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Ecological Risk Assessment of Wetlands Exposed to Anthropogenic Activities

Nahid Mohebbi[a], Jafar Nouri[b,*], Nematollah Khorasani[c], Borhan Riazi[d]

a. Department of Natural Resources and Environment, Science and Research Branch, Islamic Azad University, Tehran, Iran
b[*].Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran
c Faculty of Natural Resources, Tehran University, Tehran, Iran
d .Department of Natural Resources and Environment, Science and Research Branch, Islamic Azad University, Tehran, Iran
[*]Email Address: nourijafar@gmail.com

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Abstract

Wetlands are ecologically essential as a result of their hydrologic characteristics and their roles as an ecotone amongst terrestrials and aquatic ecosystems, which are exposed to stressors and risks by anthropogenic activities. Ecological risk assessment has been distinguished as a superior tool to categorize and prioritize risks caused by stressors and has globally developed a broadly acknowledged procedure for monitoring and managing wetlands. This study applied a hybridized and tiered method to assessing risks in combined with MIKE 21 computerized model and geographic information system for simulating and zoning risks on the Boujagh Wetland area that is located in the Southwest of the Caspian Sea shoreline and the north of Iran, as a case study. In the last step, mitigation measures have been presented by the pressure-Status-Response method, based on the ecosystem approach. As result, risk levels in the study area were 29% very high, 42% high, 20% moderate, and 9% low. Very high and high risks were distinguished on the sensitive areas involving aquatic species breeding site, immigrant birds, shoreline, Sefidrood River delta, and habitats near to landfill. So, landfill, waste disposal, and wastewater discharging should be eliminated. Besides, the establishment of an organized management office in the area is necessary.

Keywords

Boujagh Wetland; Geographic Information System; MIKE 21; Pressure-Status-Response; Tiered Ecological Risk Assessment Model.

