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Islamic Azad University, Ardabil Branch
Anthropogenic Pollution Journal, Vol. 2(1), 2018: 38-47
DOI: 10.22034/ap.2018.538376

APJ
2588-4646

Investigating multiple human pressure types in the southern Caspian Sea Basin Rivers at different spatial scales toward Integrating Water Resource Management (IWRM) in Iran

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Received: 18 October 2017/ **Accepted**: 20 January 2018/ **Published**: 30 February 2018

Abstract: Water security problems are becoming more and more challenging in Iran for several reasons such as population growth, urbanization, land-use change, unsustainable water use and climate change. All the mentioned reasons result in an increase in the human exploitation of water resources and consequently increasing anthropogenic impacts on rivers, flood plains, and fresh groundwater. Therefore, assessment of the human pressures on rivers is particularly important to find areas where water resources are threatened and subjected to rapidly increasing anthropogenic effects. By this integrated approach, a successful Integrated Water Resources Management will be achieved to guide policy makers for best protection, restoration and management. In this regard, Southern Caspian Sea Basin Rivers (including Kura-South Caspian and Caspian Highland ecoregions) were studied in terms of human pressure types. Human pressures were analyzed at different spatial scales, and finally seven main pressure types (i.e. Land use, Hydrology, Morphology, Connectivity, Water quality, Biology) were defined in which the abundance and distributions of each pressure type was different. According to this study, most areas were impacted by land use pressure type followed by water quality. Moreover, most areas were threatened by multiple pressures.
Keywords: Freshwater, Human pressure types, Spatial scale, Southern Caspian Sea Basin, Iran.

1. Introduction

Water is considered one of the fundamental keys of development, economic prosperity, and social well-being (Meador et al. 2008; Ruaro and Gubiani 2013). The security of water for people and river biodiversity throughout the world has been seriously reduced by human based pressures on freshwater resources. Almost 80 percent of the world's population is at high risk from threats to water security and 65 percent of the river habitats are under threat (Vörösmarty et al. 2010). Among plenty of rivers in the world, only small percentages are minimally affected by human activity. These rivers are generally located in remote areas with low populations or in uninhabited tropical places.

Since 2000, the European Union has adopted an ambitious water policy, the Water Framework Directive (WFD) in order to protect, restore and manage water resources and aquatic ecosystems (Pont et al. 2006, 2009; Schmutz et al. 2007). Their main objective was to reduce pressures and achieve good ecological status for all European water bodies. With this aim, they established programs of measures to reduce significant anthropogenic pressures affecting ecological status of European rivers (Schinegger et al. 2012, 2013). As a matter of fact, human activities have caused multiple pressures on waters, including water pollution, river morphology and connectivity modifications, alterations of water flow regime and the introduction of alien species. Multiple pressures cause threats to human water

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security and freshwater biodiversity, and will produce cumulative effects in aquatic ecosystems (Mostafavi et al. 2014a & b, 2015). These mentioned crises are interdependent and should not be considered separately. Therefore, any resolution must deal with all pressures, quantity, quality and equity, at the same time to achieve an appropriate solution that is economically efficient, ecologically sustainable, and politically acceptable.

In the developing countries, integrated management of water resources should be used to address multiple human pressure types. According to Coad (1980), Kiabi et al. (1999), Abdoli (2000), Esmaeili et al. (2007), Abdoliand Naderi (2009) and Mostafavi et al. (2014a &b,2015), nearly all Iranian river basins are currently suffering from numerous human pressures which are directly affecting the physiochemical conditions of the running waters. However, the decision makers in Iran still rely on single pressure or quantify different human pressures separately with focusing on the local scale not integrate them for a successful management. Therefore, in this study we are going to emphasize human pressures at multiple types and scales toward successful Integrating Water Resource Management (IWRM) for Iran. In this regard, Southern Caspian Sea Basin was selected to quantify and identify all the available human pressures.

