



Integrated Adaptation Approaches to Climate Change in Semi-arid Basin of Iran

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Abstract: The major challenges concerning freshwater include: experiencing extremes of too much and/or, too little water and consequent water issues. Each of these problems may be intensified by climate change in semi-arid areas. Existing research and observational evidence provide strong arguments that future climate may change significantly and, therefore, impact the water resources of the Karkheh basin of Iran. Thus, the strategies that can be used to mitigate possible negative impacts of climate change on water resources are of great importance. The risk of drought and heat stress is expected to increase in the whole of the study area. Overall, the present study shows the consequences of climate change on the water resources of the Karkheh Basin and shall be useful in formulating the adaptation options in a sustainable manner. SWAT model was used for impact assessment analysis by using the future climate scenario with future regional climate models. It has been found that there shall be an explicit deficit in water as well as crop yield during the end of the century. The impact of suggested adaptation activities had various effects on hydrology and the same has been depicted through tracking major hydrological components; e.g. surface runoff, groundwater and sediment erosion. Amongst the suggested adaptation scenarios, activities that include terracing, strip cropping, Grade Stabilization Structure (GSS) and contouring were found to influence the desired hydrologic components significantly. The land use and cropping pattern changes were also successful in bringing about the desired changes to the hydrologic components.

Key words: Adaptation, crop pattern, land use, Karkheh Basin, SWAT model.

An integrated management plan is required to prevent the impact of climate change on socio-economic, environment aspects and water scarcity. Each of these segments is closely connected to water resources and therefore, is expected to be strongly influenced by climate change. Thus, adaptation to climate change on water resources and resilience against the negative impacts are of primary concern. It is achieved through multiple interventions and thus, needs an integrated approach. This approach should be included the wide range of abilities to adapt the various sectors that are influenced of climate change vulnerability in the basin (Lindsey *et al.*, 2010). Adaptation to climate change can be improved by (i) adjusting exposure (ii) reducing the sensitivity of the system to climate change impacts and (iii) enhancing the system adaptive capacity (OECD, 2006).

In watershed-based studies, a regional hydrological cycle is governed more by

watershed than by an administrative boundary. Integrated watershed-based adaptation to climate change on water resources has been reported by several studies (Arnell, 1996, 1999, 2003, 2004; Arnell and Delaney 2006; Aerts and Droogers, 2003, 2004, 2005, 2009; Droogers and Aerts, 2005; Droogers, 2009; Droogers *et al.*, 2012; Dessai *et al.*, 2009; Woznicki *et al.*, 2013, 2015; Panagopoulos *et al.*, 2015). The research work has followed the strategy of the integrated hydrological model with the framework that has been applied for some of the climate change projects such as ADAPT project (<http://www.geo.vu.nl/users/ivmadapt>) developed by Droogers (2004) and Droogers and Aerts (2005). The current research paper is based on a brief explanation of existing adaptation strategies on water sector followed by suggested adaptive activities based on projected climate change.

The SWAT model (Arnold and Allen, 1993) allows for simulation of management practices and therefore, it is best used for exploring the impact of adopting a specific adaptation

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options. In the present study SWAT has been used to assess the impacts of adopting specific cultivation field operations as well as changes in land use of range and forest areas. SWAT model has been used for impact assessment analysis. The results of climate change impacts were obtained by using the future climate condition with 'PRECIS' and 'REMO' regional climate models dynamically downscaled from the latest GCMs. It has been found that there shall be explicit deficit in water and crop yield during the end of the century (2070-2099) (Solaymani and Gosain, 2015).

It is possible to formulate institutional and physical activities to achieve the outcomes of the IWRM approach without any violation of the existing policies and measures among the stakeholders. In this study, the physical scenarios have been considered, followed by the formulation and implementation process. Even purely physical adaptations (e.g. dam construction, changes in agricultural practices, the establishment of rainwater harvesting) will need integration. Panagopoulos *et al.* (2015) have used an integrated modelling system based on SWAT to estimate the in-stream water and some nutrients pollution yields in response to a wide array of alternative cropping and management strategies under projected climatic conditions of the corn belt region in the Midwestern US (De Lopez *et al.*, 2011). They realized the rate of erosion and nutrient loading to surface water bodies were reduced compare to the baseline condition and also understood that the corn and soybean yields were highly influenced by the agricultural management scenarios. Another relevant study has been done by Woznicki *et al.* (2015) for the Tuttle Creek Lake watershed in Kansas and Nebraska, in which they studied the impact of some agricultural Best Management Practices (BMPs); e.g. terraces, contour farming, etc. on water yield, surface runoff, base-flow, load of sediment, nitrogen and phosphorus by using SWAT with respect to projected climatic conditions. It was observed that terraces, contour farming and spread of native grass were quite effective in pollution load reduction and per cent efficiency at the field and watershed scales under future scenarios. Porous gully plugs and filter strips showed no significant changes in pollution load or per cent reduction. Grazing management, under no-tillage, conservation tillage and