Introduction

Coastal wetlands are known as the most dynamic, productive, and appreciated of the whole ecosystems nonetheless involve merely 15 per cent of total wetland areas on the Earth [1]. Ecologically, wetlands are essential as a result of their hydrologic characteristics and their roles amongst terrestrials and aquatic ecosystems [2]. These aquatic biomes have involved the consideration of scientific societies besides a multitude of singular attention assemblies in the last few decades, due to their complicated functions and conservation issues [3]. Wetlands can distribute an extensive assortment of ecosystem services, purify water, contribute to the welfare of lots of people, and support biodiversity [1]. The ecological and social profits of wetlands are typically recognized as ecosystem services that these ecosystems make to human well-fare [4]. Scientists have noticed the proficiencies of these environments to respond impacts of global warming [5]. However, the relationship between wetlands and human society has differed meaningfully during the time [6]. Meanwhile, the wetland areas have been exposed to resource utilization and land-use change continuously and for a long period [4]. Cui *et al*. (2016) have studied human activities impacts on the coastal wetlands in China and found that wetlands have suffered an excessive encounter principally due to human activities and anthropogenic stressors, such as population growth, industrial and economic development, introducing species, aquaculture, agriculture, and tourism [7]. Therefore, wetlands are the greatest threatened ecosystems with quicker rates of ruin than other ecosystems [8]. Damages are associated with human activity pressures such as landscape modification and conversion for agriculture, urbanization, industrial development, climate changes, and sea-level rise [9]. In order to conserve wetland and its biodiversity, the managerial process would be required that is carried out with a detailed interpretation of problems and ecosystem approach; the importance of such tools has increasingly been recognized by both academic researchers and environmental managers [10]. Since environmental managers and planners used Ecological Risk Assessment (ERA) for the wetland alteration [11]. An ERA is a multifarious process to analyse innumerable ecological, socio-economic, and managerial variables [4] that can offer a systematic framework for managing risks in the wetlands and their surrounding area [12]. ERA principles can be applied to a range of circumstances for instance assessing anthropogenic activities risks [13]. ERA surveys the likelihood of exposure to stressors. The term stressor most often refers to toxic substances [14] including toxic, chemical, physical, or biological factors arising from human activities that can produce an ecological disturbance [10]. ERAs are generally classified into two types of analysis including predictive and or retrospective. Predictive risk assessment emphasizes the relationship between the pollution sources, the stressors distribution, the exposure of organisms, effects of the toxicity, and managerial responses [15]. The approach of this analysis is to find cause-effect relationships between stressors and perceived ecological effects [16]. Therefore, the Tier Ecological Risk assessment (TIER) model is a hierarchical process is usually used to practice ERA on wetlands that can show a better understanding of how the stressors inter wetlands [14]. For instant, Levine *et al*. (2019) examined the ERA of pesticides from farmlands to the wetland by using a tiered assessment approach. They held a workshop in Raleigh, North Carolina, to regulate risk management authorities. Eventually, they suggested four main recommendations to improve wetland conditions [17]. However, it is essential to realize that ERAs will still need to be designed on a location or chemical particular basis to define and solve the specific concerns [18]. Both, the American Society for Testing and Materials (ASTM) and British Colombia University have undertaken efforts to develop standards for the TIER model for risk assessment and valuation of wetlands [19]. Sarkar *et al.*, 2016 presented a tiered-based approach of wetland risk assessment model that has been incorporated to define variables into GIS-based spatial analysis in the shape of linguistically. The global intergovernmental Ramsar Convention on Wetlands conservation has further proposed risk assessment techniques combined with GIS as a potentially useful model for risk management in the East Kolkata Wetland Area and ultimately concluded that the combinatorial models are efficient and can show the various levels of wetland risk zones by map [4] in addition some mathematical formula is applied to estimate and prioritize risks [20]. In fact, water is a fundamental and vital element in wetlands ecosystems; and clean water is crucial for any organism's health. Unfortunately, water quality takes effect by the pollution sources around the wetland [21]. Likewise, pollutants are significant stressors in aquatic ecosystems and can conclude various changes in species life based on their threshold [22]. According to the last decade's research, wetlands are at risk due to a widespread set of hazards and different concentrations of stressors [11]. Four main stressors that are regularly considered in wetlands risks are heavy metals and toxic non-metal elements, such as Cd, Cr, Cu, Hg, Ni, Pb, Zn, As, Bo, and Se, hydrocarbon compounds [13], organic pollutants such as pesticides, herbicides [17], and some natural parameters such as water salinity [20] which are resulted from human activities such as effluent discharge, solid waste disposal, exotic species, and agriculture drainage [9]. In this study, to identify the relationship between pollutants distribution and effects on the species MIKE model is also used. Based on the Danish Hydraulic Institute (DHI) definition, MIKE is known as a software series that has an assortment of approaches to aquatic environment issues. MIKE 21 FM uses a triangular irregular network (TIN) as input data to produce the altitude and latitude mesh [23] it is driven by the Hydrodynamic Module (HD) for flow modelling, Transport Module (TM) for pollution transport modelling, and GIS to display water pollution distribution as well [24] simulated Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) distribution in Hoogly Estuary (in India) by using MIKE 21 and could finally illustrate where species are at risk [25]. Li et al. (2020) have extended the factors to simulate water quality in the Donghu Lake in China. Consequently, they improved the Mike 21 model precision for counting the actual position of pollution in the wetland area, by using remote sensing [16]. Indeed, the target of ERA is wetland conservation and alteration [5]. So that the conceptual model of pressure-status-response (PSR) is applied for ecological risk management in this study [26] that was developed by the Organization for Economic Co-operation and Development (OECD), and can provide a mechanism for monitoring environmental and economic status [18]. Jin et al. (2016) used the model in China's Yellow River Delta to define a comprehensive assessment index system based on the PSR model and to describe how wetland responded to restoration activities, including land reclamation, and the construction of ports, roads, and upstream dams [27]. In this paper, Boujagh national Park and international wetland have opted to identify human activities and risks. As shown in Fig. 1, the study area is located on the south coast of the Caspian Sea, in the north of Iran, the Sefidrood River estuary, and nearby Kiashahr city [9]. Urban wastewater, industrial effluents, contaminated run-offs and drainages, solid wastes disposal, agricultural fertilizers and pesticides, aquaculture, and land use changing were distinguished as popular environmental challenges [28]. Stressors such as nitrogen, phosphor, heavy metals, toxic components, detergents, and other substances have confronted significant species to the risks. For instant Caspian Seal (Phoca caspica), white-fronted goose (Anser albifrons), red-breasted goose (Branta ruficollis), dalmatian pelican (Pelecanus crispus), white-tailed eagle (Haliaeetus albicilla) [29], and starry sturgeon (Acipenser stellatus) [9] are classified as protected species and others such as kingfisher (Alcedo atthis), pygmy cormorant (Phalacrocorax pygmeus), swans, ducks, crane, flamingoes, [29], brown trout (Salmo trutta), amphibians (Rana. spp and Bufo. spp), and reptiles [9]. The current study aims are to focus on the effect of the intensity and location of anthropogenic activities on coastal wetland ecosystems by an ecological risk assessment that can probe any changes in detail. This study has been carried out in Boujagh Wetland in 2020.

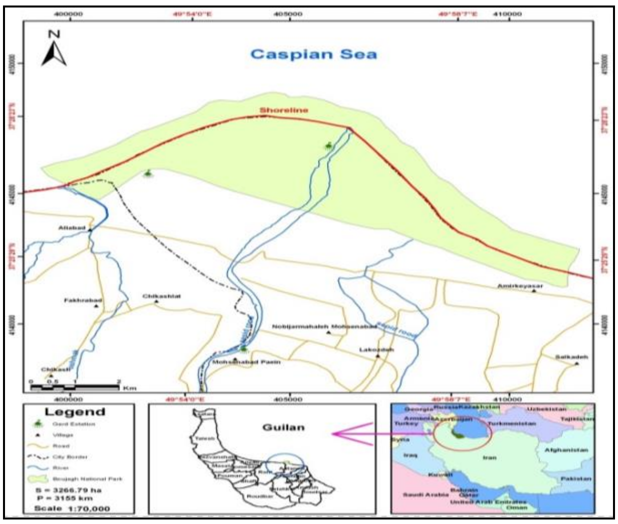


Figure1. The geographic location of the study area in Boujagh National Park and Wetland, Iran [28]

