Environmental Engineering and Management Journal March 2019, Vol.18, No. 3, 707-718
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

"Gheorghe Asachi" Technical University of Iasi, Romania

TECHNICAL SUPPORT FRAMEWORK FOR SUSTAINABLE MANAGEMENT OF TRANSBOUNDARY WATER RESOURCES

Furat Al-Faraj[1], Miklas Scholz[1,2,3*]

[1]*Civil Engineering Research Group, School of Computing, Science and Engineering, The University of Salford, Salford, Greater Manchester M5 4WT, United Kingdom*
[2]*Division of Water Resources Engineering, Faculty of Engineering, Lund University, P.O. Box 118, 22100 Lund, Sweden*
[3]*Department of Civil Engineering Science, University of Johannesburg, Johannesburg, South Africa*

Abstract

Sustainable management of transboundary rivers, especially in water-scarce regions is increasingly becoming more challenging due to the collective adverse impact of upstream development and climate change on transboundary scale. Two major tributaries of the Tigris River, the Diyala (Sīrvān) and the Lesser Zab River basins, are shared between Iraq and Iran. They were adopted as representative basins for a large number of transboundary rivers, where short-sighted perspectives are currently ruling their management policies. Climate change is anticipated to lead to greater frequency and intensity of droughts, and higher tension is likely to emerge. The authors developed a technical support framework (TSF) that helps decision-making to alleviate the combined negative impact of climate change at basin scale and upstream human-induced impairments. The TSF encompasses six key measures: (1) cross-sectoral trade-offs; (2) improved water-use efficiency and reduction of losses; (3) development of a sound groundwater planning policy; (4) cutbacks in demand while maintaining environmental flow in the river; (5) inter- and intra-basin water transfer systems; and (6) quantification of current supply-demand gaps and sizing a future gaps. The framework supports the sustainable management of water resources in both Diyala and Lesser Zab basins as well as others in common river catchments. The recommendation is that a lower riparian country should put in place measures such as increasing water-use efficiency, rehabilitation of damaged and deteriorated irrigation facilities, and inter- and intra-basin water transfer arrangements to reduce the gap between growing water demands and corresponding supplies.

Keywords: anthropogenic intervention, climate change, riparian country, shared river basin, water governance

Received: April, 2016; Revised final: July, 2016; Accepted: August, 2016; Published in final edited form: March, 2019

1. Introduction

The management of water resources of transboundary river basins in a sustainable manner is of critical importance for social, economic and environmental development in riparian countries. Achieving a sustainable use of shared waters forms a major challenge, in particular, to the downstream country, due to a joint effect of upstream anthropogenic activities and the advent of climate change and variability. The growing imbalance between available water and the rapid increase of water demand has exacerbated the rivalry between the upstream and downstream riparian countries to unilaterally over-exploit the transboundary water resources.

One of the main keys towards a sustainable management of transboundary rivers is the management of shared water resources in an integrated manner. Given the complexity of development and management of transboundary watercourses associated with intensifying pressure on competitive water resources, a better understanding of challenges is a vital component to achieve a successful implementation of transboundary integrated water resources management (TIWRM). A broad spectrum

*Author to whom all correspondence should be addressed: e-mail: miklas.scholz@tvrl.lth.se; Phone.: +44 161 2955921; Fax: +44 161 2955575

of disparities between or among two or more riparian countries such as future national development trends, human resources and institutional capacities, physiographic features, socio-economic attributes, hegemonic position, conflicts of interest, and political orientation represent the major challenge to soundly manage and protect shared water resources at the transboundary scale (Feng and He, 2009; Gol et al., 2017; INBO-GWP, 2012; Savenije and van der Zaag, 2000; Zeitoun and Warner, 2006; Zeitoun et al., 2013).

The asymmetry has shaped different responses in terms of priorities and arrangements, hydro-meteorological monitoring networks, data-processing practices and management strategies (Al-Faraj and Al-Dabbagh, 2015; Al-Faraj and Scholz, 2015; SWH, 2012; UNECE, 2011). However, the ambivalence and diversity in the plans and actions could foster engaged riparian countries' actors to open up some opportunities to transform disparities and potential conflicts into active long-term collaboration rules.

Despite the efforts of some riparian countries to reach a binding agreement on shared water apportionment, the current eminent trend is that the upstream countries unilaterally endeavour to excessively utilise the transboundary waters on their territories (Ahmmad, 2010; Al-Faraj and Al-Dabbagh, 2015; Al-Faraj and Scholz, 2015). The upstream man-made interventions such as damming, large-scale water withdrawal practices and inter-basin water transfer systems have unequivocally raised concerns about the potential hydrologic alterations in flow regime at the downstream states (Al-Faraj and Al-Dabbagh, 2015; Al-Faraj and Scholz, 2014a,b; Magilligan et al., 2003; Olden and Poff, 2003; Poff et al., 2007; Rosenberg et al., 2000; Shiau and Wu, 2004; UNECE, 2010; Vorosmarty and Sahagian, 2000).

Climate change is likely to intensify many of these challenges despite uncertainty about the detail of its influence on water resources (Goulden et al., 2009; Hall et al., 2012). Miller and Yates (2006) have underlined the substantial importance of understanding how climate change may disturb the quantity and quality of water resources on which riparian neighbours depend on and compete over. The USAID (2012) highlighted the major challenges to climate change adaptation. These challenges include, but are not limited to data and information gaps, inadequate coverage of hydro-meteorological monitoring stations, lack of effective coordination across involved agencies, inadequate capacity to develop and implement adaptation plans, limited understanding of adaptation concepts by policy makers, little public awareness and weak engagement of civil society, inefficient irrigation practices, financial constraints as well as absence of clear and consistent legislations and regulations.

The main challenges in mitigating potential impacts of climate change and variability in river governance (Cap-Net UNDP, 2009; Al-Faraj et al., 2015b) are:

a) *Inadequate monitoring and observation networks as well as lack of data sharing:* appropriate understanding of current water resources conditions forms the baseline for detecting and examining the significance of trends; e.g., in rainfall and run-off patterns. The lack of efficient hydro-meteorological monitoring systems, including recording water quality parameters, is one of key factors hindering the sound management of transboundary river basins. Insufficient data and lack of transparent channels to exchange data and information at the local and transboundary levels would largely affect the quality of pointing out and assessing hydrological changes due to climate change. Even if data are available, they are likely to be treated as strategic national security resources and may not be disseminated widely enough, or the institutional arrangements may not be sufficiently robust enough to produce decisive conclusions about the state of the resource.

b) *Vulnerability:* climate change is anticipated to intensify these problems by altering the frequency and/or intensity of water-related hazards such as flash floods and severe prolonged droughts. Rapid population growth and urbanisation are the major drivers that contribute to increase pressure on finite freshwater resources, expanding the vulnerable zones and sizing the complexity of the problem. Developing a set of spatial distribution maps of vulnerable areas requires special attention while developing proper plans for climate change mitigation.

c) *Appropriate political, technological and institutional frameworks*: climate change mitigation measures should be integrated into the process of short- to long-term plans and strategies of water and land resources development and management. Organizational structures and institutional capacity are key elements of the water sector in developing countries, which require urgent and immediate strengthening and a clear definition of the role of all water-relevant stakeholders. Non-governmental organizations and the private sector should be involved in the shift towards adequate economic efficiency, as well as socially acceptable and environmentally sustainable mitigation options. The political support to develop the institutional structure and capacity is of paramount importance to successfully put potential measures into practice.

d) *Presence of public and stakeholders in decision-making*: the lack of public and stakeholder representation and involvement in decision-making is a major obstruction to appropriate solutions in water management. Vulnerabilities to the potential impacts of climate change and variability along with increasing stresses on limited water resources would increasingly exacerbate societal inequalities, in particular, in rural areas, where the communities are mainly dependent on agriculture for their livelihood. This entails the necessity to broaden the involvement of the public, stakeholders, non-governmental organizations and the private sector in shaping and putting potential measures and arrangements into practice.