2. Material and Methods

The study area is located in the Southern Caspian Sea Basin, north of Iran. Two ecoregions i.e. Kura-South Caspian Drainages and Caspian Highlands were selected according to Abell et al. (2008), and then190 sites (including 95 references and 95 impacted sites)- allocated at 130 medium sized streams (up to 20m width)- were randomly defined.

To quantify different anthropogenic pressures, we surveyed 30 pressure variables according to Degerman et al. (2007); EFI+ consortium (2009) and Schinegger et al. (2012) (Table 1). Thirty pressure variables were relevant to the following seven pressure types: (1) land use, (2) connectivity disruption, (3) morphological alteration, (4) hydrological alteration, (5) water quality deterioration, (6) biological pressures and (7) other pressures (Table 1). All pressures were measured at four spatial scales: drainage, primary catchment, segment and site. Land use pressures were measured on drainage, catchment and site scale. Information on connectivity pressures was collected on the segment level. The remaining pressures were collected on site level (Table 1). Afterwards, all pressure variables were classified along a five-step graded classification scheme, i.e. (1) high, (2) good, (3) moderate, (4) poor and (5) bad status according to Degerman et al. (2007); EFI+ consortium (2009), Schinegger et al. (2012) and Anonymous (2013). Finally, a Spearman's rank correlation test was used to identify redundant variables in order to exclude variables with high co-linearity ($\rho > |0.70|$). All the remained pressure variables were calculated to achieve a global pressure index. This index was finally rescaled into five classes (i.e. Class 0 – containing values less than 3 (unimpacted/slightly impacted sites (reference sites are included in this class); Class 1 - values ranging from 3 to 5 (single pressure from respectively one group); Class 2 - values ranging from 6 to 8 (double pressures from respectively two groups); Class 3 - values ranging from 9 to 11 (triple pressures from respectively three groups); Class 4 - values greater than 11 (multiple pressures from respectively four or five groups)) according to the number of pressure groups involved, which was named human pressure class (see Mostafavi et al. 2014a & b, 2015).

Table 1. Human pressure classification into seven human pressure types (LUP: Land Use Pressure, CP: Connectivity Pressure, MP: Morphological Pressure, HP: Hydrological Pressure, WQP: Water Quality Pressure, BP: Biological Pressure, OP: Other Pressure) and their definitions.

Human pressure variable	Type	Code	Classification
Agriculture	LUP	LU_agri_sit	Range: 50m from stream; 1 = none, 3 = along one side, 5 = along both sides