2. Materials and Methods

Regarding ERA and conservation goals in the wetlands area from one side and the complex interactions among aquatic ecosystem components and stressors, a holistic and comprehensive method is required to solve problems [30]. Likewise, the Boujagh Wetland has been exposed to human activities risks during the last decades. Therefore ecological risks are properly expected complex [9]. Understanding, analysing, and simplifying multifaceted ecological risks, in this study, a conceptual and hybrid model would be suitable for risk assessment [26]. Having been presenting a comprehensive ecological framework, Mike 21, GIS, and Tier Risk Assessment method have been thoroughly integrated for ERA of the Boujagh Wetland [9]. TIER is a semi-quantitative risk assessment process for aquatic ecosystems. It can distinguish, categorize, calculate, and prioritize risks in the one, two, three, or more steps [22]. The utilized model and framework of the study are illustrated in Fig. 2.

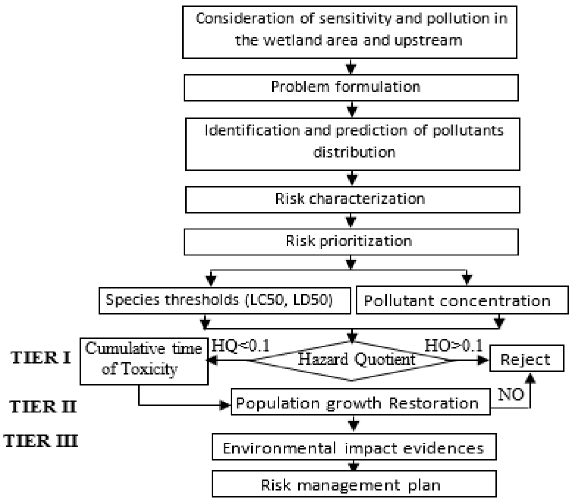


Figure 2. Flowchart of the study framework [30]

Tier I is the first screening step of risk assessment (SRA) that indicates an evaluation of the potential risks based on literature searches and existing data [19]. Tier II is the second step and is named the baseline ecological risk assessment (BERA), which requires a more detailed approach incorporating features exposure factors [20]. In both mentioned steps, bioavailability and food web are considered during the exposure assessment. Tier III might involve reconsidering steps 3 through 8, and selecting new measurements for exceedingly focused or long-term investigations [17]. Since the Tiered model has been used in this study is counted as an advantage. The whole evidence is collected through site surveying and assessment, containing that is relating to the bioavailability, should be evaluated when considering the various remedial alternatives [6]. Risk characterization results would be inter to risk estimation step, for quantifying ecological risks, Hazard Quotients (HQ) is used as an index of risk measure. HQ is accounted for via equation 1 [31].

$$HQ = PEC / Threshold \quad (1)$$

PEC is an abbreviation of Predicted Environmental Concentrations. Besides, the Threshold is extracted from previous valid scientific references such as EPA research. NOEC (No Observed Effect Concentration), NOEL (No Observed Effect Level), LC50 (Median Lethal Concentration), and LD50 (Median Lethal Dose) are four scientific scales, which indicate the measure of threshold [22]. Predicted Environmental Concentrations (PEC) or Estimated Environmental Concentrations (EEC) are related to the measure of stressor that can affect any organism [31]. Five levels of risks identified by HQ amount, less than one means there are risks in very high level (VHL), between 1 and 4 are high level (HL), 4 to 7 are in moderate level (ML), 7 to 14 are in low level (LL), and upper than 14 is negligible (NL) [9]. Regarding the sensitivity of organisms, ecosystem food web, and the place of organisms in the food chain, some species have been determined as indicators of the wetland including invertebrates, plants, birds, mammals, amphibians, reptiles, and fishes [32]; as well as, the value of organisms threshold has been extracted from previous studies [33]. Understanding which stressors might depute bio-organisms, what size of the community would be under pressure by risks, chemical how, where, and which concentration is required to make a decision and risk management. So, TIER Model has been developed through MIKE 21 FM-ECOLAB as a computational simulation model and GIS [34]. MIKE 21 has been used to simulate pollutants distribution and the results have been used in ERA [5]. Thus, it could prepare an illustration of pollutants distribution on the wetland and Sefidrooud River [35]. To simulate pollution diffusion, the required database has been prepared of existing reports of the Department of Environment (DOE). Samples of water have been already collected in two stations during a year for four seasons [9]. To summarize results from GIS and RS have adequately been executed to interpret MIKE simulation and risk levels zones via maps [34]. Finally, risk management has been conducted by a conceptual management model that is entitled Pressure – Status – Response method (PSR) [27]. Fig. 3 shows the framework of the PSR model.