Since the beginning of the 21st century, climate change-related problems and adaptation arrangements have been seen as a growing concern at national and international levels. Examples of recent research work have been widely documented (Al-Faraj and Al-Dabbagh, 2015; Al-Faraj et al., 2014, 2015b; Arnell and Charlton, 2009; Conway, 2005; Hiscock et al., 2002; Goulden et al., 2009; Hall et al., 2012; Kundzewicz et al., 2007; Keskinen et al., 2010; Kistin and Ashton, 2008; Ragab and Prudhomme, 2002; Timmerman and Bernardini, 2009; Tompkins et al., 2009; Timmerman et al., 2011; UNECE, 2009; USAID, 2012). A close examination of the literature shows that the mitigation options in the water sector are mainly grouped into three themes: (1) supply-side; (2) demand-side; and (3) cross-sectoral trade-offs (Fig. 1). In a related matter, Kundzewicz et al. (2007), Arnell and Charlton (2009) and Antwi-Agyei et al. (2013) have pointed out four main barriers and limits that may impede the process of adaptation to climate change. These barriers are of physical (i.e. deteriorated and/or damaged infrastructure), economic (i.e. lack of sufficient financial resources) and socio-political nature, and also comprise the capacity of water management institutions (i.e. lack of transparent coordination, lack of active programmes and insufficient knowledge).

With respect to developing adaptation strategies at transboundary scale, the IPCC (2001) reported that the current knowledge of adaptation and adaptive capacity to climate change is insufficient, and that there are serious limitations in existing evaluations of adaptation measures. Goulden et al. (2009) pointed out that few studies addressed adaptation to climate change in transboundary river basins. The UNECE (2010) indicated that in most cases, adaptation strategies are developed without taking transboundary aspects into account.

UNECE (2009, 2010, 2011) and FAO (2012) highlighted the need to develop adaptation strategies to cope with the range and depth of anticipated climate change impacts. Mitigating or adaptive actions by an individual state to address potential climate change impacts in a shared river basin are unlikely to achieve this objective (Swain, 2011). Despite the essential endeavours and investments in research work on mitigation options, no functional on-ground adaptation actions have been accomplished (Wise et al., 2014).

The UNECE (2011) underlined that very little is done at basin level in assessing the climate change impact and developing adaptation strategies to cope with the range and depths of anticipated effects. The report also highlighted the need for discussing water and climate change in the transboundary context. Furthermore, the SWH (2012) has pointed out that the knowledge on transboundary water management is deficient, fragmented and often case-specific.

Despite the growing need to consider IWRM at river basin scale, the current prevailing tendency is country-based unit management, which reduces the size of the problem and weakens actions. Moreover, there is a lack of profound understanding on water exploitation development and absence of workable adaptation measures to handle and mitigate the mutual impact in the transboundary context. A major challenge ahead is to develop measures for sustainable use of shared water resources. This paper thus attempts to develop a coherent technical framework that supports decision-making to successfully implement the TIWRM approach, under the joint impact of climate change and upstream human interventions, using the Diyala and Lesser Zab Rivers case studies where appropriate.

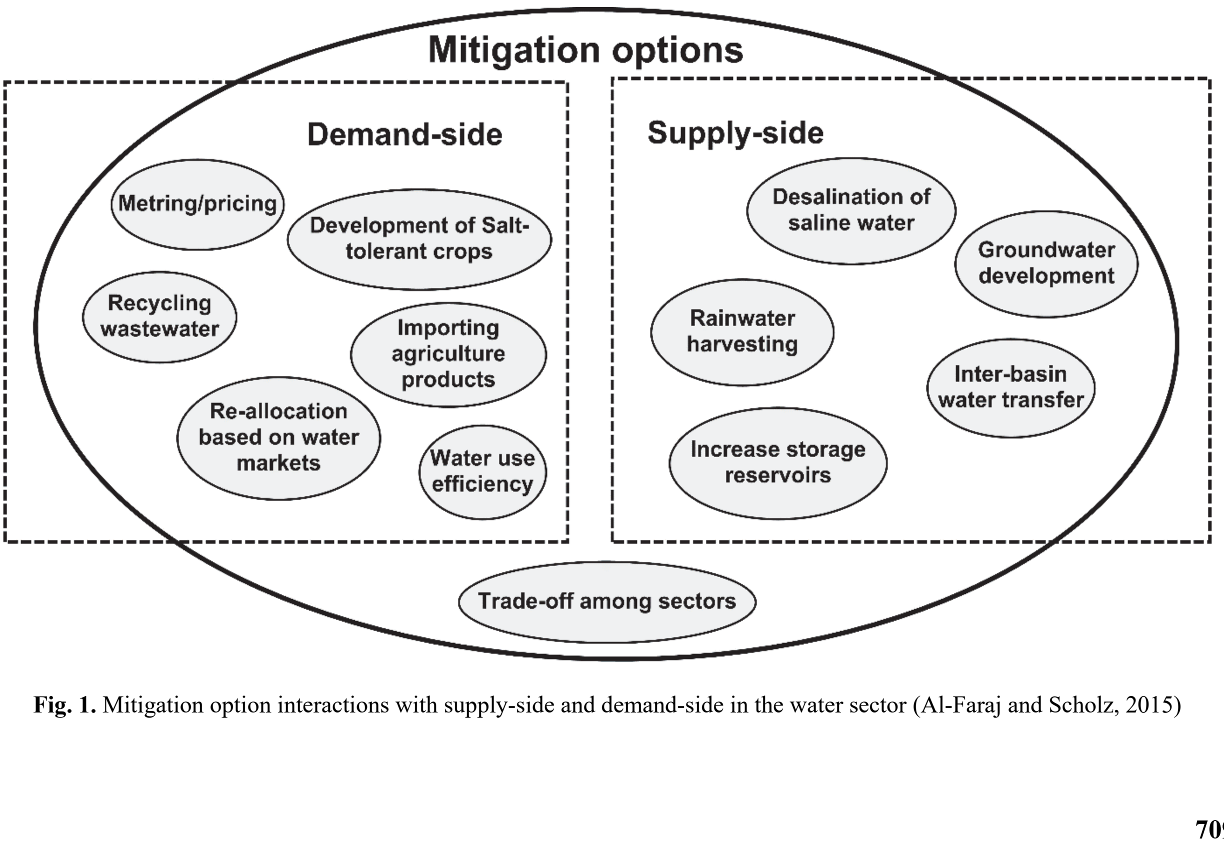

Fig. 1. Mitigation option interactions with supply-side and demand-side in the water sector (Al-Faraj and Scholz, 2015)