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Urbanisation	LUP	LU_urb_sit	Range: 100m from stream; 1 =<5%, 3 = ≥5% &<10% , 5 = ≥10%
[a]Agriculture	LUP	LU_agri_pc	Extent and pressure of agriculture and silviculture; 1 = <10% , 3 = ≥10% &<40% ,5 = ≥40%
[a]Urbanisation	LUP	LU_urb_pc	Extent and pressure of urban areas; 1 = <1 %, 3 = ≥1% &<15%, 5 = ≥15%
[a]Agriculture	LUP	LU_agri_dr	Extent and pressure of agriculture and silviculture; 1 = <10%, 3 = ≥10% &<40%, 5 = ≥40%
[a]Urbanisation	LUP	LU_urb_dr	Extent and pressure of urban areas; 1 = <1%, 3 = ≥1% &<15%, 5 = ≥15%
Migration barrier upstream	CP	C_B_s_up	Barriers on the segment level upstream; 1 = no, 3 = partial, 3 = yes
Migration barrier downstream	CP	C_B_s_do	Barriers on the segment level downstream; 1 = no, 4 = partial,4 = yes
Channelisation	MP	M_channel	Alteration of natural morphological channel plan form; 1 = no, 3 = intermediate, 5 = straightened
Channelisation	MP	M_crosssec	Alteration of cross-section; 1 = no, 3 = intermediate, 5 = technical cross-section /U-profile
Channelisation	MP	M_instrhab	Alteration of in-stream habitat condition; 1 = no,3 = intermediate, 5 = high
[a]Channelisation	MP	M_embankm	Artificial embankment; 1 = no (natural status), 2 = slight (local presence of artificial material for embankment), 3 = intermediate (continuous embankment but permeable), 5 = high (continuous, no permeability)
Channelisation	MP	M_ripveg	Alteration of riparian vegetation close to shoreline; 1 = no, 2 = slight, 3 = intermediate, 5 = high (no vegetation)
Flood protection	MP	M_floodpr	Presence of dykes for flood protection; 1 = no, 3 = yes
[a]Flood protection	MP	M_remfloodpl	If the river has a former floodplain- Proportion of connected floodplain still remaining. Floodplain = area connected during the flood; 1 = >50%, 2 = 10-50%, 3 = <10 %, 5 = some water bodies remaining or no
Sedimentation	MP	M_sediment	input of fine sediment (mainly mineral input; bank erosion, erosion from agricultural land); 1 = no, 3 = yes
[a]Flow velocity increase	HP	H_veloincr	Pressure on flow conditions (mean velocity) due to channelization, flood protection, etc.; 1 = no, 3 = yes
Impoundment	HP	H_imp	Natural flow velocity reduction on site because of impoundment; 1 = no (no impoundment), 3 = intermediate, 5 = strong
Hydropeaking	HP	H_hydrop	Site affected by hydropeaking; 1 = no (no hydropeaking), 3 = partial, 3= yes
Water abstraction	HP	H_waterabstr	Site affected by water flow alteration/minimum flow; 1= no (no water abstraction), 3 = intermediate (less than half of the mean annual flow), 5 = strong (more than half of mean annual flow)
[a]Reservoir flushing	HP	H_reflush	Fish fauna affected by flushing of reservoir upstream of site; 1 = no, 3 = yes
[b]Temperature pressure	HP	H_tempimp	Water temperature pressure; 1 = no, 3 = yes
[b]Eutrophication	WQP	W_eutroph	Artificial eutrophication; 1 = no, 3 = low, 4 = intermediate (occurrence of green algae), 5 = extreme (oxygen depletion)
[b]Acidification	WQP	W_aci	Acidification; 1 = no, 3 = yes
[b]Organic siltation	WQP	W_osilt	Siltation; 1 = no, 3 = yes

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[a,b] Organic pollution	WQP	W_opoll	Is organic pollution observed; 1 = no, 3 = intermediate, 5 = strong
[b]Toxicity	WQP	W_toxic	Toxic priority substances (organic and nutrient appearance); 1= no or very minor, 3 = weak (important risk, link to particular substance), 5 = high concentration (a clearly known input)
Pressure of exploitation	BP	B_explo	Fishing, at site affecting fauna, information based on local fishermen; 1 = no, 3 = intermediate, 5 = strong
Introduction of fish	BP	B_intro	New fish species to river basin; 1 = no introduction, 2 = introduction, but no reproduction and low density, 3 = not reproduction, high density, 4 = reproducing, low density, 5 = reproducing, high density
Other pressures	OP	O_imp	E.g. explosion of oil pipe 1=no, 3=weak, 5=strong (expert judgment)

3. Results and Discussion

Overall, among all impacted sites, all seven pressure types were recognized and confirmed for the studied rivers of Southern Caspian Sea Basin (Figure 1). “Other pressure” (OP) was related to an oil pipe explosion. After accounting for redundancy ($\rho > |0.70|$), 21 pressure variables remained for further calculations (see Table 1).

Un-impacted sites

Impacted sites with land use pressure type

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Impacted sites with hydro-morphology and water quality pressure types

Impacted sites with hydro-morphology pressure types (channelization)

Impacted sites with connectivity pressure type

Impacted sites with hydrology pressure type

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Impacted sites with water quality pressure type

Impacted sites with biological pressure type (invasive species)

Fig.1. The affected sites with different human pressure types in the studied area.