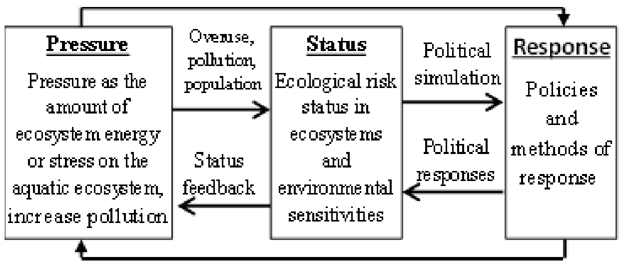


Figure3. PSR Method framework of Ecological Risk Assessment [18]

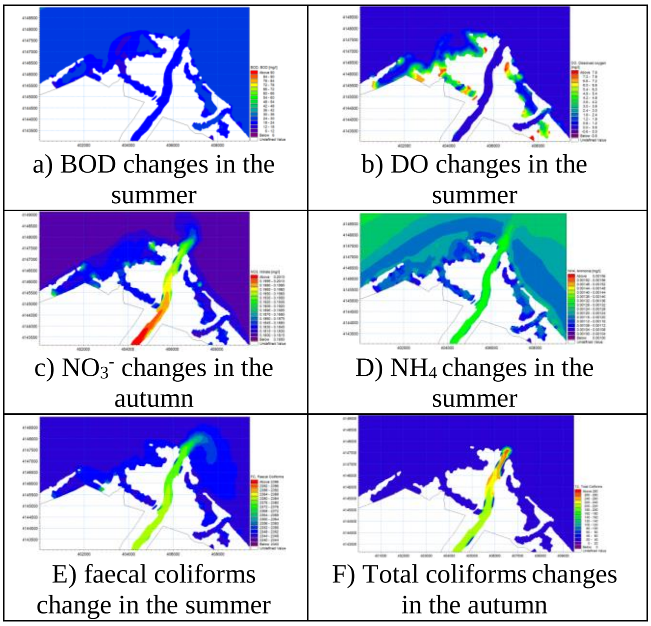
3. Results & Discussion

Based on the site surveying and prioritizing results, agricultural areas, aquaculture, residential wastewater, and recreational utilization are distinguished as the most significant pollution sources in the study area. The proportion of pollution sources in the wetland area and the upstream river is classified including the agriculture sector, industrial section, urban and residential parts, and aquaculture with 69, 13, 11, and 7 percentages, respectively. Thus, sampling was examined in two sample points from Sefidrood Dam to the last point in the Sefidrood estuary in Boujagh Wetland, in four seasons. In this study sampling parameters include temperature, colour, Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), salinity, turbidity, Total Suspended Solids (TSS), Total Dissolved Substances (TDS), Electrical Conductivity (EC), pH, nitrate, nitrite, ammonia, phosphate, and faecal and gastrointestinal coliforms. Table 1 indicates the measure of the significant physicochemical and biological parameters of the samples, which are related to anthropogenic activities around the wetland and river, for instant agriculture fertilizers, residential wastewater, and industrial effluents. In addition, heavy metals, hydrocarbon, and oily chemical pollutants have been considered during sampling and then ecological risks of these stressors have been estimated for each sensitive species. However, showing distribution was not possible by modelling, because of some issues such as the amount of concentration, deposition to the sediment, some unanticipated chemical reactions, and volatility.

Table1- Measures of physicochemical and biological parameters of the samples

Stations	**Frequency of measurement**			
	Winter	Spring	Summer	Autumn
Parameters	DO (mg/l)			
S1-Measurement	7.60	9.04	3.93	8.19
S2-Measurement	8.12	8.84	3.85	8.18
Modelling	8.20	8.83	3.84	8.10
Parameters	BOD (mg/l)			
S1-Measurement	14	11	98	11
S2-Measurement	16	10	34	10
Modelling	16.0	10.2	35.1	10.0
Parameters	Phosphate (mg/l)			
S1-Measurement	< 0.05	0.07	< 0.05	0.239
S2-Measurement	< 0.06	< 0.05	< 0.05	1.335
Modelling	0.007	0.03	0.0002	1.355
Parameters	Nitrate (mg/l)			
S1-Measurement	0.56	0.35	0.55	0.23
S2-Measurement	0.46	0.19	0.45	0.21
Modelling	0.45	0.21	0.45	0.21
Parameters	Nitrite (mg/l)			
S1-Measurement	-	-	-	0.34
S2-Measurement	-	-	-	0.4
Modelling	0.000	0.000	0.000	0.38
Parameters	Ammonia (mg/l)			
S1-Measurement	< 0.1	0.57	< 0.1	0.38
S2-Measurement	< 0.1	0.45	< 0.1	0.31
Modelling	0.000	0.44	0.001	0.31
Parameters	Faecal coliform (MPN)			
S1-Measurement	3	15000	2400	24000
S2-Measurement	9500	120	2400	240
Modelling	9403	3151	2386	251
Parameters	Total Coliform (MPN)			
S1-Measurement	9000	42000	2400	24000
S2-Measurement	95000	24000	2400	2900
Modelling	94115	24167	2386	3234