load reduction under future scenarios varied at the field and watershed scales. The study demonstrated that BMP performance in terms of sediment, nitrogen and phosphorus reduction significantly changes under future climate scenarios at the field scale, while performance generally does not change significantly at the watershed scale.

Study Area

In order to evaluate the general performances of various adaptation scenarios/activities, SWAT was applied to Karkheh Basin (KB). The KB is located in the western part of Iran (Fig. 1). The drainage area of the basin is about 50,764 km², out of which 80% falls in the Zagros mountain ranges. The topography depicts large spatial variation with elevations ranging from 3 to more than 3,000 MASL. The elevation of about 60% of the basin area is 1,000-2,000 MASL and about 20% is below 1,000 MASL (Ashrafi *et al.*, 2004). The population living in the basin is about 4 million (in 2002) and about one third resides in the rural areas (JAMAB, 1999; Ashrafi *et al.*, 2004). Hydrological features of the KB were complex and heterogeneous because of its diverse topography and natural settings of geology, climate and ecology. The precipitation (P) pattern depicts large spatial and intra-and inter-annual variability across the basin. The mean annual precipitation ranges from 150 mm yr⁻¹ in the lower arid plains to 750 mm yr⁻¹ in the mountainous parts (JAMAB, 1999). This variability divides KB in three main sub-basins: upper Karkheh, middle Karkheh and lower Karkheh. On an average, the middle part receives higher P than the upper and lower parts as per the records of Kermanshah (450 mm yr⁻¹), Khorramabad (510 mm yr⁻¹) and Ahwaz (230 mm yr⁻¹). Most of the precipitation (about 65%) occurs during the winter months from December to March and almost none P during the summer season, i.e., June to September. In the mountainous parts during winter, as temperatures often falling below 0°C, the winter P falls as snow and rain. The temperature shows large intra-annual variability, with January being the coolest and July the hottest month. The potential evapotranspiration (ETp) largely follows a similar pattern as the temperature (T) with the highest in the southern arid plains and the lowest in the mountainous semi-arid region. There is a large gap between ETp and P in most of the months, which widens as we