2. Case study presentations and methods

2.1. Representative case study basins

The size, magnitude and complexity of the problems plaguing the IWRM of transboundary watersheds make it essential to use a case study analysis to assess the various problems and potential solutions. The Diyala and the Lesser Zab River basins, shared between Iraq and Iran, were used in this study. The two basins encounter common challenges with a large number of other transboundary watersheds such as the rivers Nile, Euphrates, Tigris, Karkheh, Karun, Jordan, Shatt El-Arab, Yarmuk, Volta and Senegal, where the problem of unilateral management and the over-exploitation of shared waters are anticipated to intensify under the joint influence. Moreover, this is likely to lead to the emergence of socio-economic and environmental impairments.

2.1.1. Diyala watershed (case study I)

The Diyala watershed (Fig. 2) drains approximately 32,600 km^2, of which 43% and 57% belong to Iraq and Iran, respectively. The river basin is located within arid to semi-arid climate zones. The precipitation mainly falls between November and April, accounting for nearly 90% of the entire hydrologic year (Al-Faraj et al., 2015a). The majority of runoff is generated between November and May. The mean annual precipitation within the basin is estimated at approximately 500 mm. The potential evapotranspiration is estimated to be between 1500 mm/yr in the highlands and 2650 mm/yr in the lower portion of the basin.

Al-Faraj et al. (2015a) reported that the basin is becoming drier, with lower amounts of precipitation and higher rates of potential evaporation. The basin is extensively stressed, densely dammed and agriculturally highly developed, including a complex web of hydraulic control and diversion structures, irrigation projects, fish farms and public water distribution systems. Some hydraulic facilities and inter-basin water transfer facilities (Dariyan dam and Nosoud tunnel) are currently under construction and anticipated to be functioning in 2018. Irrigated agricultural land consumes the largest proportion of the annual water withdrawal, in particular, in the upper and middle segments of the basin in Iran, and in the lower part of the basin in Iraq. Irrigation areas of nearly 4446 km^2 and 1305 km^2 in Iraq and Iran, respectively, are the total potential targeted agricultural areas for irrigation. The annual irrigation water requirements are about 4.73 km^3 and 1.27 km^3 in Iraq and Iran, respectively (Al-Faraj et al., 2015b).

The middle and lower segments of the basin in Iraq are insecure and politically and socio-economically unstable. Some key water infrastructure (i.e., barrages, regulators and water diversion facilities) on the Diyala river have been controlled by Daesh (also known as Islamic State) several times during the recent war, cutting the water supply to thousands of people and posing a humanitarian crisis and security threat. Moreover, this has deprived large irrigation projects from benefiting from the Diyala River and has subsequently forced thousands of people working in the agriculture sector to flee their homes and lose their livelihoods (ORSAM, 2014).

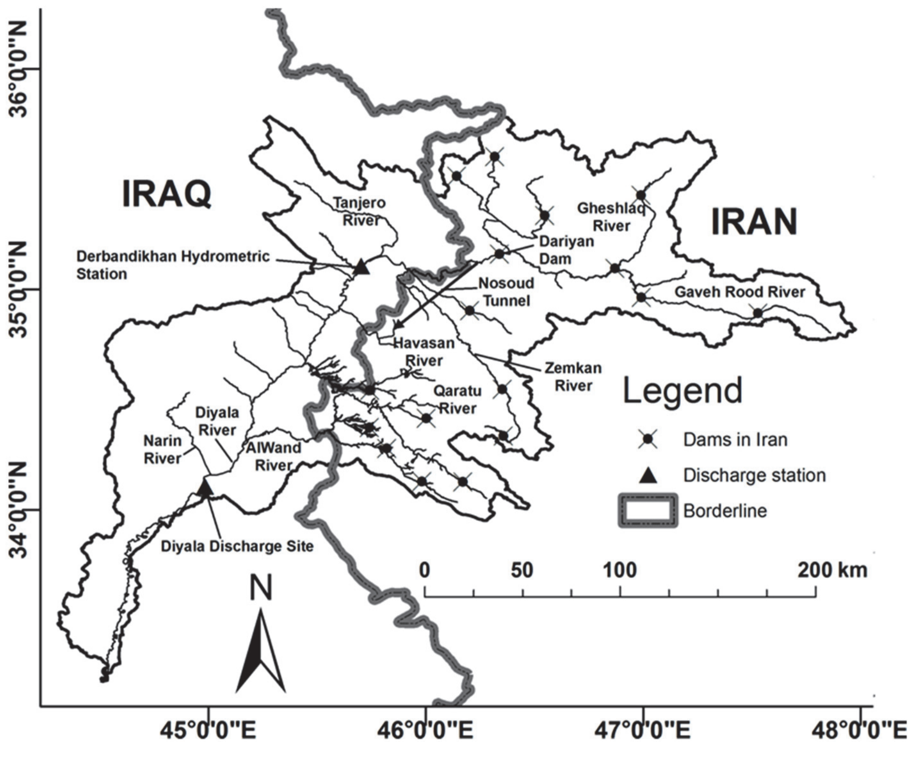

Fig. 2. Diyala River basin shared between Iraq and Iran (Al-Faraj and Scholz, 2014a)

Most of the irrigation infrastructure and associated arrangements are deteriorated and inefficient. A set of water pumps that is located on the left bank of the Tigris river in Iraq are being used to shift about 288 × 10^6 m^3 of water per year from the Tigris River in an attempt to compensate water shortages in the lower segment of the Diyala basin. Moreover, a recommendation (yet not implemented) has been made to convey water from the Lesser Zab River in Iraq to the Diyala basin via the proposed Lesser Zab-Diyala inter-basin water transfer canal. The yearly average flow volume that is recommended to be conveyed is estimated at about 945.4 × 10^6 m^3 (Al-Faraj et al., 2015b).

The Diyala basin may be seen as a long-term example for the politics of silence, mutual accusations and non-cooperation. The absence of a promising water treaty, inability to achieve binding water sharing agreements in the foreseeable future, and short-sighted governance of water resources in the lower riparian party, low irrigation efficiency at basin-scale, and lack of an information-sharing medium are the main drivers hindering the implementation of TIWRM. Moreover, data and information are regarded as a country secret.

