades, prolonged droughts in this region have not become exceptional events but a prevailing condition, which contributed to the reduction of water resources (Rateb, et al., 2021).

State

The multi-scale analysis of the land cover changes in TERB shows the following changes in the state of the ecosystem of TERB:

- Increase in the area of artificial lakes and dams, especially in the upstream segment,
- Increase in the area of agricultural lands and gardens in the upstream segment,
- Reduction of rangelands and natural vegetation covers in the entire basin (the greatest reduction is observed in Syria),
- Reduction of natural lakes area especially in Syria and Iran,
- Reduction of the available water in the rivers downstream of the basin.

Impacts

Changes in the state of the ecosystem in TERB have led to negative impacts on the natural and human environment of the region. The most important of these effects are as follows:

- Reduction in the stream flow in the downstream part (Al-Hasani, 2021),

- Water pollution in the downstream area (Al-Ansari, et al., 2019; Chabuk, et al., 2020),
- Intensification of the water crisis and the creation of transboundary water problems for the downstream neighboring countries (Mueller, et al., 2021),
- Increasing political tensions in TERB (Kucukmehmetoglu & Geymen, 2014; Zarei, 2020),
- Soil instability and dust creation (Darvishi Boloorani, et al., 2020),
- Degradation of wetland ecosystems and their related biodiversity (Berkun, 2010),
- Migration and population displacement (Ayboga, 2019),
- Degradation or destruction of aquatic habitats and rivers (Adamo, et al., 2020),
- Loss of biodiversity and destruction of terrestrial ecosystems (Jones, et al., 2008),
- Soil erosion and loss (Berkun, 2010),
- Security threats related to the use of water as a weapon and the destruction of water infra-structure in war by militants (Jones, et al., 2008),
- Degradation or destruction of natural vegetation (Kibaroglu, 2017),
- Soil pollution and salinization, especially downstream (Berkun, 2010),
- Intensification of natural disasters such as prolonged droughts (Rateb, et al., 2021),
- Reduction of fertility and destruction of agricultural lands (Berkun, 2010),
- Submergence of settlements and displacement of population due to being in the dam reservoir (Ayboga, 2019),
- Degradation or destruction of cultural heritage (Sabri & Emin, 2010).

Structuring the model and providing Responses

Figure 9 demonstrates the structured Driving force- Pressure- State-Impact-Response framework derived from analyzing different aspects of the water scarcity crisis in TERB. The Proposed responses and strategies for Improving environmental and economic-social-cultural sustainability for each component of the DPSIR framework for the TERB region are presented in Table 2. If the responses are repetitious from the above rows of the table, only the codes are presented.

In this study, using satellite images to investigate the changes in land cover in two decades and also applying the DPSIR framework, we tried to assess and analyze the environmental impacts and consequences caused by the activities related to water resource management and allocation in the upstream segment of the TERB on the downstream segment.

The macroscale analysis of the land cover changes showed that the total area of water bodies in the basin had increased and mesoscale analysis revealed that this increase had mainly happened in Turkey, which could be as a result of the construction of large dams and artificial lakes. The findings of Ataol and Onmus (2021) confirm an increase in the area of artificial lakes whereas a notable decrease in the area of natural wetlands in this country. Additionally, due to the agricultural development policies recently followed by Iraq, the emergence of artificial water bodies to expand cultivated areas was also traceable in this country in the mesoscale.

The reduction of natural lakes area especially in Syria and Iran is witnessed in this research which is also stated by Zarei (2020). Also, similar to the findings of the present research, Balist, et al. (2022) indicated the reduction in river flows in the downstream of the basin.

The development of green land cover in the upstream part of the basin was so considerable that despite the increased aridity and the decreased water resources in downstream, the total amount of this index had increased in the whole basin. Microscale analysis showed that in particular, the area of green cover near the southern borders of Turkey with Syria shows a considerable increase. Also, it could be seen in this scale that the area of natural water bodies had decreased for which Qarnah and Al-Hammar Mesopotamian wetlands could serve as examples, which supports the work of Al-Quraishi and Kaplan (2021). Also, drying of the wetlands located on the border of Iran and Iraq was one of the important environmental degradations observed in