According to the MIKE 21 simulation method, there are several types of stressors in the wetland area, which are depended on temperature, the concentration of chemicals, interactions between substances, flow rate, the hydraulic system of wetland and river, etc. BOD is one of the important biological indicators and shows the amount of biodegradable organic matter. High concentrations of BOD cause oxygen consumption of water and eventually lead to an anaerobic system. According to the results, the amount of BOD in summer would be much higher than the others. On the other side, DO is an indicator of water quality. Oxygen is slightly soluble in water and its solubility varies with atmospheric pressure and water temperature. This parameter would have its lowest value in summer and its changes in other seasons have not been very significant. In addition, phosphorus is known as an index factor of the nutrition of reservoirs as well as the growth of phytoplankton. Phosphorus in the form of phosphate (PO_4^{3-}) can be absorbed by phytoplankton. As a result of the simulation, there is not a forecasted considerable difference between the various concentrations of phosphorus in different seasons. Examination of the nitrate (NO^{3-}) simulation shows that the concentration might be in maximum size, adverse the lowest scale has been predicted in autumn. In general, the amount of this parameter is less than the standard of water quality and it indicates the appropriate quality status of the river.Analysis of ammonia (NH_4) concentration shows that the concentration of this contaminant in summer was predicted in the highest amount and for other seasons did not fluctuate remarkably. Results show that the concentration of this parameter is in the range of water quality standards and is almost suitable for general applications. Although simulation has been done for every parameter and in each season, Fig. 4 (a, b, c, d, E & F) show the sample of simulated BOD, DO, nitrate (NO^{3-}), ammonia (NH_4), faecal coliforms, and total coliform changes by MIKE 21 in the wetland area, respectively.



a) BOD changes in the summer; b) DO changes in the summer; c) NO_3^- changes in the autumn; D) NH_4 changes in the summer; E) faecal coliforms change in the summer; F) Total coliforms changes in the autumn

Figures 4 – Sample of simulation of variables by MIKE 21 Model

The concentration of each stressor would have different effects on receptors. Every receptor that is exposed to chemicals depending on its threshold would be faced a dangerous situation. Stressors can affect in two ways chronic and acute toxicity, which is related to the time of exposure, concentration of substances, and also threshold, summarized bioavailability. In this study, HQ is estimated to quantify bioavailability, which could be conducted on Tier I and II levels. Table 2 foreshortened the results of HQ estimation of species in the wetland area.

Table2- Estimation of hazard quotient for indicator species of wetlands

Indicator species	Stressor	HQ	Risk level
Quail	Heavy metals	0.20	VHL
	Poisons (PCBs)	14	LL
Green duck (Mallard)	Heavy metals	4.2	ML
	Poisons (PCBs)	18	NL
White-fronted goose	Heavy metals	0.42	VHL
	Poisons (PCBs)	16	NL
Dalmatian Pelican	Heavy metals	0.39	VHL
	Poisons (PCBs)	23	NL
Pheasant	Heavy metals	1.23	HL
	Poisons (PCBs)	121	NL
Slender-billed Gull	Heavy metals	0.38	VHL
	Poisons (PCBs)	68	NL
Red-breasted goose	Heavy metals	0.02	VHL
	Poisons (PCBs)	3	HL
white-tailed eagle	Heavy metals	0.4	VHL
	Poisons (PCBs)	16	NL
Caspian hydrothermal fish (Carp, Kora vobla, and Southern Caspian kutum)	Arsenic, Chrome, Lead, Cadmium, Mercury, Zink, PCBs,	2.3	HL
Caspian cold fish (trout and salmon)		0.94	VHL
Starry sturgeon		0.94	VHL
Kilka fish		2.3	HL
Aquatic benthos and macroinvertebrates		6.2	ML
Aquatic plants		5.2	ML

PAH = Poly aromatic hydrocarbons;
PCB = Polychlorinated biphenyl;
TRV = Toxicity reference value

Then, overlaying MIKE 21 results and several maps of the natural environment could sum up the location of ecological risks in the study area, sensitive areas layer, ecologically important wildlife species, significant invertebrates, as well as vegetation, have been used for this target. Regarding the study results, chemical stressors would have various effects on the organisms throughout the ecosystem, although the threshold of any species depends on its LC_{50}, LD_{50}, NOEL, or NOEC, toxicity would remain in its body texture and is transmitted during the food web to the next species that feeds on it. Consequently, regarding the distribution of different species (Fig. 5), the results from the risk analysis, estimation, and assessment were overlaid and compared with the spatial information of MIKE 21 modelling. Summarizing and zoning the risk levels in the Boujagh Wetland area, the map of risk classes was prepared (Fig. 6).

