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Diagnosis and Planning of Impacts of Land-Cover Changes on the Runoff

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Abstract: Caspian basin is one of the main six basins of the country which is influenced by Caspian region in the north of Iran. Because of the growth of human activities and following the changes in land using over the past years, land-cover has changed greatly in this area. The purpose of the article is to study the impact of land-cover changes on the surface of runoff and the quality of water resources in years of 2001-2012, in the Caspian basin. MODIS of terra satellite images have been used to do this action.

The results showed that impenetrable surfaces that influence the production of surface runoff have covered 32.25 percentage of the whole of Caspian basin in 2001. And the level of impenetrable surfaces have decreased to 1.39 percentage by reducing 1.86 percentage. Also, in 2002, the surfaces that changed the quality of water, composed 14.54 percentage of the whole of basin land-cover reached to 17.78 percentage by 3.24 growth until 2012. In order to have a constant profit from water resources and to decrease land-cover impacts on water resources in this basin, providing the management plan of land-cover which includes pre-programmed planning, implementation, monitoring, and compliance steps which are related to water resources is necessary.

Key words: Land cover, water resources, MODIS satellite images, Caspian basin.

Introduction

Water is a precious and valuable commodity which due to its increasing demand for agriculture, domestic and industrial uses, is decreasing (Zhang et al., 2014a). The discussion of optimal management of water resources has been a very significant issue because of the increased competition in allocation of water resources to different parts and fields during the past decades (Huang and Chang, 2003; Wang et al., 2003). Furthermore, significant changes have occurred in land use and land cover during this time (Deng et al., 2015; Lambin and Meyfroidt, 2011), especially in developing and highly developed countries (Deng et al., 2006; Seto et al., 2011). This ongoing changes of land cover will have a huge impact on climate and water balance (Anav et al., 2010; Kueppers and Snyder, 2012; Deng et al., 2013). For this purpose, the effects of changes in land cover will attract a lot of attention to itself in the future (Chen et al., 2005; Seneviratne et al., 2006). Human activities will cause changes in the Earth's surface by altering the land cover (Ramankutty et al., 2008; Margono et al., 2012) and these changes in turn will cause other changes to the global patterns of water regimes (Chen et al., 2005; Seneviratne et al., 2006).

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Research shows that large-scale changes in land cover could cause change in the balance of water regimes due to change of biochemical and biophysical processes finally (Jigant et al., 2011; Liu and Deng, 2011; Deng et al., 2012; Huang et al., 2013). One of the most important effects of changes in land cover is related to its impact on quantitative and qualitative characteristics of groundwater and surface water. When the natural cover of the earth's surface is changed, the water permeability could have impact on the production of surface runoff and its following groundwater. Table 1 and Figure 1 represent the impact of land-cover changes on the quantity and quality of water resources.

So far the discussion about the impact on the changes in land cover and its effect on water resources has been proven entirely (Johnson and Gaga, 1997; Allen, 2004; Hurley and Mazumder, 2013; Bu et al., 2014; Ye et al., 2014; Yu et al., 2015). There is a strong relationship among land use, land cover and water resources (Gyawali et al., 2013).

Another important and basic application of the study of land-cover changes is its investigation of the quantity and quality of water resources (Zhang et al., 2014b). Land-cover changes can reduce water quality or change the hydrological processes (Seeboonruang, 2012; Warburton et al., 2012; Erol and Randhir, 2013). And likewise, water bodies react to these changes in water quality and quantity. Therefore, providing policies and operating plans of land-cover changes is very important in order to reduce vulnerability of groundwater and surface water resources (Valle Junior et al., 2015; Meneses et al., 2015).