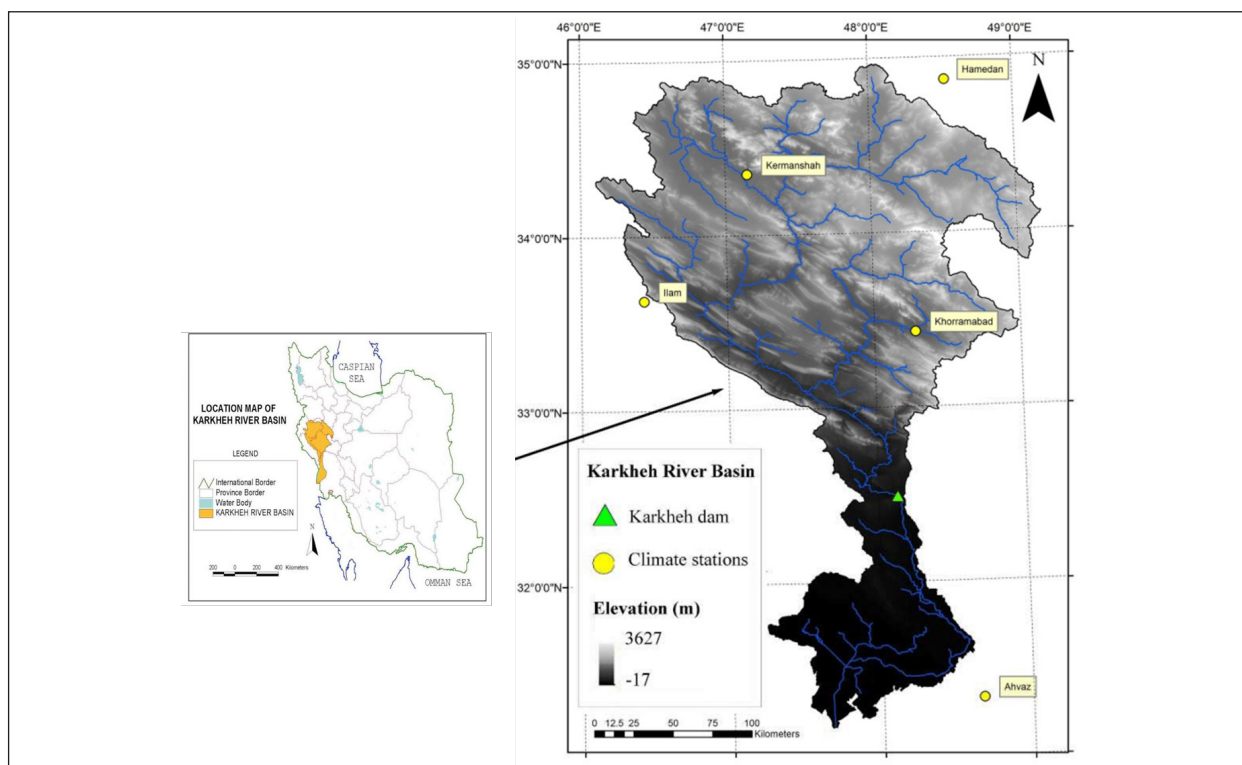


Fig. 1. Location of KB in Iran and delineation of sub-basin and rivers.

move from upper northern semi-arid regions to the lower southern arid parts of the basin. The hydrological analysis and assessment of water resources in such semi-arid to arid regions with high climatic variability is a challenging compared to humid areas where P exceeds the ET_p in most of the months (Sutcliffe, 2004).

Materials and Methods

The current research not only used the previous methods and results of the aforementioned research works but also, suggests as an innovative method to select/prioritize the proper activities based on the relevant effective parameters in SWAT. Formulating integrated adaptation scenario included the common issues of interests and extent of damages coupled with the problem of attributing the interests and extent of damages coupled with the problems of various sectors. In order to formulate the adaptation scenario, various possible adaptation options should be first identified and then the application possibilities can be validated. Adaptation activities take place in the wide range of physical options based on integrated approach. In this context six main scenarios were reported by De Lopez *et al.* (2011):

- Diversification of water supply,
- Groundwater recharge,
- Preparation for extreme weather events,
- Resilience to water quality degradation,
- Storm-water control and capture and
- Water conservation.

These scenarios include various practices/technologies and management operations. Therefore, the adaptation activities are classified based on the suitability and capability of the area under study. Then, the eight possible options of adaptation activities based on a questionnaire and experts' judgment approach are:

- A1: Management operations for agricultural purpose (e.g. terracing, tile drains and strip cropping)
- A2: Management operations for natural system purpose (e.g. contouring and grade stabilization structure - GSS)
- A3: Establish the big reservoirs (e.g. dam construction)
- A4: Rainwater harvesting from ground surfaces (e.g. small reservoirs and micro-watersheds)
- A5: Changing crop pattern

- A6: Water reclamation and reuse
- A7: Applying efficient water-use technologies (e.g. modern irrigation system)
- A8: Changing the land-use (e.g. converting the low yielding rainfed land to rangeland/forest)

It is required to prioritize the above eight operations, with respect to functionalities and/or capabilities for the hydrological character, socio-economical attributes and ecological/technological limitations in the study area. In order to achieve this objective, it is needed initially to know the strength, weakness, opportunities and threats of each scenario; followed by their ordering and prioritization using order analysis. Integrated adaptation approach involves operations and actions anticipated to improve water conservation and its use, while decreasing conflicts among competing uses, both in forms of quantity and quality. Therefore, it is intended to prepare a possible methodology to prioritize adaptation activities agreed on the IWRM approach. The later part is achieved using SWOT and Partial Order Analysis (POA) (Solaymani and Gosain, 2015). In POA, the objects characterized by multiple indicators can be compared and ordered. Partial order as the theory of order is applied to the set of objects and it delivers insights which result in an appropriate ranking of objects (Bruggmann and Patil, 2011).