2.1.2. Lesser Zab watershed (case study II)

The Lesser Zab River (Fig. 3) has its source in the Zagros Mountains in Iran at an elevation of 3,000 meters above sea level and joins the Tigris River in Iraq, and belongs to one of the main transboundary basins between Iraq and Iran. For a short distance, the Lesser Zab forms the border between Iran and Iraq. The River is approximately 400 km long draining a total area of about 22,000 km^2 (Merufinia et al., 2014). The larger part of the basin of approximately 77% lies within the Iraqi territory; the residual 23% extends to Iran. The basin spans over diverse climatic and ecological zones. The mean annual precipitation diminishes from over 1,000 mm in the Iranian Zagros Mountains to less than 200 mm at the confluence with the Tigris River in Iraq. Nearly 92% of the total annual precipitation takes place between November and May (wet season), and there is often little to no rain between June and early autumn in October. The amount and timing of precipitation within the wet season is highly variable between years.

The main watercourse of the Lesser Zab and its tributaries has recently been dammed in the upper riparian country Iran to meet multiple water demands. A number of dams and water control and diversion facilities have recently been constructed and commissioned such as the Baneh and Sardasht dams. Some other dams are at the planning stage such as the Shivahan and Garjhal dams (Al-Faraj and Al-Dabbagh, 2015). An inter-basin water transfer system is currently under construction to divert water from the Lesser Zab River basin to Lake Urmia in the north-western corner of Iran, in an attempt to ecologically restore and improve the ecosystem of the lake and irrigate about 9,400 hectars of farmland (Merufinia et al., 2014).

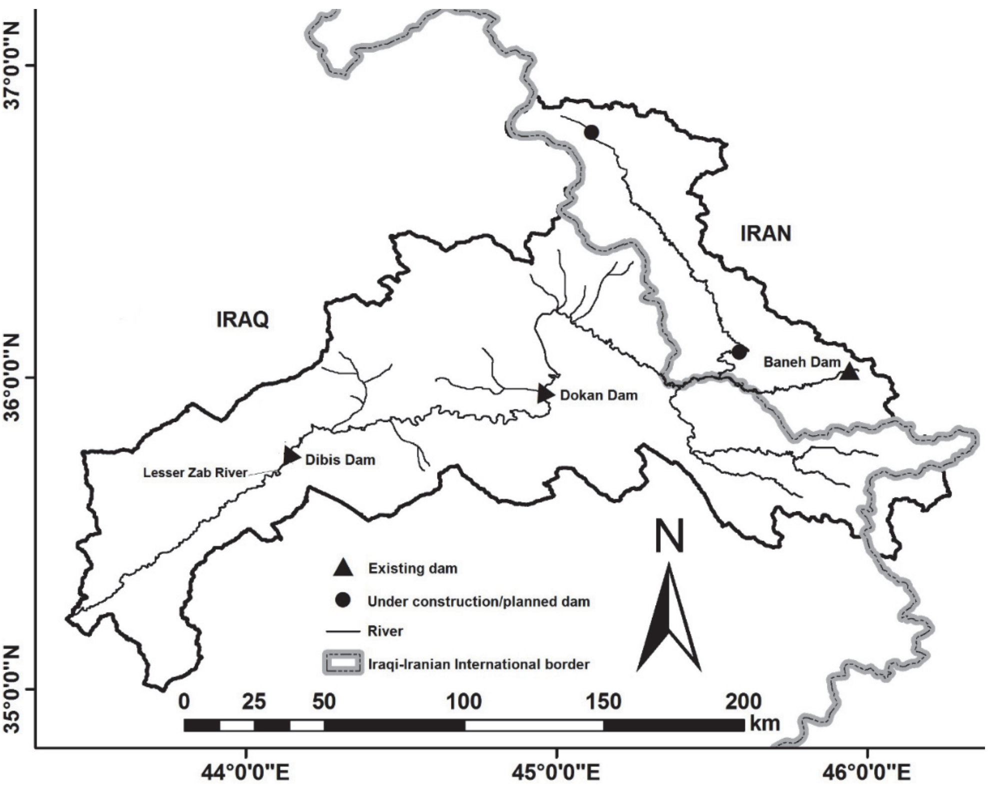

Fig. 3. Lesser Zab River basin shared between Iraq and Iran (Al-Faraj and Al-Dabbagh, 2015)

Al-Faraj and Al-Dabbagh (2015) pointed out that the rate of water supply and demand in the upstream country is anticipated to grow. They also indicated that the runoff observed in the downstream country has experienced a significant drop due to the combined effects of river regulation upstream and successive droughts, particularly during the drought episodes 1999-2001 and 2008-2009. The projection of future climate change highlights that the basin is anticipated to be drier, with lower precipitation and higher rates of temperature and potential evapotranspiration. However, they reported that the effect of the consecutive basin-wide droughts has remarkably outweighed the influence of the current upstream human-induced regulations. The recent and future anticipated developments need to be considered to properly quantify the influence of the upstream man-made interventions on the flow regime characteristics of the downstream riparian country.

Iraq's economy is currently suffering from great challenges due to its direct dependency on oil production, for which the global price has dropped to a relatively low level, which adversely impacts on the economy of Iraq. Moreover, fighting against the so-called Islamic State and the high number of displaced people has remarkably exhausted the economy and left Iraq in a very vulnerable situation. This has made any action towards the application of the IWRM plan at national and at transboundary scales extremely difficult. The Baneh Dam is situated 5 km northeast from Baneh town in Kurdistan Province (Iran). The Sardasht Dam situated at latitude 36°04′51.8″N and longitude 45°33′59.1″E is an embankment rock-fill earth core dam located 13 km southeast of Sardasht in the Iranian province of West Azerbaijan. The associated reservoir has a total storage capacity of 545 million m^3 (storage capacity of 380 million m^3 at normal reservoir elevation), height of 114 m from the river bed and length of 275 m. This water body supports a hydroelectric power station with an installed capacity of 150 MW and agricultural water supply for 14,000 hectares (Al-Faraj and Al-Dabbagh, 2015; Moshanir Consulting Company, 2015).

In Iraq, the Lesser Zab River is occupied by the Dokan Dam (35°57′15″N 44°57′10″E), where the drainage area is about 11,700 km^2; i.e., 53% of the total drainage area and the Dibis Dam (35°41′19″N 44°06′33″E), which is located approximately 140 km downstream of the Dokan dam, (130 km upstream of the confluence with the Tigris River). The main purpose of the Dibis Dam is to divert water from the river to the Kirkuk irrigation project, which is linked to a net irrigation area of 175,000 ha (MoWR, 2010). The irrigation practices within the area located upstream of the Dokan Dam at the Iraqi/Iranian border benefit Penjwin and a number of small farms such as Sangasar, Sarujawa, Ranya and Saraiyan. The information concerning these projects (MoWR, 1982, 2010) shows that the year 1991 was noticeably associated with some human-induced intrusions and disturbances (i.e. development in the irrigation area), which impaired the flow regime observed at the Dokan hydrometric station (DHS). Concerning the development in Iran, the Baneh Dam in Iran was operated in 2013 and Sardasht Dam was commissioned in 2015 (Al-Faraj and Al-Dabbagh, 2015; Khezeli, 2015).