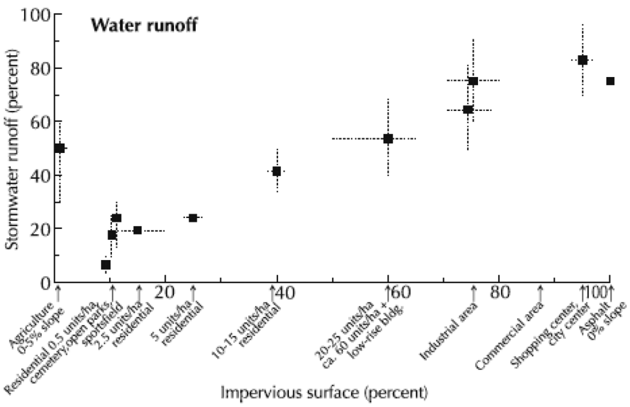

Figure 1: The relationship between impermeable surfaces and industrial pollution caused by runoff at every level (Forman, 2014).

Land-cover planning is a sustainable form of land use and to start necessary actions to implement and for supervision of land-cover changes from the view of decision-makers (Gyawali et al., 2013). Land-cover planning provides required prerequisites for forming stable use of social, economic and environmental land and resources (Kueppers and Snyder, 2012).

According to the importance of water in Iran, at the same time of the increase of water-related crises and the impact that can affect the growth and economic and social development at national and regional level, management of pressure agents on water resources is necessary. Especially changes in land cover that affect the quantity and quality of hydrological regimes and hence the sustainability of water resources and providing their policies and management practices is necessary and that we will refer to them in this article.

Materials and Methods

Study Area

Caspian basin is one of the main six basins of country that influence Caspian region in the north of Iran and includes seven second rate sub-basin by Aras, Talesh, Sefidrud, Sefid-Rud-Haraz, Haraz-Gharah Su, Gorganrud-Ghareh-Su and Atrak names (Figure 2). The area of the Caspian basin is more than 170 thousand kilometres, and it covers about 10 percent of Iran. Because of considerable growth of population in this area, the growth of human activities and other factors, the relatively high rainy basin of Iran has been under intense land-cover changes. The land-cover changes have an undesirable impact on quality and quantity of surface water resources such that in case of not

Table 1: Hydrological components in lands with different permeability

	Evaporation (%)	*Runoff (%)*	*Deep permeability (%)*	*Surface permeability (%)*
Forest ecosystem	40	10	25	25
Impermeability 10-20%	38	20	21	21
Impermeability 35-50%	35	30	15	20
Impermeability 75-100%	30	55	5	10

Retrieved from Paul and Meyer, 2001

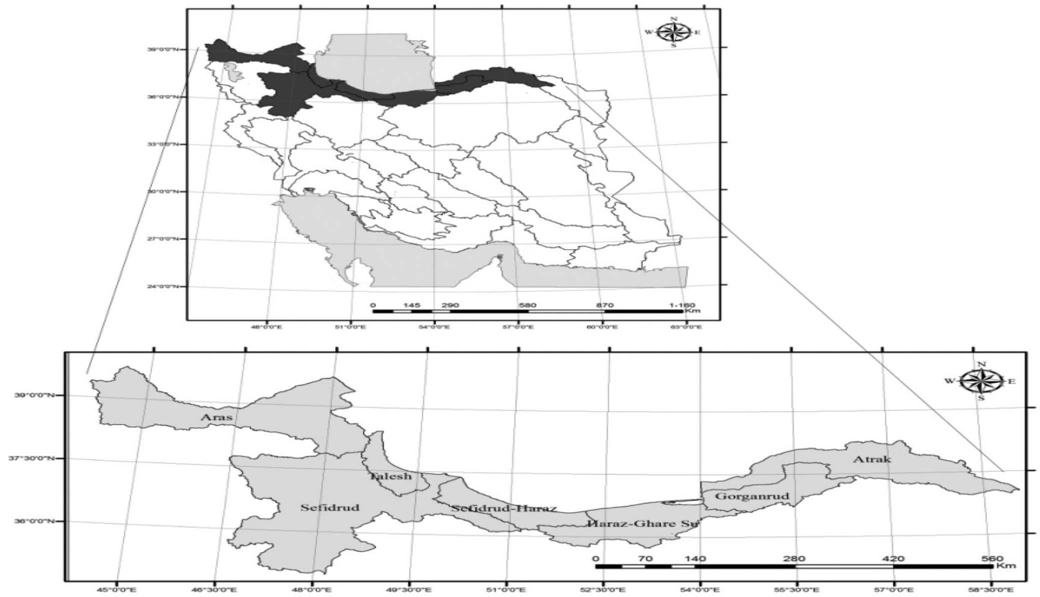

Figure 2: Caspian basin and its sub basin

controlling and managing the land cover changes very soon, this area will also be faced with crises of quality and quantity of freshwater resources.

