Risk evaluation of ground water table decline as a type of desertification. A case study area: Southern Iran

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ABSTRACT
This paper presents a model to assess risk of ground water table decline. Taking into consideration eleven indicators of lowering of ground water table the model identifies areas with 'Potential Risk' (risky zones) and areas of 'Actual Risk' as well as projects the probability of the worse degradation in future. The Mond river basin, located centrally to this zone, has been selected as a test area to assess the risk of lowering of ground water table. For this purpose two sub basins of the Payab and Qareh Aghaj have been chosen for detailed study. By fixing the thresholds of severity classes of the eleven indicators a hazard map for each indicator was first prepared in GIS. The risk map was prepared by overlaying eleven hazard maps in the GIS, deploying the new model. The GIS analysis has made it possible to distinguish the areas with 'potential risk' from those widespread areas that showed the 'actual risk' of lowering of water table. Although the areas under potential risk form a lower proportion in the both sub basins, but the vulnerable potential risk areas with moderate and severe classes are more in the Qareh Aghaj plains compared to the Payab. A conclusion is that the already over evacuated lands (severe risk + moderate actual risk) are more widespread in the Qareh Aghaj plains (54%), with semi arid climate, compared to the Payab (10%), with arid climate. Areas under potential risk when classified into subclasses with different probability levels the model projects a statistical picture of the risk of lowering of ground water table.

Key words: Risk, Ground water table, Indicators, hazard map, GIS

INTRODUCTION

In the last years, the international scientific community has shown great interest on water resources and, thus, many works focused on environmental management for ground water protection (Adams and Foster, 1992; Drew and Hotzl, 1999; Arnaud, 2001; Morris, 2001; Eliasson et al., 2003; Gerth and Forstner, 2004). In recent years, due to the combined effect of drought, the increase of irrigated surfaces and also permeability characteristics of the geological formations, water storage has gradually decreased in the many parts of country. This includes the large proportion of the arable land (33%) that has already been affected by lowering of ground water table which forms one of the major types of land degradation or desertification in Iran (FAO, 1994). Ground water models using indicators are being developed in many regions to guide water management. This paper attempts at evolving a model for assessing risk of ground water decline in southern part of Iran. For this purpose the Mond river basin for which enough data were available has been chosen. The present work has given the opportunity to compare the intensity of ground water decline related to the two sub basins of Qareh Aghaj (upper reaches of Mond River) and Payab sub basin (lower reaches of Mond River) which differ in elevation, climate and agricultural activities. The total area covered in the GIS analysis is 1,787,000 ha**.**

METHODS

The data for this study were obtained from the local and main offices and institutes of the Ministries of Agriculture and Energy of Iran and processed thoroughly, using the GIS technique. The thematic maps were digitized and some numerical data related to the plains of each hydrological unit have been considered for the plains to further prepare different hazard maps.

The assessment of the risk of ground water table decline has been attempted by first identifying the main indicators of ground water table decline in the study area and then establishing the thresholds (class limits) of severity for indicators. The recommendations appearing in some literature as well as the statistically suitable parameters of local conditions for some indicators have also been taken into consideration while fixing the thresholds of the five classes of severity (ratings scores between 1 to 5) for each indicator. The eleven indicators (Table 1) have been processed in the GIS to arrive at the hazard map for each indicator. The indicators are related to exploitation of water resources (No. 1 to 6), climatic factors (No. 7 to 9) and geological characteristics (No. 10 & 11). In order that the effect of all the indicators gets projected in the risk maps, the overlays of the individual hazard maps were analyzed simultaneously. The severity of final hazard assigned to each polygon has been assessed by summing all the attributes (rating scores) of indicators in the GIS using the following equation, giving proper weighting for each indicator:

Risk score for lowering of ground water table = ((Annual rainfall + Hydrogeology of plains + Over exploitation + Increased consumption of ground water in the 10 years + Surface water consumption + Average water consumption in irrigated areas) × 2) + Ratio of non irrigated areas to irrigated areas + Ratio of water evacuation from qanats to that from wells + Climate + Coefficient variation (CV) of annual rainfall + Influence of carbonate formations.

The risk score in each polygon denotes the cumulative effect of all the indicators and has been used to classify the five severity classes (Table 2) ranging from 'none' to 'very severe' in the risk maps.