2.2. Transboundary integrated water resources management

The Technical Advisory Committee (TAC) of the Global Water Partnership (GWP) (GWP-TAC, 2000) stated that there is no *"universal blueprint"* as to how the principles underlying IWRM can be put into practice, pointing out that*: "The nature, character and intensity of water problems, human resources, institutional capacities, the relative strengths and characteristics of the public and private sectors, the cultural setting, natural conditions and many other factors differ greatly between countries and regions. Practical implementation of approaches derived from common principles must reflect such variations in local conditions and thus will necessarily take a variety of forms"*. Moreover, GWP-TAC (2000) pointed out that *"Although there are substantive principles in international water law such as equitable utilization and prohibition of significant harm, there are formal constraints on their application, because countries are not obliged to resort to any third party unless they agree on a specific conflict resolution procedure"*.

Literature demonstrates the growing international and national recognition of the need to manage water using the IWRM approach (AWRA, 2011a, 2011b, 2015; USACE, 2010). The IWRM of transboundary waters has become a great challenge encountering riparian states. The diversity and differences in political attitudes, power asymmetry, socio-economic development, institutional capacity and skilled human resources, geopolitical sovereignty, cross-sectoral coordination and efficiency of physical infrastructure make it difficult to achieve a provident joint governance of transboundary waters.

It is noteworthy to mention the target 6.5 of the recently agreed sustainable development goals (UNESCO-IHP, 2016) highlighting that "*By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate*". Moreover, the UNESCO-IHP (2016) reported that "*transboundary water cooperation is intrinsically connected to several other principles of sustainable development reflected in the goals and targets, including environment, energy, and food amongst others, and therefore must be viewed as an integral piece of global water management*". The three-geographical scales of transboundary river basins are illustrated in Fig. 4: (a) the upper scale referring to the portion of the basin within the territory of the upper riparian country; (b) basin-wide scale representing the entire watershed; and (c) the lower scale referring to the portion of the basin within the territory of the lower riparian country. Differences in institutional capacity, unilateral water exploitation schemes of the transboundary water in the upper country, the absence of technical cooperation between the upper and lower riparian actors, the short-sighted management of water resources and the current insecure and unstable conditions in the lower riparian country have made it a complex challenge that is difficult to resolve under the current political circumstances.

The asymmetry between riparian countries emphasises the necessity of the inclusive approach for sustainable management and protection of transboundary waters (Swain, 2011). The differences have resulted in various outlooks, priorities and arrangements as well as monitoring networks, management plans and practices, and conflicting attitudes over transboundary water resources (Al-Faraj and Scholz, 2015a; Kundzewicz et al., 2007; Swain, 2011). The asymmetry is a critical element, which may lead to the dominance of one party (often the upstream state) over other riparian countries. Recent droughts and climate change implications have intensified the challenge, especially for the downstream countries (Caitlin and Francesco, 2013; FAO, 2011; Swain, 2011).

The disparities could open up an enabling environment in which adaptation to and mitigation of the combined impact of basin-wide climate change and upstream human-induced interventions and disturbance can be shaped. The three geographical scales can be considered as a platform where the vulnerability level can be assessed and appropriate actions to become more resilient can be taken. The platform offers better understanding of the drivers and supports the identification of thresholds for various variables. The United Nations Department of Economic and Social Affairs (UNDESA, 2014) reported that issues at transboundary scale predominantly include either the absence of a water treaty that govern water utilisation among riparian countries or considerable shortcomings in most of the signed water-related agreements. In the same regard, Brels et al. (2008) have stated that despite the increase of formal agreements, there are still numerous watersheds, which lack a rational legal framework for coordination and collaboration.

Swain (2011) argued that some riparian countries, believe that they have the absolute sovereign right to fully control and use the part of transboundary waters within their territorial boundaries. Tiwary et al. (2014) called for more cohesive, cross-disciplinary policy frameworks, going beyond the local administrative domains to maximise the co-management potentials while mitigating the wider environmental impacts.

2.3. Technical support framework

Some of the common key driving forces that affect the development of the two investigated example basins (Diyala and the Lesser Zab), which are utilized to develop the technical support framework, are as follows: (a) both basins have their sources in the upstream riparian country; (b) there is a lack of technical collaboration relevant to the management of transboundary watercourses as well as an absence of water agreements between the upstream and the downstream riparian countries; (c) both basins are characterized by an irregular and perennial flow regime that strongly depends on rainfall and high flows dominate between November and May; (d) firm agreements to share hydro-meteorological data between the upstream and downstream riparian countries is currently not present; (e) similar impacts of climate change; (f) inter-basin water transfer systems are currently under construction in the upstream country to convey water from the Diyala and the Lesser Zab basins to other basins; and (g) rates of irrigation efficiency are low over the entire basins.

The information obtained from both case studies and the literature review as well as the expertise from their research team were utilized by the authors in informing the research methodology. In essence, the proposed framework is based on expert judgement due to the high complexity of transboundary challenges.

The challenge of access to available water resources in many water-scarce countries is escalating rapidly due to ever-growing demands from agriculture, wetland restoration, fish farming, public water supply, hydropower generation and navigation. The demand is fueled by factors such as population growth, urbanization, increasing water abstraction associated with economic growth and industrialization. Climate change is anticipated to further increase water-stress in many areas.

The proposed technical framework (Fig. 5) encompasses a set of measures to contribute to decision-making by achieving a successful implementation of TIWRM. Each measure can be achieved through accomplishment of a number of arrangements and practices. These measures are: (a) increasing water use efficiency and reducing losses, including canal lining, closed conducts and sprinkler/drip irrigation systems; (b) undertaking cross-sectoral trade-offs between agriculture and fish farming, wetland restoration and public water supply (The water allocation should be economically efficient, socially acceptable and environmentally sustainable.); (c) developing a sound groundwater planning policy, including identification of aquifer characteristics, analyzing historical groundwater data, assessing the contribution of groundwater to total runoff, and legislations to control groundwater abstraction; (d) implementing cutbacks in demand while ensuring the environmentally acceptable flow in the river (reduction in water supply relative to water availability); (e) introducing inter- and intra-basin water transfer schemes, including water transfer from a donor basin to a basin of water deficiency within the same basin and/or between different basins; and (f) quantifying the current and future water supply-demand gaps.