Data and Methodology

In this study, MODIS satellite images have been used from 2001 to 2012 to assess the changes in land cover of Caspian basin and its impact on water resources.

After processing the image, in mentioned intervals and its classification into different levels of land-cover, these levels are studied and their changes are calculated in the two intervals. Then, the changes that influence runoff and the quality of water resources in Caspian basin in levels were examined. Finally, strategy was provided to manage changes in land cover that are related to water resources.

MCD12Q1 MODIS image is used to investigate the changes in land cover in this paper. MODIS (Medium Resolution Imaging Spector radiometer) is sensor that has been on the Terra satellite (EOS AM-1). A MODIS has been placed in each of the EOS AM and EOS PM satellites. MODIS Terra satellite photographs all ground once every two days and receives the data in 36 spectral bands. These data along with the data which have been located on Aqua satellites are received by second MODIS and they notify us about movement, global changes and also processes that occur on Earth's surface, oceans and atmosphere at low levels.

MODIS plays a major role in the development of flexible models of earth systems and enables us to precisely forecast our global changes that can help managers and policy makers in the field of environmental protection and optimal management of resources (NASA, 2014).

In this study, two images of land cover of MODIS Terra and Aqua satellites have been used that include five land cover classifications by Resolution of 463 m for studying the level of water infiltration or runoff formation and water resources management resulting from changes in land cover in Caspian basin.

After processing images of changes in the Earth's surface by sensor each year, only an image of the sensor is published; the first picture is for 2001 and last published image is for 2012. In the following and in Tables 2 and 3 characteristics of the images are presented (NASA, 2014).

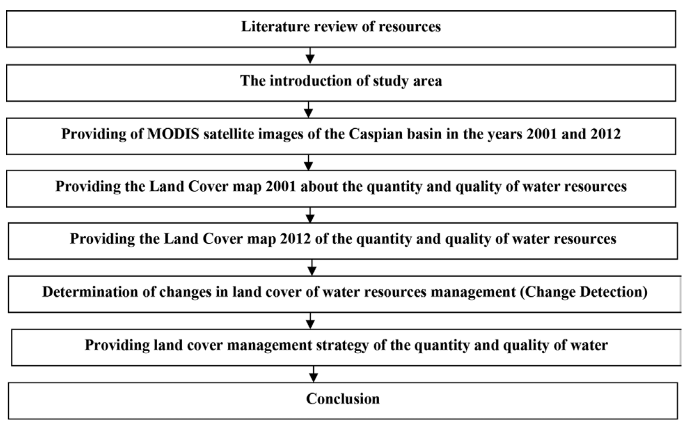

Figure 3: Materials and methods.

Table 2: The characteristics of MODIS images used in this article

Temporal coverage	*2001–2012*
Earth-gridded tile area	~1200 × 1200 km (~10° × 10° at the equator)
Image dimensions	2400 × 2400 rows/columns
Resolution	500 (463) metres
Projection	Sinusoidal
Data type	8-bit unsigned integer
Data format	HDF-EOS
Science Data Set (SDS) layers	16
Day/Night	Day

Table 3: The characteristics of the five classes of MODIS images

Land Cover Type 1	IGBP global vegetation classification scheme
Land Cover Type 2	University of Maryland (UMD) scheme
Land Cover Type 3	MODIS-derived LAI/ fPAR scheme
Land Cover Type 4	MODIS-derived Net Primary Production (NPP) scheme
Land Cover Type 5	Plant Functional Type (PFT) scheme

Since the study area of Caspian Basin has a large extent, it has very diverse land cover because of the diversity of climate changes, longitude and altitude and they can be classified in different classes. Therefore, IGBP1 classification of MODIS is also used that has 17 separate classifications for assessment of changes in land cover and its impact on the quality and quantity of water resources management.