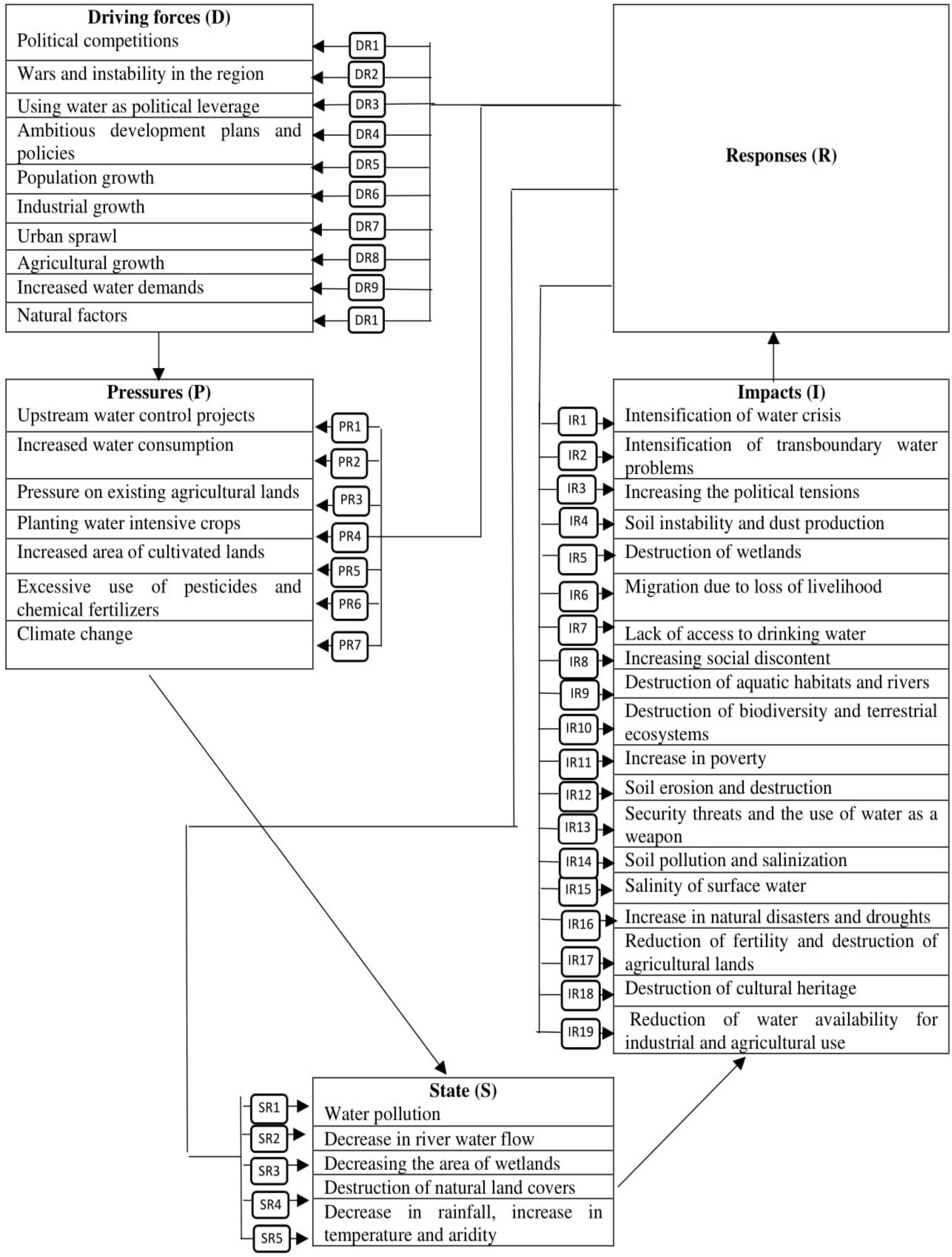

Fig. 9. Driving force- Pressure- State-Impact-Response framework developed from analyzing the water scarcity crisis in TERB

Table 2. Proposed responses and strategies for Improving environmental and economic-social-cultural sustainability for each component of the DPSIR framework for the TERB region