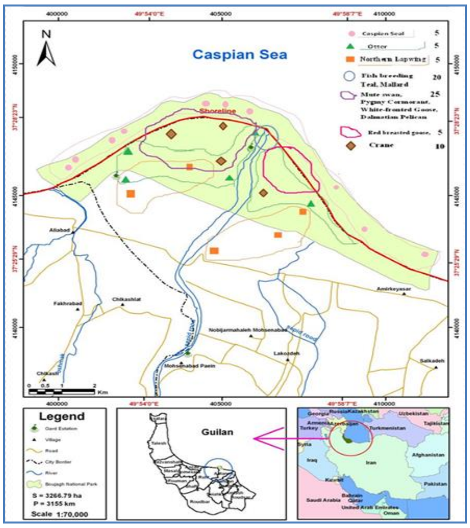


Figure 5 – Distribution of indicator species in Boujagh Wetland area

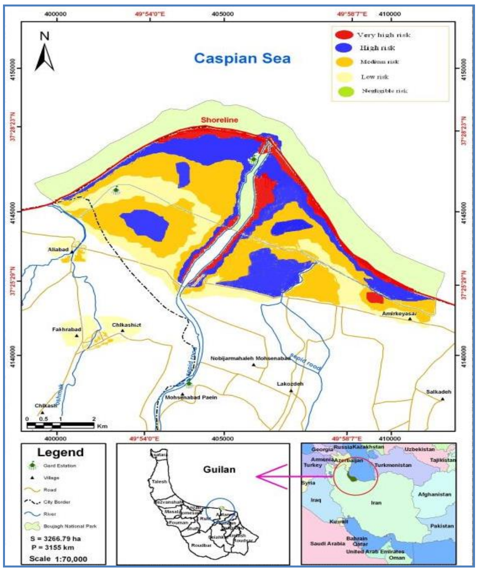


Figure 6 – Ecological risk classification in Boujagh Wetland area

Overall, almost 42 per cent of the wetland area has faced with high-level ecological risks, were covered the sensitive habitats and location of aquatic species and immigrant birds, in the second rank, 29 per cent of ecological risks have merged in very high-level class. These are located on shoreline areas, as well as a breeding site in the Sefidrood delta, and the edge of the river. In addition, the place surrounded by solid wastes in the landfill site is exposed to a dangerous condition, which is recommended to replace. Although the wetland area is very sensitive, there are identified 9 per cent of the risks in a low level. Other remaining places have been categorized as having a moderate risk level with 20 per cent. Negligible risk level has not been located in this area. Ultimately, to reduce risks and manage environmental issues, risk management has been conducted in the PSR model. Based on the results utilization of wetland and upstream basin is remarkable pressure on the area such as agriculture pollutants, fishery, land taking, aquaculture, industrial and residential pollutions, polluted sediments, military manoeuvre, boating, building, irregular recreation, and exotic species which properly generate significant deviations on the wetland existing status. Hence, there is necessary to establish a systematic, comprehensive, and integrating environmental management to conserve the wetland area and its upstream catchment. Therefore, conversation and integrated management system has been suggested as the key response, and also to improve the existing status, some main reactions have been identified such as managerial organization, site protections, budget providing, principle recreation policy-making, wisdom utilization with ecological approach, monitoring, auditing, public participation in the Boujagh national park and wetland, implementation Ramsar Convention regulations, providing environmental water demand, ecological capability assessment, and rehabilitation and restoration potential assessment. Fig. 7 summarized a sample of the PSR model of Boujagh wetland ecological risk assessment and management.