This classification has the most affinity and diversity to the land-cover situation in Caspian basin that has climate diversity, diverse and high cover. Also, these 17 classes and IGBP classifications have been reduced to seven main classes and common type of land cover that can be found in any area for ease of understanding of the impact of changes in land cover and the impact on water resources management that the following part will be expressed.

Results and Discussion

Land cover map of the area in two periods was extracted from raw satellite images after the preparation of satellite images of the region in both 2001 and 2012 and then the ratio of various land covers of any image in two periods was detected. Change detection technique of image analysis tool was used by Arc GIS software and the level of changes in each interval was determined and its results are presented in Table 4.

The layers have been addressed that influence production of surface runoff and quality of water resources in the basin for studying the effects of land-cover change on surface runoff production and quality of water resources in the Caspian basin.

According to studies that have been done and the inherent nature of layers defined above, the impact on land-cover change and water permeability has been considered for studying the production of surface runoff. And for this purpose, changes in urban and barren layers as being layers impermeable against other layers as permeable layers have been analyzed.

Also, urban and agricultural layers as changing layers of water quality and other layers that have little effect on water quality have been reviewed for the study of the impact of land-cover change on water quality characteristics (Paul and Meyer, 2001; Forman, 2014) and its results are shown in Table 5.

The study of the impact on changes in land-cover surface runoff and quality of water resources in the

Table 4: The land cover ratio of Caspian basin in 2001-2012

Layers of land cover	*2001 (hectare)*	*2012 (hectare)*	*Changes in 2012 compared to 2001 (hectare)*
Wetlands	27028	41409	14381
Forest	1549274	1551286	2012
Grasslands	12807407	12666724	–140683
Croplands	2408891	2918767	509876
Urban and built-up	115153	115196	43
Snow and ice	43	0	–43
Barren or sparsely vegetated	448993	63408	–385585

Table 5: Effective land-cover changes on surface runoff and water quality in Caspian basin in 2001-2012

Land cover layers	*2001 (hectare)*	*2012 (hectare)*	*Changes in 2012 compared to 2001 (ha)*
Impermeable surfaces	564147	242804	–321343
Permeable surfaces	16792644	17178187	385543
The ratio of impermeable surfaces to all surfaces (percent)	3.25	1.39	–1.86
The ratio of permeable surfaces to all	96.75	98.61	1.86
Surfaces that change water quality	2524044	3098164	574120
Surfaces that do not change water quality	14832747	14322827	–509920
The ratio of surfaces that change water quality to all surfaces (percent)	14.54	17.78	3.24
The ratio of surfaces that don't change water quality to all surfaces (percent)	85.46	82.22	–3.24

Caspian basin shows those impermeable surfaces that have influenced the formation of surface runoff. 25.3 percent of the Caspian basin was covered in 2001 and by reducing the 86.1 percent impermeable surfaces have been decreased to 39.1 percent until 2012.

Also, in 2001, surfaces, that can change water quality, covers 14.54% of the total land-cover basin in which these surfaces have reached a growth from 3.24 to 17.78% from the whole of basin surfaces until 2012. Each type of land cover changes related to water resources and also their rate in the Caspian basin in the years 2001-2012 was determined by change detection technique of image analysis tool in Arc GIS software for finding and detecting the type of effective changes on production of surface runoff and quality of water resources in the Caspian basin and its results have been shown in Table 6.

Also, the study of the impact of changes in land cover on production of surface runoff and quality of water resources in the Caspian sub-basins shows that most of the changes related to this issue have been in Talesh sub-basin. 21.35 percentage of the whole of changes, in this sub-basin in the years of 2001-2013, is related to water resources. Sefid-Rud by 7.73 percentage from these changes of the whole of land-cover changes has had the lowest changes among other sub-basins.

Furthermore, most of the changes that have influenced the quality of water resources in the basin is related to transformation of croplands cover to grasslands and vice versa. Transformation of croplands cover to barren and vice versa also is the most important change among other effective changes on the production of runoff in the Caspian basin.

Policy of Land-cover Changes Associated with Water Resources Management

One of the main causes of changes outbreak in land cover in Caspian basin and its following increasing pressure on water resources over the years has been climate change. Also the invasion of non-native to relatively high rainfall basin and consequently increasing population density per unit area cause land-use changes according to their needs.