In the present assessment after classifying the severity classes, areas with bad quality of ground water (EC >2250 µmhos/cm) have been considered as a mask and were excluded in the GIS from the risk maps (Fig 1), since farmers do not use and exploit saline ground water. The correction for this section has been done for severity classes as follows:

a_1) If EC>5000 µmhos/cm, → 1 class has been lowered for irrigated land (with >50% ground water consumption)

a_2) If EC>5000 µmhos/cm, → 2 class has been lowered for rest of land (like irrigated lands with <50% ground water consumption)

b_1) If EC>2250 µmhos/cm, → no class has been lowered for irrigated land (with >50% ground water consumption)

b_2) If EC>2250 µmhos/cm, → 1 class has been lowered for rest of land

This kind of classification facilitated the production of a risk map that shows only different degrees of ground water table decline but doesn't show where the risk of lowering of ground water table is higher in future. In the next step, our model using GIS analysis solved this problem and defined the distinction of areas under 'actual risk' from areas under 'potential risk' of ground water table decline. The Actual risk areas include areas that at present show a state of lowering equal or worse to the risk class predicted. The areas under potential risk have been recognized using the following criteria:

A] Potential risk area = areas where the risk class determined > present status of hazard.

For example areas under 'moderate' potential risk have at present slight or no lowering of water table (indicator 1, Table 1) but have moderate vulnerability towards worse conditions. For calculating the probability for potential risk, the risk scores have been converted to percentage. The following equation was used for this purpose:

$$\text{\% Probability of Risk in Potential Risk Areas} = \frac{X-17}{68} \times 100$$

Where X - the risk score in each polygon, 17- the least score (0% probability) and 68- the numeric difference between the highest and the least scores.

Table 1: Indicators used in the GIS model of risk assessment for lowering of ground water table

Indicators	Class limits and their ratings score				
	None (1)	**Slight (2)**	**Moderate (3)**	**Severe (4)**	**Very severe (5)**
1) Over exploitation [1]	≥ 1.1	1 – <1.1	0.9 - <1	0.8 - <0.9	<0.8
2) Increased Consumption of ground water in the 10 years	< 1.10	1.1 – 1.32	1.33 – 1.65	1.66 – 1.99	≥ 2
3) % Surface water consumption of total water consumption	≥ 75	50 - 74	25 - 49	10 - 24	<10
4) Ratio of non irrigated areas to irrigated areas	≥ 3	1.50 – 2.99	0.75 – 1.49	0.25 – 0.74	< 0.25
5) Average water consumption in irrigated areas (M^3/ha)	-	Other parts of plain	< 10500	10500 - 16500	> 16500
6) Ratio of water exploitation from qanats to that from wells	> 1	0.34 - 1	0.18 - 0.33	0.06 – 0.17	≤ 0.05
7) Climate	Sub humid and humid	Slightly semi arid	Semi arid	Arid	Very arid
8) Coefficient variation (CV) of annual rainfall[2]	< 20	20 – 29	30 – 39	40 – 49	≥ 50
9) Annual rainfall, mm	≥ 1000	500 - 999	250 - 499	100 - 249	< 100
10) Influence of carbonate formations [3]	≥ 3	1.00 – 2.99	0.50 – 0.99	0.25 – 0.49	< 0.25
11) Hydrogeology of plains	Coarse-grained texture, very thick alluvium, deep water table, excellent discharge	Medium to coarse-grained texture, thick alluvium, deep water table, good discharge	Relatively fine-grained texture, moderately thick alluvium, shallow water table, medium discharge	Fine-grained texture, thin alluvium, shallow water table, poor discharge	Fine to very fine-grained texture, very thin alluvium, shallow water table or no aquifer, very poor discharge

Table 2. The severity classes of Risk Maps produced in the GIS

Class	None	Slight	Moderate	Severe	Very severe
Risk score	17 – 25.5	25.6 – 42.5	42.6 – 59.5	59.6 – 76.5	76.6 - 85

RESULTS AND DISCUSSION

This kind of classification using two categories of 'actual risk' and 'potential risk' and its subclasses based on per cent probability in the risk maps is the first attempt of its kind for defining areas with higher risk of lowering. From the risk maps (Fig. 1), it is evident that in the Qareh Aghaj sub basin a greater proportion (17%) of plains is under 'severe risk' than in the Payab (0%) sub basin. The main part of these lands in the Qareh Aghaj is under actual risk (14% of the total plains) where the lowering of water table has led to severe conditions. Adding to these the areas under moderate actual risk, 54% plains of the Qareh Aghaj sub basin seem to be under risk of 'over evacuation' while in the Payab it would be only 10%. This analysis indicates that greater extent of land under the risk of over evacuation lies in the plains of Qareh Aghaj, with semi arid climate, compared to the Payab, with arid climate. The main reason why the Payab sub basin shows a lower risk, is the bad quality of ground water