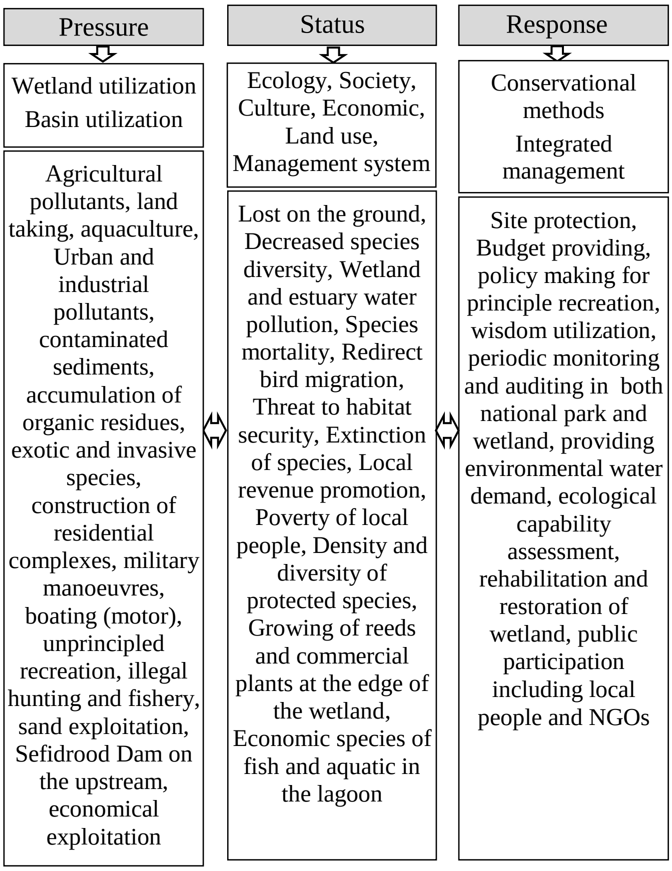


Figure 7 – PSR model of ecological risk management

4. Conclusions

Boujagh Wetland is an extraordinary precious ecosystem that has been exposed to anthropogenic activities including agriculture, residential complex building, unplanned tourism, military manoeuvre, illegal hunting and fishery, invasive species, and aquaculture. In this study, an ERA of the wetland has been undertaken by a hybridized methodology. TIER model (I and II steps) and HQ were applied to identify and estimate ecological risks, like other previous studies. As well to achieve thorough information, MIKE 21 computerized model and GIS were used to consider and localize stressors in the wetland. Using MIKE 21, pollutant distribution was simulated and then demonstrated by GIS, while the former studies did not have used this feature of the MIKE model combined with ERA. Furthermore, this study improved ecological risk assessment via adding the PSR model as a conceptual management model. Localizing ecological risks on the wetland area and showing by GIS is one of the advantages of this study, which remarks all features of receptors and stressors, involving species threshold, diversity, population, location, vulnerability, and duration of exposure, as well as pollution concentration and distribution. However, other ecological risk assessment studies rely on 2 factors exposure and threshold. Thus, the research could reach meticulous results in each section of the ERA process and make decisions. Benthos, phytoplankton, and some amphibian species were directly dealt with VHL and HL of ecological risk classes. While, aquatic macro-organisms fish, birds, mammals, and reptiles, are indirectly exposed to stressors such as their foods. In the case of endangered or vulnerable species such as starry sturgeon (Acipenser stellatus), Dalmatian pelican (Pelecanus crispus), white-fronted goose (Anser albifrons), red-breasted goose (Branta ruficollis), and white-tailed eagle (Haliaeetus albicilla), HQ was especially classified in VHL. As a final result, the proportion of risk classes in the wetland area was approximately estimated at 42 per cent high level, 29 per cent very high level, 20 per cent moderate level, and 9 per cent low level. Very high and high-risk levels were localized on the sensitive areas such as aquatic species breeding, immigrant birds, shoreline areas, Sefidrood delta and edge, and habitats near to landfill. So, any landfill or waste disposal should be eliminated in this area. Besides, there is necessary to establish a management organization and office in the national park that has a systematic plan to organize wetland restoration such as surveying the site and vulnerable animals, providing environmental water demand for wetland survival, and using public participation including residents and Non-Governmental Organizations (NGOs).

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Nomenclature

%	Per cent
ASTM	American Society for Testing and Materials
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DHI	Danish Hydraulic Institute
DO	Dissolved Oxygen
DOE	Iranian Department of Environment
EC	Electrical Conductivity
EPA	Environmental Protection Agency
EEC	Estimated Environmental Concentrations
ERA	Ecological Risk Assessment
GIS	Geographic Information System
HQ	Hazard Quotients
HL	High Level of risk
HD	Hydrodynamic Module
LC_{50}	Median Lethal Concentration
LD_{50}	Median Lethal Dose
LL	Low level of risk
ML	Moderate Level of risk
NGOs	Non-Governmental Organizations
NH_4	Ammonia
NL	Negligible level of risk
NO^{3-}	Nitrate
NOEC	No Observed Effect Concentration
NOEL	No Observed Effect Level
OECD	Organization for Economic Co-operation and Development
PAH	Poly aromatic hydrocarbons
PCB	Polychlorinated biphenyl
PEC	Predicted Environmental Concentrations
PO_4^{3-}	Phosphate
PSR	Pressure – Status – Response
RS	Remote sensing
TDS	Total Dissolved Substances
TM	Transport Module
TRV	Toxicity reference value
TIN	Triangular Irregular Network
TIER	Tiered Ecological Risk assessment model
VHL	Very High Level of risk

References

1. Isunju, J.B. and J. Kemp, Spatiotemporal analysis of encroachment on wetlands: a case of Nakivubo wetland in Kampala, Uganda. Environ Monit Assess, 2016. 188(203): p. 17.
2. Clarke, B., et al., Integrating Cultural Ecosystem Services valuation into coastal wetlands restoration: A case study from South Australia. Environmental Science and Policy, 2021. 116: p. 10.
3. Cesen, M., et al., Seasonal and spatial variations in the occurrence, mass loadings and removal of compounds of emerging concern in the Slovene aqueous

environment and environmental risk assessment. Environmental Pollution, 2018. 242: p. 12.