DPSIR Components	Code	Item	Type
Driving force (D)	DR1	Accession to the United Nations Convention on the Law of the Non-Navigational Uses of International Watercourses	Political
	DR2	Establishing a union of TERB countries to increase various multilateral cooperation, especially on water problems	Political
	DR3	Accession to bilateral and multilateral water agreements and monitoring their implementation	Political
	DR4	Preparation and implementation of Integrated River Basin Management program for TERB and its sub-basins	Supervisory
	DR5	Population management programs and reduction of population density in urban areas	Planning
	DR6	Sustainable industrial development based on low-water demanding and clean industries	Planning
	DR7	Focusing on small towns and rural development instead of large cities	Planning
	DR8	Sustainable development of agriculture with the cultivation of low-water demand crops and application of efficient irrigation methods	Planning
	DR9	DR6, DR7, DR8	Planning
	DR10	Empowering the local communities to increase their resilience to water shortage and planning for water scarcity condition.	Planning
Pressure (P)	PR1	Monitoring and preventing the construction of more large dams in the basin	Supervisory
	PR2	DR6 ،DR7،DR8	Planning
	PR3	Boosting the yield capacity of existing agricultural lands	Operational
	PR4	DR8	Planning
	PR5	PR3	Operational
	PR6	Expanding sustainable agricultural methods with minimal use of pesticides and fertilizers	Operational
	PR7	DR10	Planning
State (S)	SR1	Water treatment and desalination of seawater	Operational
	SR2	Releasing the proper flow downstream of the existing dams	Supervisory
	SR3	Providing the water requirements for wetlands	Supervisory
	SR4	Restoration of pastures, forests and natural land covers	Operational
	SR5	DR6, DR7, DR8, DR10	Planning
Impact (I)	IR1	Watershed and aquifer management, SR1	Operational
	IR2	DR1, DR2	Political
	IR3	DR1, DR2	Political
	IR4	SR2, SR3, SR4	Supervisory / Operational
	IR5	SR2 و SR3	Supervisory
	IR6	Providing stable and resilient employment and revitalizing agriculture	Operational
	IR7	SR1	Operational
	IR8	IR6	Operational
	IR9	SR2, SR3	Supervisory

Continued Table 2. Proposed responses and strategies for Improving environmental and economic-social-cultural sustainability for each component of the DPSIR framework for the TERB region

DPSIR Components	**Code**	Item	**Type**
	IR10	SR4, IR1	Operational
	IR11	IR6	Operational
	IR12	SR4	Operational
	IR13	DR2	Political
	IR14	Minimum use of saline water for irrigation, SR1	Operational
	IR15	SR1 ‹SR2	Supervisory / Operational
	IR16	DR10	Planning
	IR17	DR8 ‹PR3 ‹PR6 ‹SR1‹IR14	Planning/ Operational
	IR18	PR1	Supervisory
	IR19	DR6 ‹DR8‹SR1	Planning

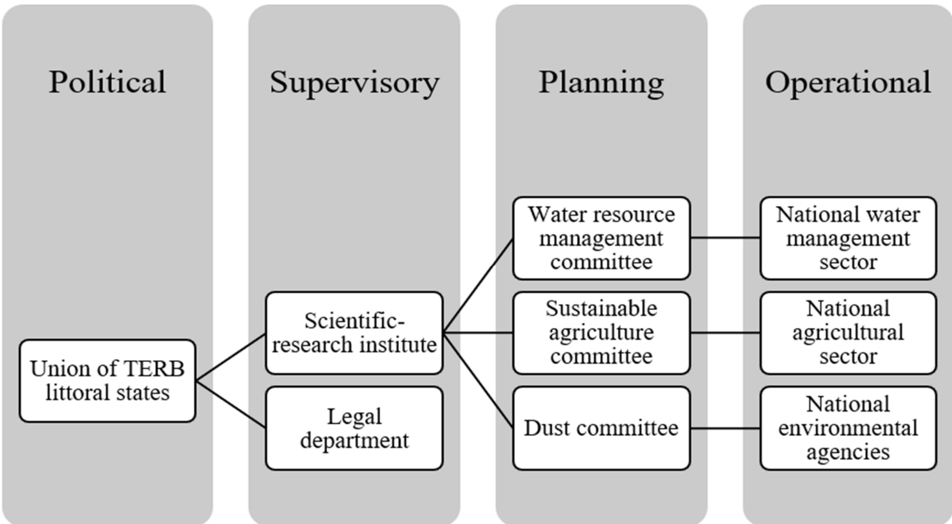

Fig. 10. The proposed framework for putting the proposed Responses into action

this area, which as Darvishi Boloorani, et al. (2021) mention can act as one of the sources of dust storms and the instability of environmental state.