Thus, first three levels of adaptation activities have been selected based on expert judgment and SWOT. The selected scenarios are the A1: Management operations for agricultural purpose (e.g. terracing, tile drains and strip cropping); A2: Management operations for natural system purpose (e.g. contouring and grade stabilization structure - GSS); A8: Changing the land-use (e.g. converting the low yielding rainfed land to rangeland/forest); and A5: Changing crop pattern, using SWAT model. In order to simplify the nomenclature in work, A1, A2, A8 and A5 are renamed as Ac. 1, Ac. 2, Ac. 3 and Ac. 4, respectively.

Specifications of Selected Activities

Evaluation of climate change has shown the negative impacts on both water resources and crop production in the KB. The next obvious requirement is to explore a set of activities to increase resilience of the watershed against vulnerabilities arising from climate change.

Cultivated area accounts for about 25% of the total area in the KB, which comprises of rainfed and irrigated farming. The main selection criterion was that the selected options should comply with the specific conditions and capabilities of the cultivated and non-cultivated lands where they are to be used. The options thus being explored are in the form of best management practices (Ac. 1 and Ac. 2), changing the land-use (Ac. 3) and changing the crop patterns (Ac. 4). These can account for the deficit in water availability through proper selection and deployment of suitable best management practices (BMPs) besides two others selected activities (Ac. 3 and Ac. 4). In the present work, the selected activities (Ac. 1....Ac. 4) are incorporated in the cultivated, range and forest areas of the basin.

Results and Discussion

The suggested adaptation activities were first simulated using baseline conditions so as to evaluate the impacts of the proposed activities on some major hydrologic components such as surface runoff, groundwater and sediment yield. The Activity No. 1 included the terracing and strip cropping was modelled on cultivated lands in the upper and middle KB due to mountainous terrain conditions. Terracing was impractical on irrigated cultivated lands due to the expense of terracing in high slopes. Location of the cultivated land on the upper range in KB also made it difficult to implement terracing. Activity No. 2 included the GSS and contouring modelled mainly on rangelands/forest since their ownership was with the government. As such, all the natural resources (rangelands, forest and water bodies) of the country are under the national ownership.

Activity No. 3 that included land-use change was modelled on low-efficiency rainfed lands. The low-efficiency rainfed lands are mostly located in the upper and middle KB mountainous region with slope usually exceeding 10%. Activity No. 4 included the change in cropping pattern. The new cultivar of durum wheat (Syrian-4) was considered in irrigated wheat cultivation area in the whole of the KB. Table 1 depicts the assessment of implemented activities in the study area in terms of some hydrologic components.

The Ac. 1 was the most effective adaptation activity to runoff and sediment reduction

Table 1. Implication of selected activities on some hydrologic components under baseline scenario in KB

Basin	Activities No.	Management application	Surface water (mm)	Ground water recharge (mm)	Total sediment (t ha ⁻¹)
Upper KB	-	No application	63.20	33.56	8.80
	Ac. 1	Terracing	14.05	48.35	0.50
		Strip cropping	NCC	NCC	NCC
	Ac. 2	Contouring	11.8	67.83	1.93
		GSS	53.10	9.09	-
	Ac. 3	Land-use change	44.24	46.63	7.40
	Ac. 4	Changing crop pattern	66.36	35.24	NCC
Middle KB	-	No application	125.76	62.71	18.93
	Ac. 1	Terracing	18.98	152.03	1.76
		Strip cropping	NCC	NCC	NCC
	Ac. 2	Contouring	23.52	127.67	2.26
		GSS	44.24	17.06	-
	Ac. 3	Land-use change	100.61	75.25	13.25
	Ac. 4	Changing crop pattern	132.05	65.85	NCC

NCC : No considerable change in comparison to "No application".

in both upper and middle KB. The surface runoff has been reduced by about 80% and 75% for upper and middle KB, respectively. There is a positive response to groundwater recharge due to surface runoff retention and subsequent infiltration. Therefore, the groundwater recharge has increased by about 14 mm and 90 mm in the upper and middle KB, respectively. Ac. 2 has similar impacts on the chosen hydrologic parameters. The surface water and total sediment erosion have reduced considerably. Total sediment was reduced by about 6 and 16 (t ha⁻¹ yr⁻¹) in the upper and middle KB, respectively. Contouring and

GSSs were incorporated on the sub-basins and streams respectively. They help in trapping the surface runoff for subsequent recharge to groundwater. Reduction in surface runoff by about 16% and 65% on account of GSS in the upper and middle KB, respectively (Table 1). A similar reduction in surface runoff is depicted on account of contouring in both upper and middle KB that is about 81%.