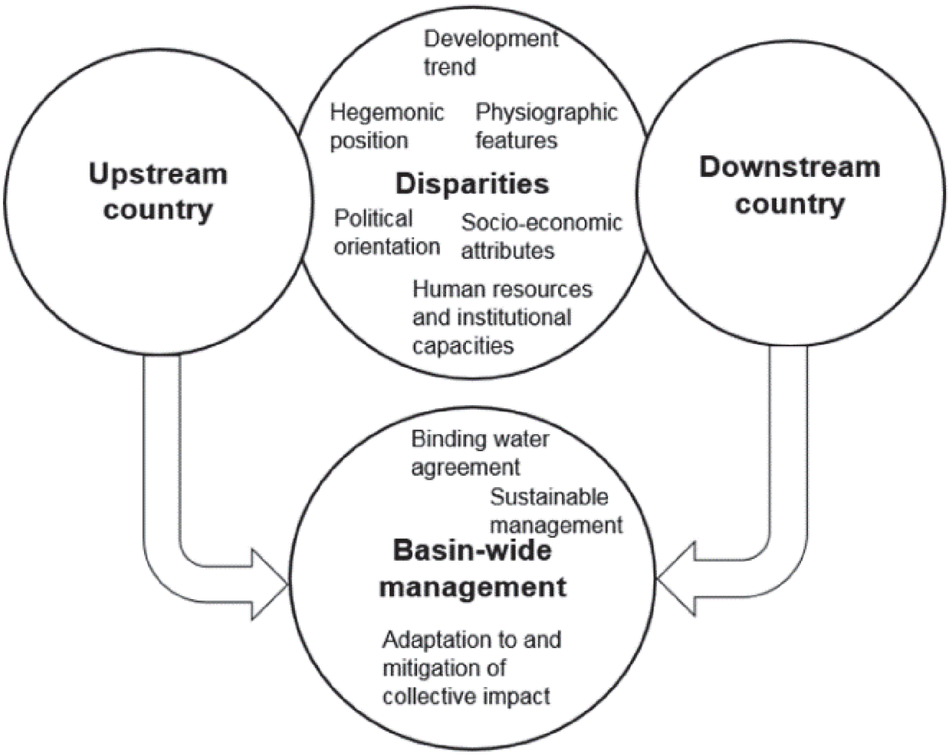

Fig. 4. Geographical scales and an overview of possible disparities between riparian countries

The framework responds to the urgent need to reduce the imbalance between the water demand and supply sides under the combined effect of man-made pressures at upstream and climate change at transboundary basin level.

3. Results and discussion

The successful implementation of the technical framework's measures is crucial to alleviate the collective potentially adverse impacts of climate change and climate variability at basin scale and anthropogenic pressure upstream. The failure to put the framework into practice would increase the reduction in water supply, deterioration of water quality, upset of food security, social and economic unrest, and potential national/regional conflicts. The delay to shift from inefficient irrigation arrangements and practices to high-efficiency delivery mechanisms would produce negative consequences on the socio-economic conditions and threaten the political stability at national and regional levels. The framework cannot be put into practice and its success ensured unless clear and consistent guidelines and binding regulatory measures are put into force, policy changes are firmly fulfilled, and a suitable fiscal budget for implementation is allocated.

Completing the formation of a national water council, is a crucial indispensable stage to chart and oversee the national water policy, draft long-term plans and help find potential solutions to handle and mitigate water shortage. Supervision of the council by the highest political level in the country and inclusion of representatives from all relevant ministries such as the ministries of water resources, agriculture, environment and industry will have a great influence on developing appropriate short- to long-term water strategies and policies. Moreover, the formation of a mandatory interdisciplinary technical body (secretariat/committee), which should be directly connected to the national council for water polices, is essential to provide technical advice and to better communicate research findings to both stakeholders and policymakers and propose sound integrated applications at national and basin-wide scales.

4. Conclusions and recommendations

The combined effect of upstream development and climate change is anticipated to intensify competition among the water users and sectors; i.e. agriculture, wetland restoration, fish farming, public water supply, navigation and energy producers. The study suggests integrating and mainstreaming the technical support framework into the core of short- to long-term water management plans and strategies at transnational and basin-wide level.

The process of bridging the disparities of two or more countries competing for transboundary waters is complicated and challenging for all actors. Accordingly, the framework demonstrates a solid platform to support decision-making, in particular, in downstream countries in the context of mutual impacts of climate change and anthropogenic activities upstream.

Securing authoritative supply of water that is appropriate in both quantity and quality is one of the most challenging issues presently facing portions of the Diyala and the Lesser Zab example basins located in the downstream country. Despite the fact that no individual measure can remedy the water shortage and alleviate the combined impact, in particular, in the lower riparian country, taking actions to put in place a number of measures such as increasing water- use efficiency, rehabilitation of deteriorated irrigation arrangements, implementing inter/intra-basin water transfer system, and introducing legislations to limit and avoid the over-abstraction of groundwater, aiming at reducing the gap between water demand and supply are crucial.

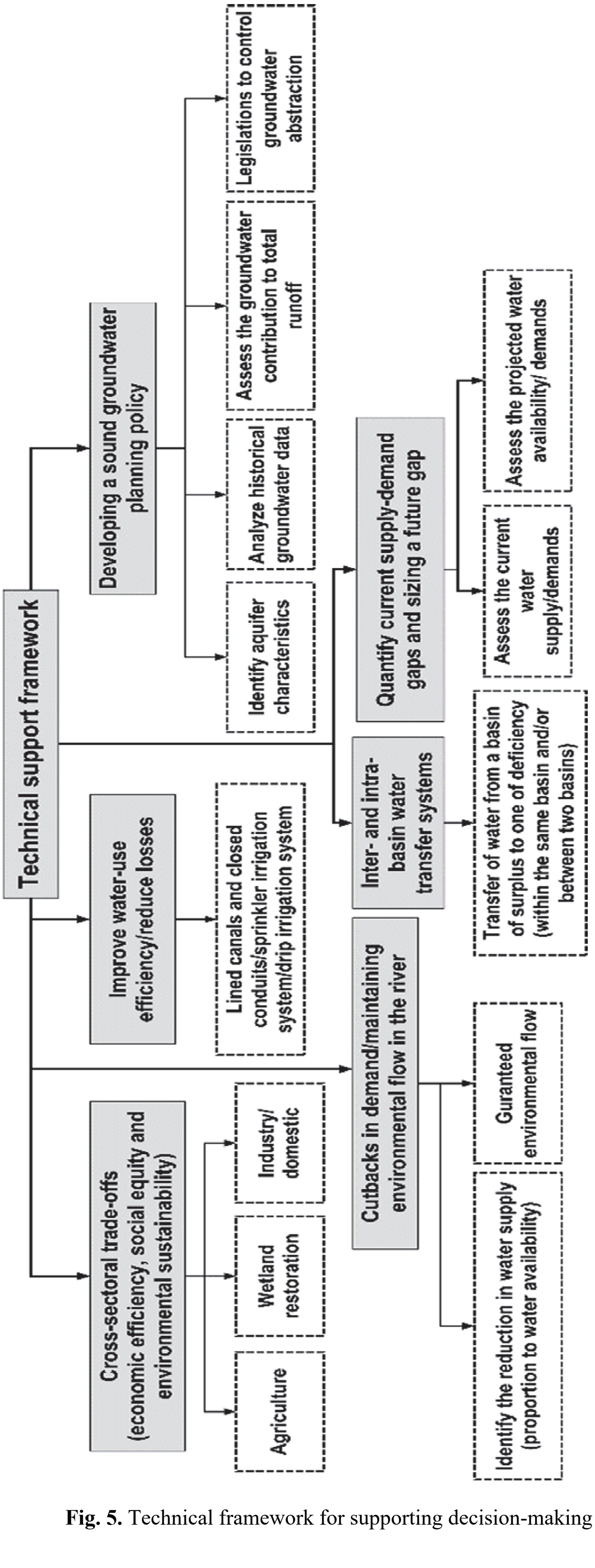

Fig. 5. Technical framework for supporting decision-making

The downstream country must endeavour to form a joint technical commission for both the Diyala and the Lesser Zab basins through which both upstream and downstream riparian countries can contribute to successfully accomplish the TIWRM. Accordingly, the basins can be examined as a pilot project through a series of joint actions.