One of the primary “Driving forces” was identified as the non-constructive political competition between the littoral states through ambitious development plans, regardless of the limited capacity of the basin in the provision of the necessary water resources, which is in line with Tinti (2023) that remark large-scale water development projects as tools to support political ambitions.

The negative consequences of such actions are the loss of biodiversity, creating unfavorable economic-social conditions, and fueling of political crises in the region.

In addition to determining the cause-effect relationship of the prevailing conditions in this region, the causal framework used in the analysis was also a way forward in providing solutions for each component of the DPSIR chain. The strategies presented in this research emphasized on the initial components of the DPSIR chain as influential factors in creating the existing unsustainable situation. Therefore, if executed efficiently and correctly, the measures proposed for this section will automatically be effective in solving the problems of the next levels. This fact is clearly seen in the repetition of the responses of the beginning sections at the latter parts of this table.

Apart from being a matter of competition and conflict, shared water resources can bring countries closer to participation and cooperation. Thus, the issue of water can play a pivotal role for the collaborations between the countries located in TERB in the form of establishing a union or a regional organization to solve common problems and political cooperation. As far as possible, this union will be responsible for the political actions defined in the proposed strategies, which will include following up on the joining of the countries of TERB to a comprehensive water agreement and monitoring its full implementation. Also, creating a system to govern shared water resources in this basin and protect them in the event of a war and a possible attack by militias will be other duties of this union.

CONCLUSION

Construction of large dams and water control infrastructures in transboundary basins of arid regions, leads to severe environmental and socio-economic consequences and political issues. Tigris-Euphrates River Basin is a clear example of this complicated situation in which despite the short-term benefits of controlling the water, the unsustainable conditions and environmental degradations will ultimately lead to a dangerous situation that will not benefit any of the countries in the region in the long term.

In this research, using the satellite images as well as the DPSIR causal framework, it was attempted to present a comprehensive and integrated assessment of the environmental condition of the Tigris-Euphrates River Basin through multi-scale analysis of the state of the ecosystem, and providing effective solutions to control this situation.

This research seeks to monitor and evaluate the environmental changes by human activities and especially the water resources exploitation plans in the basin. In this context, few researches have specifically addressed the impact of activities carried out in the water sector, including dam construction, water transfer and agricultural projects. Another notable innovation of this research is the scale of the study. In most of the cases, the impacts related to the exploitation of water resources are investigated on national scale or regional basins. However, in this research, the investigation is carried out at multi-scales. The macroscale covers a vast international basin where major changes have been demonstrated. In the mesoscale, the trend of changes has been investigated at the level of the main countries of this basin, and the differences at this level have been discussed. Micro-level analysis has also been carried out in the certain areas with significant changes. Since the evaluation of the environmental impacts was accomplished in an integrated way using the DPSIR causal chain, the strategies and solutions presented also address to the various components of the problem.

Apart from being a matter of competition and conflict, shared water resources can play a pivotal role for the collaborations between the countries located in TERB in the form of establishing a union or a regional organization to solve common problems and political cooperation. As far as possible, we suggest this union to be responsible for the political actions defined in the proposed strategies, which will include following up on the joining of the countries of TERB to a comprehensive water agreement and monitoring its full implementation. Also, developing a system to govern shared water resources and protect them in the case of wars and possible attacks will be other duties of this union.

Due to the complexity and multi-dimensionality of the problems in this basin, it is necessary to carefully define scientific and research programs to solve the mentioned problems. To define and implement these programs on common problems of TERB, using the scientific potential of the regional universities and research institutes can be very helpful. In this regard, it is suggested to establish a joint scientific research institute with the cooperation of the universities of Iraq, Iran, Turkey, and Syria and supervision of international organizations to investigate the issues in the region in a thoroughly scientific and impartial manner and to perform the supervisory role mentioned in the above table in an efficient way which all parties trust. Many of the planning solutions presented in this research, especially the "Integrated River Basin Management" program, which includes the management and sustainable exploitation of water and land resources on a large scale, can be prepared and followed by specialized committees inside of the institution. These committees may include but are not limited to water resource management, sustainable agriculture, sustainable land use management, dust prevention and control panel (Figure 10).

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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