The land use and cropping pattern change altered on the selected hydrologic components moderately. On account of land-use change, the surface flow declined by about 30% and 20% in the upper and middle KB, respectively. The

Table 2. Comparison of surface flow (m³ sec⁻¹) with selected adaptation activities and without adaptation under climate change projections in the KB

Basin	Adaptation	Statistic results	Baseline condition	Climate scenarios		
				A1B	A2	B2
Upper KB	No adaptation	Mean	46.65	58.04	76.65	10.26
		Max	718.00	1548.00	709.20	33.45
		Min	0.00	0.00	0.00	0.00
	With adaptation	Mean	50.63	55.20	76.44	9.44
		Max	323.10	1189.00	490.70	99.29
		Min	6.16	1.78	8.19	1.23
Middle KB	No adaptation	Mean	146.28	121.48	127.61	29.38
		Max	1647.00	3476.00	1174.00	217.10
		Min	0.00	0.00	0.00	0.00
	With adaptation	Mean	147.67	119.54	117.27	23.29
		Max	915.20	2643.00	849.60	100.40
		Min	10.11	7.76	14.40	3.128

cropping pattern change slightly increased the surface flow. Table 2 summarizes the results of simulation on the suggested adaptation activities based on the baseline and three climate change projections scenarios; A1, B2 and A1B. The suggested adaptation activities have been focused to ensure a reduction in flow and increase in groundwater recharge in the study area.

It may be observed that the surface flows for A2, B2 and A1B scenarios are 718, 709.2, 33.45 and 1548 $\text{m}^3 \text{sec}^{-1}$ respectively in the baseline of the upper KB having no adaptation activities. The observations with same parameter for A2 and A1B scenarios, with the adaptation activities are 323, 490 and 1189 $\text{m}^3 \text{sec}^{-1}$ respectively for the baseline. The minimum flow invariably increased from the baseline to the changing climate scenarios. This is

mainly on account of enhanced precipitation and consequent groundwater recharge. Similar trends are also observed for the middle KB. Therefore, simulation of appropriate adaptation activities can influence the local hydrology by regulating the maximum and minimum flow values range and the results of the impact of the above selected activities is visualized under the baseline and the future projected various climate scenarios (A1B, A2 and B2) in the semi-arid study area (Table 2).

Figure 2 provides the influence of adaptation activities at monthly interval for each of the climate change projections in both upper and middle KB. The maximum flow reduction on account of the adaptation activities takes place during November to April under A2, B2 and A1B scenario in both upper and middle KB. The various adaptation activities also