The most frequent human pressure among all of the human pressure types was land use (LUP), occurring at 29.27% of sites, followed by water quality (25.20%) and morphological pressures (23.58%) respectively (Fig. 2).

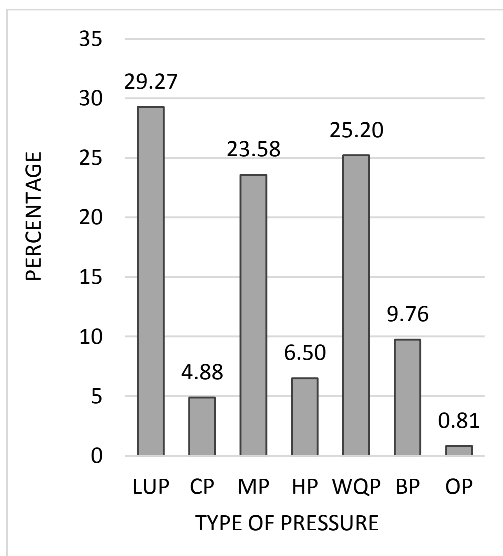

Fig. 2. Percentage of the sites affected by no/slight pressure, land use pressures (LUP), connectivity pressures (CP), morphological pressures (MP), hydrological pressures (HP),

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water quality pressures (WQP), biological pressures (BP) and other pressures (OP) in the studied area.

Moreover, most sites were affected by multiple pressures (38.54%) followed by double and triple pressures (27.08% each) and few sites were only influenced by a single pressure (7.29%) (Fig. 3). The distribution of the Global pressure index (RPI) for sampling sites is delineated in Figure 4.

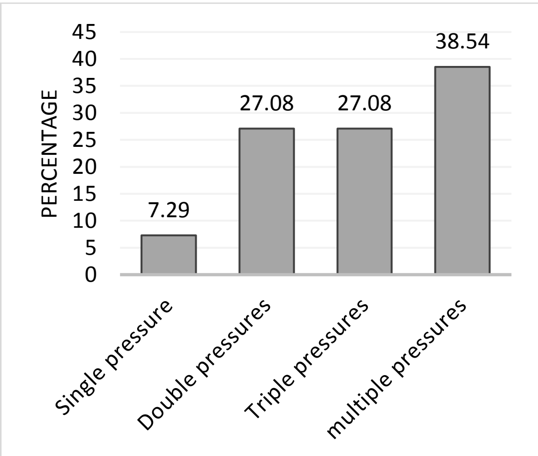

Fig. 3. Number of sites affected by no, single, double, triple and multiple pressures in the studied area.

Freshwater ecosystems are an integral part of human beings. By developing of societies, Human manipulates rivers to meet their needs. They created dam and straighten them, introduce exotic species that compete with native biota, extract water to irrigate crops, and also divert them to develop urban, agricultural and recreational areas (Bjorkland et al. 2003).