In general the population density in Iran has been 46 people per square kilometre in 2012 that in Caspian basin this rate 64.3 people has been estimated per square kilometre (Statistical Center of Iran, 2012). Many favourable and suitable lands of these areas belong to all people of Iran and especially indigenous people of the region.

Since at the moment much of lands are the state's territory, a series of actions are needed at different levels of government to achieve an efficient sustainable management against land cover changes. Because, sustained security of water supply is done by sustainable use from the inherent land use in these areas and can improve water resources management it is essential to go with the following strategy (Bu et al., 2014).

Improving the supervision and management of land-cover changes includes decisions about the optimal use of land (Will lead to increased efficiency from water resources and or preserving natural land cover). Accordingly, and to achieve this important, planning processes of land cover are divided into five categories for success which include pre-planning, planning, implementation, monitoring and adaption, as shown in Figure 7.

Table 6: Changes in land cover in the sub-basins of the Caspian basin between 2001-2012

The type of land cover changes on water resources in Caspian basin	*The level of effective cover changes on water resources in each sub-basin of Caspian basin (hectare)*						
	Atrak	*Gorganrud-Ghareh-Su*	*Haraz-Gharahsou*	*Sefid Rud-Haraz*	*Sefid-Rud*	*Talesh*	*Aras*
Croplands to wetlands	-	-	171	-	407	-	171
Croplands to forest	21	5821	11941	15108	10550	19346	5585
Croplands to grasslands	20822	35438	47936	50932	89944	28227	227824
Croplands to wetlands	-	21	835	1562	865	3617	21
Croplands to barren or sparsely vegetated	300	21	85	-	128	-	64
Fixed areas of croplands	47893	480986	321920	73595	141561	111387	653791
Wetlands to croplands	21	64	877	235	21	278	-
Forest to croplands	-	32997	43977	20052	6912	16157	1113
Grasslands to croplands	90800	114105	131353	77939	225342	73124	242419
Wetlands to croplands	-	-	1263	578	257	728	-
Barren or sparsely vegetated to croplands	3360	621	64	21	2247	21	706
Barren or sparsely vegetated to wetlands	86	64	107	428	64	364	-
Barren or sparsely vegetated to forest	43	128	21	-	64	43	-
Barren or sparsely vegetated to grasslands	231034	25937	26087	942	112650	43	21678
Fixed barren or sparsely vegetated areas	4023	8346	4644	150	-	-	214
Wetlands to barren or sparsely vegetated	449	193	342	21	43	43	64
Forest to barren or sparsely vegetated	-	-	107	-	21	-	-
Grasslands to barren or sparsely vegetated	2354	2932	3638	150	6976	21	1969
Wetlands to barren or sparsely vegetated	-	21	-	21	21	43	21
Wetlands to urban and built-up	-	-	43	-	-	21	-
Urban and built-up fixed areas	5136	17848	41623	10572	12712	10871	16371
Urban and built-up to Wetlands	-	-	-	-	-	21	-
Total of fixed points of effective land cover on water resources (hectare)	57052	507180	368187	84317	154273	122258	670376
Total of effective land cover changes on water resources (hectare)	449290	218379	268847	167989	456503	241097	501645
The area of each sub-basin (km²)	26327	13035	18167	10841	59046	6657	39493
The ratio of the total of effective land cover changes on water resources to the whole of basin area (percent)	17.07	16.75	14.80	15.49	7.73	21.35	12.70

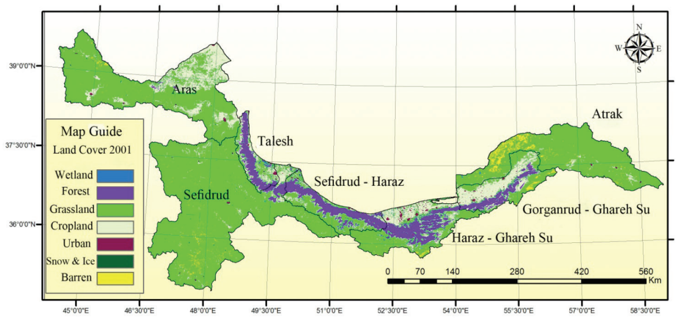

Figure 4: Caspian basin land-cover classification in 2001.