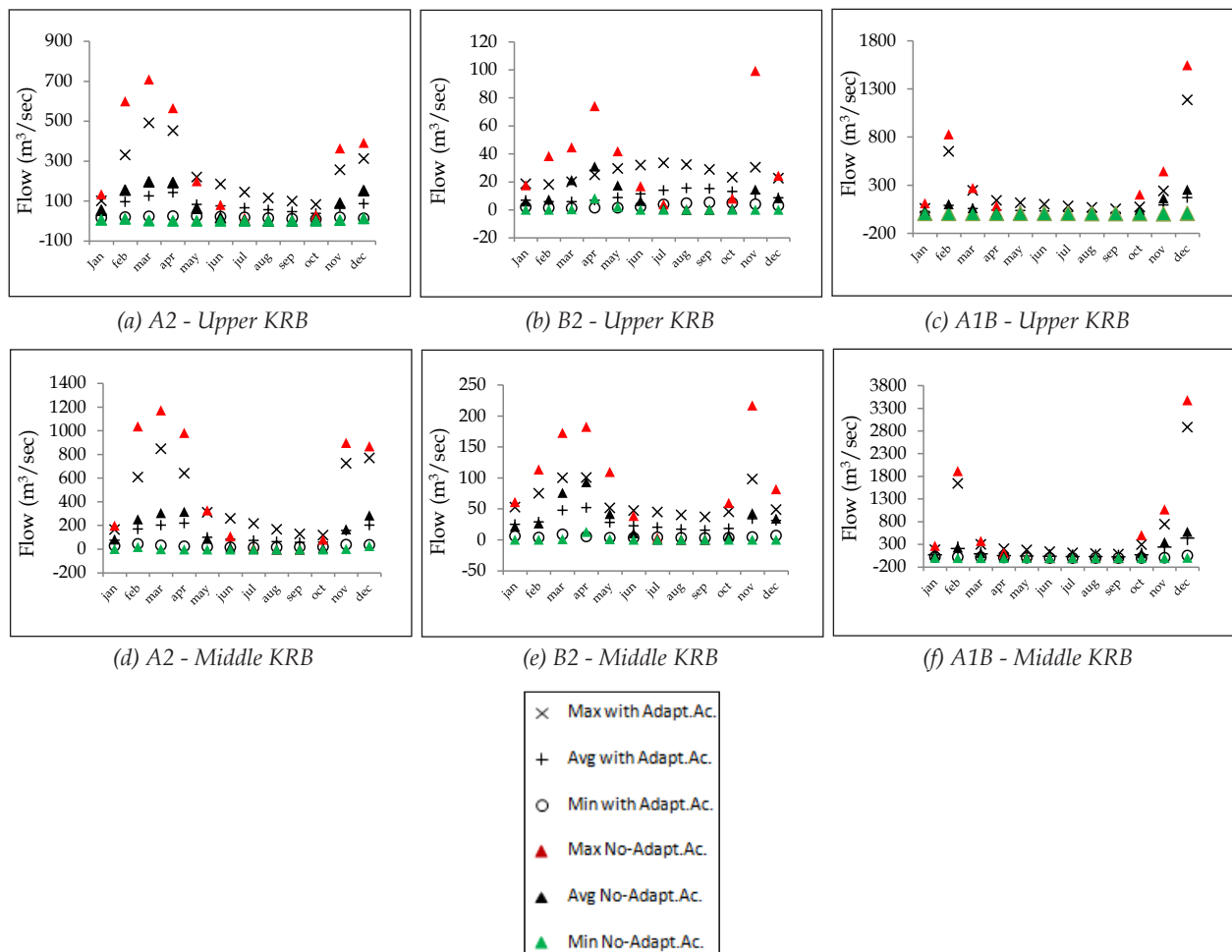


Fig. 2. Influence of choice of BMPs implementation on surface flow for various climate change projections in the KB; (a) A2 scenario in the upper KB, (b) B2 scenario in the upper KB, (c) A1B scenario in the upper KB, (d) A2 scenario in the middle KB, (e) B2 scenario in the middle KB and (f) A1B scenario in the middle KB.

result in increase in minimum, average and maximum flow during June to October under the A2, B2 and A1B scenario. The influence of specific adaptation activity is governed in a very complex manner on the projected climatic entities of precipitation and other meteorological parameters as well as their spatial distribution based on each scenario.

Conclusion

Capability of the SWAT model to evaluate the adaptation activities in detail through management and cultivation field operations as well as to operate on range and forest has been deployed. The impact of suggested adaptation activities were quantified and had various effects on the major hydrological components e.g. surface runoff, groundwater and sediment erosion. Amongst the suggested adaptation activities, Ac. 1 and Ac. 2, included terracing, strip cropping, GSS and contouring were found to influence significantly on selected hydrologic components. Both Ac. 1 and Ac. 2 were found to supplement the crop production against the extreme hydrologic condition. The effect of land-use change, the third activity (Ac. 3) on selected hydrologic components, was found to be comparatively less. The main impact of converting agriculture land to range and forest will result in the loss of income to the farming community. Agriculture in the KB is fully integrated with the economic activity of the region - the more efficient agriculture activities such as using the new technology to irrigate, using more efficient cultivars and using the proper fertilizers can compensate the loss of income. Thus, for an effective solution to reduce nutrient loading in the watershed, along with the management operations, the economic model of the region also needs to be addressed. The crop pattern change (Ac. 4) (using the Syrian 4, cultivar of durum wheat) results in slight increase in surface flow. The Ac. 3 and Ac. 4 have comparatively less impact on selected hydrologic components in comparison to both Ac. 1 and Ac. 2. The land-use and crop pattern changes are found to moderately alter the selected hydrologic components.

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