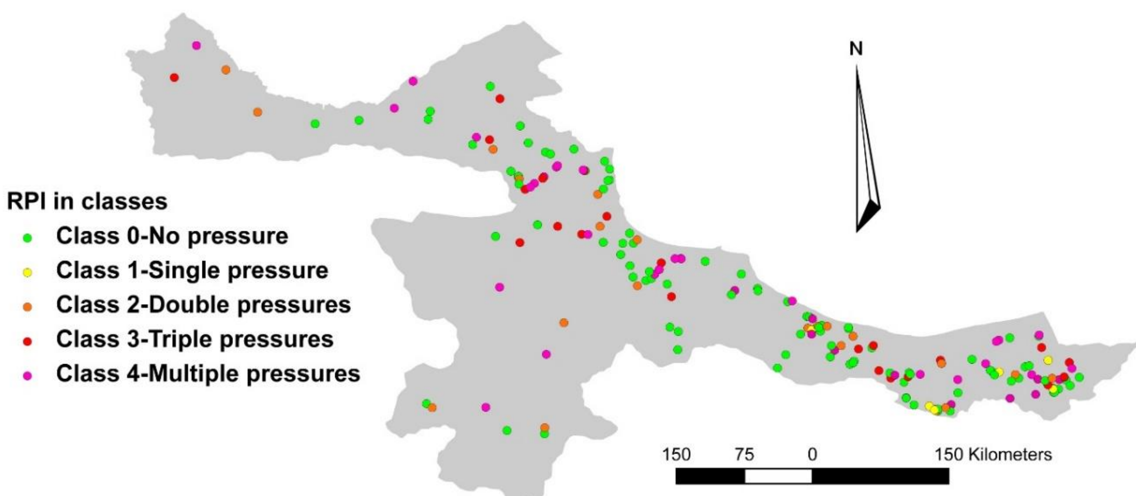

Fig. 4. Map of the sites affected by no, single, double, triple and multiple pressures in the studied area.

Integrated water resources management (IWRM) is a systematic process for the sustainable development, allocation and monitoring of water resource use in the context of social, economic and environmental objectives. IWRM is based on the understanding that all the different uses of finite water resources are interdependent. IWRM is hence a "process which promotes the coordinated development and management of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner, without compromising the sustainability of vital ecosystems" (Rahaman et al. 2004; Biswas et al. 2005).

Likewise the other countries, rivers play critical role in underpinning development of Iran e.g. their water supply industry, agriculture and domestic user, generation of energy, trade route etc. (Mostafavi et al. 2004, 2014a&b). However, river basin management in this country has insufficiently understood the importance of an intact aquatic ecosystem as a basis for various functions and services. During the last decades, as the rest of world, Iranian running waters have been facing many human pressures. Although Iran is a very diverse country and there are some parts with plenty of water, many parts are very dry. Therefore, the proper use of water is a critical issue for the development of Iran, and disturbance of the water cycle results in gradual emergence disturbance in the life cycle. Consequently, it is highly necessary to protect, enhance and restore all surface waters with the aim of achieving a good ecological status by balancing different needs in various riverine systems, as e.g. demanded by the EU-Water Framework Directive. And, management of river basins must include maintaining ecosystem functioning as a paramount goal.

Human Pressure Types

According to our findings, seven human pressure types were recognized in the Southern Caspian Sea Basin Rivers as follow;

Land Use Pressures

Land uses that impact water resources include; agriculture, forestry, urbanization, recreation, and industrialization. According to Akhani et al. (2010), half of the forest in the Southern Caspian Sea Basin was eradicated in recent decades (from 3.6 million to 1.8 million hectares). In contrast, the extent of agriculture and build-up areas increased. This finding is well mirrored by our data as the most sites were affected by land use pressures. According to Osborne and Wiley (1988), land use changes promote longer dry season flows, concentrating contaminants, allowing the accumulation of detritus, algae, and plants, and fostering higher temperatures and lower dissolved oxygen levels, all of which may extirpate sensitive native species. Exotic species often thrive in med-rivers altered by human activity, further homogenizing river communities worldwide (Mostafavi et al. 2004; Trautwein et al. 2012). All were in line with our finding in this study.

Hydrological Pressures

Water abstraction is one of the most important hydrological pressures according to our findings not only for this basin but also for other basins in Iran. Water abstractions may be taken directly from the flowing waters in the rivers, or indirectly from wells by pumping water from aquifers that may be closely connected to rivers. Water is mostly abstracted for the purpose of agricultural irrigation via establishment of dams as well as direct water abstraction from streams by artificial channels and pumps. Due this, some rivers have no flowing water for some months (specially in summer) of the year, or flows are reduced to only a fraction of their original magnitude. Water abstraction decrease water velocity, water depth, and wetted channel width and changes in thermal regime and water chemistry. And all these findings are in agreement with other studies (e.g. Bernardo et al. 2003; Meador and Carlisle 2007).