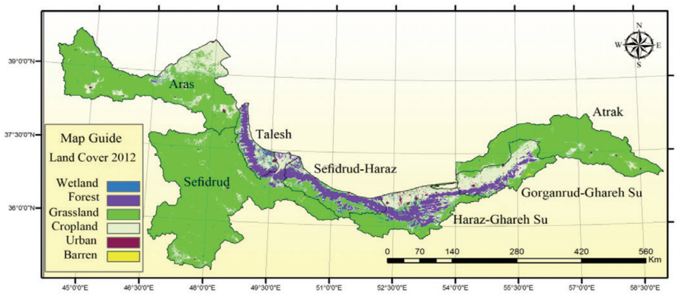

Figure 5: Caspian basin land-cover classification in 2012.

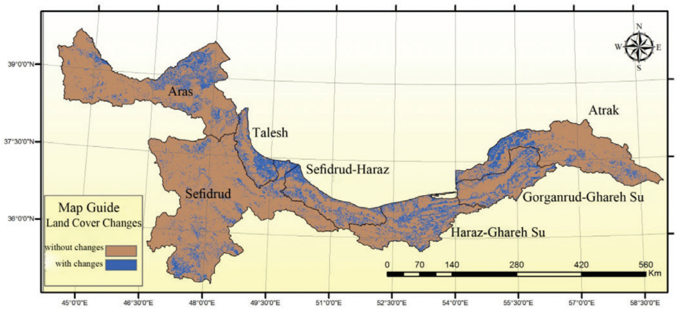

Figure 6: The total of land-cover changes in the sub-basins of the Caspian during the years 2001-2012.

Conclusion

Water is a vital and very valuable commodity and sustainable maintaining water resources especially according to Iran conditions is essential and necessary. Caspian basin is one of the main basins of our country that has been under for various reasons including rapid changes and without land use planning over the years, land cover and then its freshwater resources. Changes in land cover has been studied by MODIS satellite images in this area for review of impact of changes in land cover on water resources in the basin. The results of changes in land cover in the Caspian basin shows impermeable surfaces influence the surface runoff production has decreased in the area, but surfaces that impact on water quality has increased during 2001 to 2012.

Accordingly, impermeable surfaces has surrounded 25.3 percent of the Caspian basin in 2001 and until 2012, impermeable surfaces has decreased to 1.39 by 86.1 percent reduction. Also in 2001, surfaces that could change water quality composed 14.54 percent of the whole of land cover of basin and this surface by growth of 3.24 percent increased to 17.78 percent of the whole of the Caspian basin surface until 2012. Also, surveying the affect of land-cover changes on the production of surface runoff and the quality of water resources in Caspian basins show that most changes related to this subject has been in Talesh basin where 21.35 percent of the whole of changes are related to water resources from the whole of land-cover changes in sub-basin in the period of 2001-2012. Sefid-Rud sub-basin has the lowest changes among other sub-basins by 7.73 percent of these changes from the whole of land cover changes. Furthermore, most of the changes that impact on the quality of water resources has been transformation of croplands cover to grasslands and vice versa. Transformation of grasslands cover to barren and vice versa is the most important change among other effective changes on the production of runoff in Caspian basin.

Overall, based on the studies and analyses, land-cover changes in Caspian basin during 2001 to 2012 show that the impact of changes in land cover in the area is decreasing on the quantity of water resources and is increasing Quality of fresh water resources. Since land-cover changes impact on the quantity and quality of surface waters and groundwater in the basin of the Caspian and also its following, water resources react to these changes. Therefore, land-cover changes management is essential and necessary for performance improvement of water resources in the Caspian basin by the correct policy of land-use changes and providing management programmes in its regard. Accordingly, and to control the effect of land-cover change on the quantity and quality of water resources in the Caspian basin, preparation and implementation of integrated system of land use management and land cover is essential in Caspian basin. Such a system by scrutiny dimensions of land-cover change caused by human and natural activities in pre-planning level, planning, implementation, monitoring and adoption of programmes and objectives is provided and can play important role in reducing vulnerability of water resources in the Caspian basin. To achieve this important factor is possible only by cooperation of all interest