[1] Over exploitation = Safe exploitation (MM^3) / actual extraction (MM^3) MM^3: Million cube meter
[2] CV= (Standard deviation of rainfall / Average rainfall) × 100
[3] R = extent of carbonate formations / extent of non carbonate formations

in almost all parts with EC>2250 µmhos/cm. Therefore farmers in the small scattered spots of irrigated lands in these plains consume the surface water more.Areas under potential risk form a lower proportion in the both sub basins (23% in the plains of both the sub basins). But the vulnerable potential risk areas with moderate and severe classes are more in the Qareh Aghaj plains (20 %) compared to the Payab (10%). Also Fig. 1 shows that among the three classes of slight, moderate and severe risk, areas under moderate risk (potential + actual) have a greater spread (55% of the total plains) in the Qareh Aghaj while in the Payab the areas under slight risk dominate.

CONCLUSIONS

The Mond Basin model is the first attempt of its kind for defining the risk of ground water table decline and can be made applicable for other areas in Iran and elsewhere. The main results of the present paper are: The hazard maps of eleven indicators processed in the risk assessment model give a far better opportunity to distinguish the severity classes of risk of lowering of ground water table. The model based on the statistical parameters helps to identify the areas under actual and potential risk, and their sub classes based on per cent probability. The areas under 'actual risk' in both the sub basin are more extensive, compared to those under 'potential risk'. A general conclusion is that the already over evacuated lands (severe risk + moderate actual risk) are more widespread in the Qareh Aghaj plains (54%) compared to the Payab (10%), indicating greater pressure in the northern sub basin.

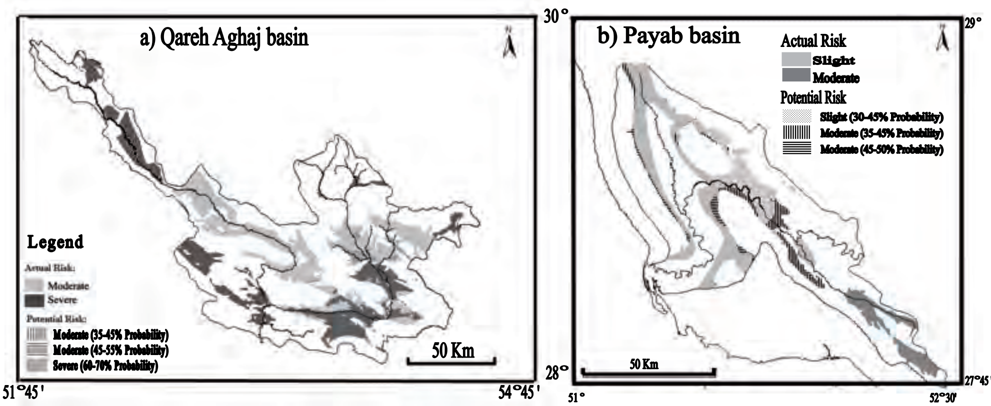

Figure 1. Risk of lowering of ground water table in the study area

REFERENCES

- Adams, B. and Foster S.S.D. 1992. Land-surface zoning for groundwater protection. *J Inst Water Environ Manag. 6*, 312– 20.
- Arnaud, C. 2001. *Groundwater protecting—catchment protection and regulation*. Houille Blanche. 1, 81–83.
- Drew, D. and Hotzl, H. 1999. *Karst hydrogeology and human activities. Impacts, consequences and implications*, vol. 20. International Contributions to Hydrogeology (IAH). Rotterdam7 Balkema; 322 pp.
- Eliasson, A., Rinaldi, F.M. and Linde, N. 2003. Multicriteria decision aid in supporting decisions related to groundwater protection. *Environ Manag. 32(5)*, 589– 601.
- FAO .1994. *Land degradation in South Asia: its severity causes and effects upon the people*. FAO, UNDP and UNEP report: Rome.
- Gerth, J. and Forstner, U. 2004. Long-term forecast: key to groundwater protection. *Environ Sci Pollut Res Int. 11(1)*, 49– 56.
- Morris, B.L. 2001. Practical implications of the use of groundwater-protection tools in water-supply risk assessment. *J Chart Inst Water Environ Manag. 15(4)*, 265–70.