The actions may include but are not limited to (a) cooperation at various levels; (b) urgent improvement of irrigation efficiency and rehabilitation of the infrastructure of irrigation arrangements; (c) setting up of hydro-meteorological monitoring network; (d) exchange of data and experiences in a transparent manner; (e) estimations of the current and projected water demands; (f) assessment of the future potential gaps between water demand and supply; (g) quantification of the groundwater contribution to total runoff; (h) examination of various scenarios of inter/intra-basin water transfer schemes; and (i) assessment of the potential impact of climate change on the whole basin. Findings would support decision-making to achieve effective TIWRM.

It would also demonstrate a solid approach and platform for adequate policies and actions that could contribute to the sustainable development and management of transboundary waters in other similar watersheds in the region.

References

Ahmmad Y., (2010), *Establishing a legal framework for the use and protection of Iraq's equitable right to the Tigris and the Euphrates River Basin*, PhD Thesis, University of Dundee, United Kingdom.

Al-Faraj F., Scholz M., (2014a), Assessment of temporal hydrologic anomalies coupled with drought impact for a transboundary river flow regime: The Diyala watershed case study, *Journal of Hydrology*, **517**, 64-73.

Al-Faraj F., Scholz M., (2014b), Incorporating the flow duration curve method within the digital filtering algorithms to estimate the base flow contribution to total runoff, *Water Resources Management*, **28**, 5477-5489.

Al-Faraj F.A.M., Al-Dabbagh B.N.S., (2015), Assessment of collective impact of upstream watershed development and basin-wide successive droughts on downstream flow regime: The Lesser Zab transboundary basin, *Journal of Hydrology*, **530**, 419-430.

Al-Faraj F., Scholz M., (2015), Impact of upstream anthropogenic river regulation on downstream water availability in transboundary river watersheds, *International Journal of Water Resources Development*, **31**, 28-49.

Al-Faraj F., Scholz M., Tigkas D., (2014), Sensitivity of surface runoff to drought and climate change: application for shared river basins, *Water*, **6**, 3033-3048.

Al-Faraj F., Tigkas D., Scholz M., (2015a), Sensitivity of irrigation requirements to improvement in irrigation system performance efficiency. Example of transboundary watershed, Proc. of the 9th World Congress of the European Water Resources Association (EWRA), Istanbul, Turkey, 10-13 June 2015, 1-13.

Al-Faraj F., Scholz M., Tigkas D., Boni M., (2015b), Drought indices supporting drought management in transboundary watersheds subject to climate alterations, *Water Policy*, **17**, 865-886.

Antwi-Agyei P., Dougill A.J., Lindsay C.S., (2013), Barriers to climate change adaptation in Sub-Saharan Africa: Evidence from Northeast Ghana & systematic literature review. Centre for Climate Change Economics and Policy. Working Paper No. 154, Sustainability Research Institute, Paper No. 52. On line at: http://www.cccep.ac.uk/Publications/Working papers/Papers/150-159/WP154-Barriers-to-climate-change-adaptation-in-sub-Saharan-Africa.pdf.

Arnell N.W., Charlton M.B., (2009), *Adapting to the Effects of Climate Change on Water Supply Reliability*. In: *Adapting to Climate Change: Thresholds, Values. Governance*, Adger W.N., Lorenzoni I., O'Brien K.L., (Eds), Cambridge University Press, Cambridge, 42-53.

AWRA, (2011a), Position statement: call for a national water vision and strategy. On line at: http://www.awra.org/policy/policy-statements-water-vision.html

AWRA, (2011b), Position statement: integrated water resources management in the US. On line at: http://www.awra.org/policy/policystatements-IWRM.html.

AWRA, (2015), Applied integrated water resources management. On line at: http://www.awra.org/impact/issues/1505imp_toc.pdf

Brels S., Coates D., Loures F., (2008), Transboundary water resources management: the role of international watercourse agreements in implementation of the CBD. CBD Technical Series no. 40, Secretariat of the Convention on Biological Diversity, Montreal.

Caitlin E.W., Francesco F., (2013), The Arab Spring and climate change. A Climate and Security Correlations Series, On line at: http://climateandsecurity.files.wordpress.com/2012/04/climatechangearabspring-ccs-cap-stimson.pdf.

Cap-Net UNDP, (2009), IWRM as a tool for adaptation to climate change: training manual and facilitator's guide, On line at: http://www.cap-net.org/documents/2014/06/iwrm-cc-training-manual.pdf.

Conway D., (2005), From headwater tributaries to international river: observing and adapting to climate variability and change in the Nile watershed, *Global Environmental Change*, **15**, 99-114.

FAO, (2011), Climate change, water and food security. Report No. 36. On line at: http://www.fao.org/docrep/014/i2096e/i2096e.pdf.

FAO, (2012), Adaptation to climate change in semi-arid environments. Experience and lessons from Mozambique. Environment and Natural Resources Management Series. Rome, 1-83, On line at: http://www.fao.org/docrep/015/i2581e/i2581e00.pdf.

Feng Y., He D., (2009), Transboundary water vulnerability and its drivers in China, *Journal of Geographical Sciences*, **19**, 189-199.

Gol C., Edis S., Yilmaz H., (2017), Legal and administrative problems in watershed management in Turkey: Case of Tatlicay watershed, *Environmental Engineering and Management Journal*, **16**, 2685-2698.

Goulden M., Conway D., Persechino A., (2009), Adaptation to climate change in international River watersheds in

Africa: a review, *Hydrological Sciences Journal*, **54**, 805-828.

GWP-TAC, (2000), Integrated water resources management. Technical Advisory Committee background papers No.4, On line at: http://waterwiki.net/images/a/a5/GWPIWRM.pdf.

Hall J.W., Watts G., Keil M., de Vial L., Street R., Conlan K., O'Connell P.E., Beven K.J., Kilsby C.G., (2012), Towards risk-based water resources planning in England and Wales under a changing climate, *Water and Environmental Journal*, **26**, 118-129.

Hiscock K., Rivett M., Davison R., (2002), Sustainable groundwater development, Geological Society, London, *Special Publications*, **193**, 1-14.

INBO-GWP, (2012) The handbook for Integrated Water Resources Management in transboundary basins of rivers, lakes and aquifers, On line at: http://www.gwp.org/Global/About%20GWP/Publications/INBO-GWP%20Transboundary%20Handbook/MGIREB-UK-2012_Web.pdf.

IPCC, (2001), Climate change: Synthesis report. On line at: http://www.ipcc.ch/pdf/climate-changes-2001/synthesis-syr/english/front.pdf (assessed 10 May 2016).