Connectivity pressures. Almost all of the rivers in the Southern Caspian Sea Basin are disconnected from the sea due to ground sills (with drops up to 1.5 m for the establishment of bridges) or/and dams. Due to the mentioned connectivity barriers, no long-distance migratory species (e.g. *Acipenser sp.*, *C. wagneri; R. caspicus; R. rutilus*) were observed in our study sites, while these species have been reported in many of the sampled rivers in the past (e.g.Holčík and Oláh 1992; Mostafavi 2007; Abdoli and Naderi 2009).

Water Quality Pressures

Observed water quality pressures are mostly related to untreated sewage of cities and agriculture for the recent decades. It was observed that the effluent of agriculture and some livestock, factories, slaughter houses, hospitals, restaurants and etc. is directly discharged into rivers without any treatment. Agricultural effluents also contain high levels of phosphate, nitrogen, potash and pesticides which is in line with our study as increases measured parameters like NO_2^-, NO_3^- and PO_4^{3-}. Another issue can be related to the sewage of fish farming in this basin which are considerably distributed in most areas. They generally, decrease pH and dissolved oxygen, in contrast to chemical oxygen demand, ammonia, phosphates and microbiological parameters, were increased downstream from the fish farm discharges. Other significant variations were also found for conductivity and temperature.

Morphological Pressures

This type of pressure is mostly related to Channelisation. Channelisation is generally linked to farmland acquisition, construction of bridges or roads, flood prevention as well as river bed and bank erosion control. Moreover, gravel mining and sand extraction are other main drivers for morphological pressures, changing the stream's physical habitat characteristics and leading to e.g. siltation, clogging of the riverbed, turbidity and degradation of the riparian vegetation (Lau et al. 2006; Padmalal et al. 2008; Paukert et al. 2011). The intensity of this pressure in some rivers we sampled is very high and the associated fine sediment inputs result in high turbidity (values up to 1185 NTU were observed).

Other Biological Pressure

Actually, overexploitation and unusual methods of fishing such as using cast net, electricity, toxics and dynamite are the other known threats based on our study and others (Abdoli 2000; Esmaeili et al. 2007; Mostafavi et al. 2015). Most people's idea of water pollution involves things like sewage, toxic metals, or oil slicks, but pollution can be biological as well as chemical. In some parts of the world, alien species are a major problem. Alien species (sometimes known as invasive species) are animals or plants from one region that have been introduced into a different ecosystem where they do not belong. Outside their normal environment, they have no natural predators, so they rapidly run wild, crowding out the usual animals or plants that thrive there. In our study, *Carassius carassius*, *Gambusia holbrooki*, *Hemiculter leucisculus*, *Pseudorasbora parva* and *Oncorhynchus mykiss* were observed in the impacted sites which their influence on the aquatic ecosystems need to be investigated in future.

In conclusion, our statistical classification models can show human pressure types patterns. Our findings show that the ecological status of rivers can be explained by multiple pressures, and in particular by a combination of local pressures (i.e. hydro-morphological alterations) and catchment pressures (i.e. land use). Such standardised tools are necessary to make profound decisions regarding implementation of a successful IWRM. It is necessary to be indicated that, in spite of all serious pressures on the Iranian waters which we encounter with them today, all of them together are not considered for an integrated water resource management therefore sustainable development can be missed. Therefore, the main goal of this paper is to establish an integrated approach for IWRM.

Acknowledgements

Part of this work was funded by the Austrian Science Fund (FWF, Predictive Index of Biotic Integrity for running waters of Iran, contract number P 23650-B17) and the Ministry of Sciences, Technology of Iran. Special thanks are given to Stefan Schmutz for his kind support during my study in Vienna.

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