4. Sarkar, S., S.M. Parihar, and A. Dutta, Fuzzy risk assessment modeling of East Kolkata Wetland Area: A remote sensing and GIS-based approach. Environmental modeling & software, 2016. 75: p. 14.
5. Endter-Wada, J., K.M. Kettenring, and A. Sutton-Grier, Protecting wetlands for people: Strategic policy action can help wetlands mitigate risks and enhance resilience. Environmental Science and Policy, 2020. 108: p. 8.
6. Land, M., et al., How effective are created or restored freshwater wetlands for nitrogen and phosphorus removal? A systematic review. Environmental Evidence, 2016. 5(9): p. 26.
7. Cui, B., et al., China’s Coastal Wetlands: Understanding Environmental Changes and Human Impacts for Management and Conservation. Wetlands, 2016. 36: p. 9.
8. Boon, P.I., et al., Coastal wetlands of Victoria, south-eastern Australia: providing the inventory and condition information needed for their effective management and conservation. Aquatic Conservation: Marine and Freshwater Ecosystems, 2014. 25(4): p. 26.
9. Mohebbi. N., et al., Integrated environmental management for human communities risks around wetlands by ecological risk approach. International Journal of Human Capital in Urban Management, 2022. 7(1): p. 16.
10. Grechi, L., et al., An ecosystem model of the lower Po river for use in ecological riskassessment of xenobiotics. Ecological Modelling, 2016. 332: p. 17.
11. Raimondo, S., et al., Aunified approach for protecting listed species and ecosystem services in isolated wetlands using community-level protection goals. Science of the Total Environment, 2019. 663: p. 14.
12. Zhai, T., et al., Identification and Prediction of Wetland Ecological Risk in Key Cities of the Yangtze River Economic Belt: From the Perspective of Land Development. ustainability, 2021. 13(411): p. 17.
13. Ke, X., et al., Ecological risk assessment and source identification for heavy metals in surface sediment from the Liaohe River protected area, China. Chemosphere, 2017. 175: p. 38.
14. Ai, S., et al., Exposure and tiered ecological risk assessment of phthalate esters in the surface water of Poyang Lake, China. Chemosphere, 2021. 262: p. 9.
15. Tian, D., et al., Novel two-tiered approach of ecological risk assessment for pesticide mixtures based on joint effects. Chemosphere, 2018. 192: p. 10.
16. Li, X., M. Huang, and R. Wang, Numerical Simulation of Donghu Lake Hydrodynamics and Water Quality Based on Remote Sensing and MIKE 21. International Journal of Geo-Information, 2020. 9(94): p. 20.
17. Levine, S.L., et al., Overcoming Challenges of Incorporating Higher Tier Data in Ecological Risk Assessments and Risk Management of Pesticides in the United States: Findings and Recommendations from the 2017 Workshop on Regulation and Innovation in Agriculture. Integrated Environmental Assessment and Management, 2019. 15(5): p. 12.
18. Wang, Q., S. Li, and R. Li, Evaluating water resource sustainability in Beijing, China: Combining PSR model and matter-element extension method. Journal of Cleaner Production, 2019. 206: p. 171-179.
19. Mendes, M.P., et al., Ecological Risk Assessment in a Tropical Wetland Contaminated with Gasoline: Tier 1. Human and Ecological Risk Assessment: An International Journal of Cleaner Production, 2017. 23(5): p. 16.
20. Niemeyer J.C., et al., Ecological Risk Assessment of a Metal-Contaminated Area in the Tropics. Tier II: Detailed Assessment. PLoS ONE, 2015. 10(11): p. 25.
21. Mahdi, A., et al., Waste Water Pollution zoning of sensitive coastal-marine areas with an environmental protection approach(Study area: Boujagh International Park and International Wetland). Anthropogenic Pollution Journal, 2021. 5(1): p. 15.
22. Riva, F., et al., Risk assessment of a mixture of emerging contaminants in surface water in a highly urbanized area in

Italy. Journal of Hazardous Materials, 2019. 361: p. 8.
23. Ahn, J., Y. Na, and S.W. Park, Development of Two-Dimensional Inundation Modelling Processusing MIKE21 Model. KSCE Journal of Civil Engineering, 2019. 23(9): p. 10.
24. Nirwana, N., et al., Sediment Transport Pattern Modelling in Bojong Salawe Coast Pangandaran using Mike 21. International Journal of Quantitative Research and Modeling, 2021. 2(2): p. 20.
25. Paliwal, R. and R.R. Patra, Applicability of MIKE 21 to assess temporal and spatial variation in water quality of an estuary under the impact of effluent from an industrial estate. Water Science and Technology, 2011. 63(9): p. 13.
26. Harwell, M.A., et al., Conceptual Framework for Assessing Ecosystem Health. Integrated Environmental Assessment and Management, 2019. 15: p. 21.
27. Jin, Y., et al., Effects of seashore reclamation activities on the health of wetland ecosystems: A case study in the Yellow River Delta, China. Ocean & Coastal Management, 2016. 123: p. 9.
28. Alemi Safaval, P., et al., Morphological changes in the southern coasts of the Caspian Sea using remote sensing and GIS. Caspian Journal of Environmental Science, 2018. 16(3): p. 15.
29. Ashoori, A., The birds of Bujagh national park, Iran, 2004–2016. Sandgrouse, 2018. 40: p. 13.
30. Nys, C., et al., A framework for ecological risk assessment of metal mixtures in aquatic systems. Environmental toxicology and chemistry, 2017. 37(3): p. 20.
31. Liang, J., et al., A method for heavy metal exposure risk assessment to migratory herbivorous birds and identification of priority pollutants/areas in wetlands. Environmental Science and Pollution Research, 2016. 23(12): p. 8.
32. Chaves, M.J.S., et al., Pharmaceuticals and personal care products in a Brazilian wetland of international importance: Occurrence and environmental risk assessment. Science of the Total Environment, 2020. 734: p. 11.
33. Sattari, M., et al., Determination of Trace Element Accumulation in Gonads of Rutilus kutum (Kamensky, 1901) from the South Caspian Sea Trace Element Contaminations in Gonads. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences, 2019. 90(4): p. 8.
34. Karimi, M., J.M.V. Samani, and M. Mazaheri, Shoreline spatial and temporal response to natural and human effects in Boujagh National Park, Iran. International Journal of Sediment Research, 2021. 36(5): p. 11.
35. Nasrolahi, A., et al., Biomonitoring of trace metal bioavailability in the barnacle Amphibalanus improvises along the Iranian coast of the Caspian Sea. Iranian Journal of Fisheries Sciences, 2017. 16(1): p. 25.