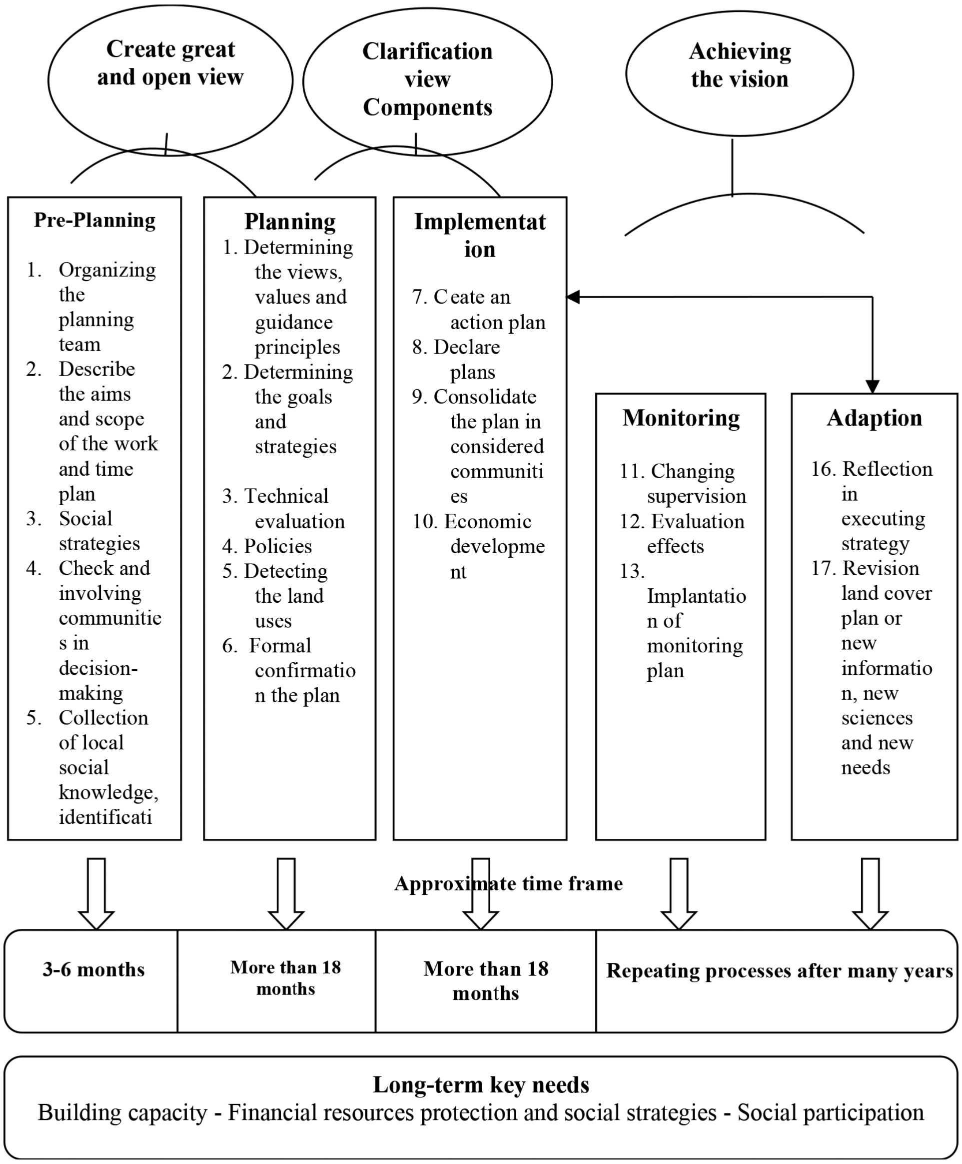

Figure 7: Successful framework of planning land cover related to water resources in Caspian basin.

groups, provision of budget and investment and long-term and continuous monitoring by state.

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