Keskinen M., Chinvanno S., Kummu M., Nuorteva P., Snidvongs A., Varis O., Vastila K., (2010), Climate change and water resources in the Lower Mekong River Basin: putting adaptation into the context, *Journal of Water and Climate Change*, **1**, 103-117.

Khezeli, A.R., (2015), Opportunities and challenges of using value engineering in Iran's Dam projects, *Current World Environment*, **10**, 389-396.

Kistin E., Ashton P., (2008), Adapting to change in transboundary rivers: an analysis of treaty flexibility on the Orange-Senqu river watershed, *International Journal of Water Resources Development*, **24**, 385-400.

Kundzewicz Z,, Mata L., Arnell N., Döll P., Kabat P. B., Jiménez K., Miller T., Oki Z., Shiklomanov I. (2007), Freshwater resources and their management. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry M.L., Canziani O.F., Palutikof J.P., van der Linden P.J., Hanson C.E., (Eds.), Cambridge University Press, Cambridge, 173-210.

Magilligan F., Nislow K., Graber B., (2003), Scale-independent assessment of discharge reduction and riparian disconnectivity following flow regulation by dams, *Geology*, **31**, 569-572.

Merufinia E., Aram A., Esmaeili F., (2014), Saving the Lake Urmia: from slogan to reality (challenges and solutions), *Bulletin of Environment and Pharmacology Life Science*, **3**, 277-288.

Miller K., Yates D., (2006), Climate change and water resources: a primer for municipal water providers, On line at: http://waterinstitute.ufl.edu/WorkingGroups/downloads/WRF%20Climate%20Change%20DocumentsSHARE/Project%202973%20%20Climate%20Change%20and%20Water%20Resources.pdf.

Moshanir Consulting Company, (2015), Sardasht dam and power plant, On line at: http://www.moshanir.co.ir/en/sardasht.aspx.

MoWR, (1982), General Scheme of Water Resources and Land Development in Iraq - Unpublished Technical Report, vol. III, Book 2, Appendix 23.4, Ministry of Water Resources, Iraq.

MoWR, (2010), Irrigation and Drainage Projects in Iraq. Unpublished Technical Report (in Arabic), Ministry of Water Resources, Iraq.

Olden J., Poff N., (2003), Redundancy and the choice of hydrologic indices for characterizing streamflow regimes, *River Research and Applications*, **19**, 101-121.

ORSAM, (2014), ORSAM Review of Regional Affairs, No. 6, July 2014: ISIS, KRG and New Hydropolitics order in the Euphrates-Tigris Basin.

Poff N., Olden J., Merritt D., Pepin D., (2007), Homogenization of regional river dynamics by dams and global biodiversity implications, *Proceedings of the National Academy of Sciences of the United States of America*, **104**, 5732-5735.

Ragab R., Prudhomme C., (2002), SW-Soil and Water: Climate Change and Water Resources Management in Arid and Semi-Arid Regions: Prospective and Challenges for the 21st Century, *Biosystems Engineering*, **81**, 3-34.

Rosenberg D., McCully P., Pringle C., (2000), Global-scale environmental effects of hydrological alterations: introduction, *BioScience*, **50**, 746-751.

Savenije H.H.G., van der Zaag P., (2000), Conceptual framework for the management of shared river basins; with special reference to the SADC and EU, *Water Policy*, **2**, 9-45.

Shiau J., Wu F., (2004), Assessment of hydrologic alterations caused by Chi-Chi diversion weir in Chou-Shui Creek, Taiwan: Opportunities for restoring natural flow conditions, *River Research and Applications*, **20**, 401-412.

Swain A., (2011), Challenges for water sharing in the Nile basin: changing geo-politics and changing climate, *Hydrological Sciences Journal*, **56**, 687-702.

SWH, (2012), Transboundary water management: Who does what, where? Analyzing the data in SIWI's transboundary water management database, On line at: http://www.siwi.org/documents/Resources/Reports/2012_TWM_REPORT.pdf.

Timmerman J., Bernardini F., (2009), Adapting to climate change in transboundary water management, On line at: http://www.worldwatercouncil.org/fileadmin/wwc/Library/Publications_and_reports/Climate_Change/PersPap_06._Transboundary_Water_Management.pdf

Timmerman J.G., Koeppel S., Bernardini F., Buntsma J.J., (2011), *Adaptation to Climate Change: Challenges for Transboundary Water Management*, In: *The Economic, Social and Political Elements of Climate Change. Climate Change Management,* Leal Filho W. (Ed.), Springer, Berlin, Heidelberg, 523-541.

Tiwary A., Chatterton T., Namdeo A., (2014), Co-managing carbon and air quality: pros and cons of local sustainability initiatives, *Journal of Environmental Planning and Management*, **57**, 1266-1283.

Tompkins E.L., Boyd E., Nicholson-Cole S.A., Weatherhead K., Arnell N. W., Adger W. N., (2009), An inventory of adaptation to climate change in the UK: challenges and findings, Working Paper 135, Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, On line at: http://www.tyndall.ac.uk/sites/default/files/twp135.pdf

UNDESA, (2014), International decade for action 'Water for Life' 2005-2015, On line at: https://www.un.org/waterforlifedecade.

UNECE, (2009), Guidance on water and adaptation to climate change. Convention on the protection and use of transboundary watercourses and international lakes, On line at:

http://www.unece.org/fileadmin/DAM/env/water/publications/documents/Guidance_water_climate.pdf.

UNECE, (2010), Water and climate change: How to develop an adaptation strategy in transboundary basins. A report for the workshop held in Geneva, 10–11 May 2010, On line at: http://www.docme.ru/doc/395811/1-water-and-climate-change--how-to-develop---unece.

UNECE, (2011), Second workshop on adaptation to climate change in transboundary watersheds: challenges, progress and lessons, On line at: http://www.unece.org/env/water/meetings/transboundary_climate_adaptation_workshop.html.

USACE, (2010), National Report: Responding to National Water Resources Challenges, Building Strong Collaborative Relationships for a Sustainable Water Resources Future. Washington, D.C. On line at: http://www.buildingcollaboration-for-water.org/Documents/nationalreport_final.pdf.

USAID, (2012), Climate change and adaptation plan, On line at: http://www.usaid.gov/sites/default/files/documents/1865/Agency%20Climate%20Change%20Adaptation%20Plan%202012.pdf.

Vorosmarty C., Sahagian D., (2000), Anthropogenic disturbance of the terrestrial water cycle, *BioScience*, **50**, 753-765.

Wise R.M., Fazey I., Stafford Smith M., Park S.E., Eakin H. C., Archer Van Garderen E.R M., Campbell B., (2014), Reconceptualising adaptation to climate change as part of pathways of change and response, *Global Environmental Change*, **28**, 325-336.

Zeitoun M., Goulden M., Tickner D., (2013), Current and future challenges facing transboundary river basin management, *WIREs Climate Change*, **4**, 331-349.

Zeitoun M., Warner J., (2006), Hydro-hegemony-A framework for analysis of transboundary water conflicts, *Water Policy*, **8**, 435-460.