ASSESSING LAND DEGRADATION HAZARD INTENSITY AND MANAGEMENT PLANS USING SUBJECTIVE MODELS AND THE ANALYTICAL HIERARCHY PROCESS IN GORGAN, IRAN

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ABSTRACT
Land use planning is a comprehensive master plan for any sustainable development action plan and can integrate all land resources and natural hazards management alternatives (strategies, plans and scenarios). This can be done via a multi-attribute decision method such as Analytical Hierarchy Process (AHP) under data and decision uncertainty. In this paper, first, the potential land degradation hazard was mapped at 1:250,000 scale as four hazard classes. This was done in the context of 14 micro (unit) and six macro (type) physiographic units, regarding the synergetic effects of five key processes (salinization, ponding, water erosion, wind erosion, and vegetation deterioration). A five-class numerical subjective model was used. Secondly, with respect to the nature of land degradation mechanism and intensity in the Gorgan coastal plain (a complex mosaic for land use planning and natural hazard management) four hazard mitigation plans were proposed These were aligned with the goals of national combating of desertification. These include: (1) Drainage and surface flow water collection, (2) shrub plantation and green belt creation, (3) soil physicochemical improvement, and (4) protection and preservation. Finally, the relative weights and priorities of management plan alternatives were determined in each hazard class zone. This was accomplished with respect to the hazard intensity and plan implementation cost and effectiveness using AHP model (CR=0.04 for plans, and CR=0.03 for hazard classes). The results indicate land degradation hazard classes I, II, III and IV which are extended with a spatially ordered pattern from forest covered mountain in the south to steppic coastal plain in the north along a sharp geo-ecological gradient of the study area. The differences of hazard class weights and surface areas, and the priority weights of the plans are significant at 0.01 and 0.05 level, respectively. These differences lead to different possible alternatives for hazard management plans and decision making.
Keywords: Analytical Hierarchy Process, Gorgan Plain, hazard management plan, land degradation, land use planning.

1 INTRODUCTION

In the Caspian lowland region about 81% of the area is natural desert or other further degraded types of natural landscapes. In the past decades, different regions around the Caspian Sea have been degraded so that about 39% of the area must be classified as severely to very severely degraded land [1]. Land degradation at its most spectacular form includes vegetation deterioration, wind and water erosion and poor soil fertility and low socioeconomic development. These can often remain unseen except by the specialists and those suffering their consequences [2–4].

Land degradation/desertification is a dynamic, myriad, pervasive and multidimensional hazard that is very sensitive to the spatial and temporal changes in natural and anthropogenic causative factors. An example is evolution of the Mu US desert in north China in the past 2000 years [5]. However, desertification is ongoing despite the endeavors to mitigate it over the past 50 years as a developmental problem [6]. Understanding the dynamic and complex nature of the spatial planning process, shortage of accurate recorded data, budget inefficiency, and the necessary implementation of urgent land and natural hazards integrated management plans have led to the creation and vast application range of multi-attribute decision methods. This includes an Analytical Hierarchy Process (AHP) plus individual and group subjective models (Delphi method) as a flexible and fast decision support system (FFDDS) since the 1960s. As Ferrand [7] states, spatial planning is essentially a decision process, and there are no data involved in it, only models.

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In regional scale spatial planning, development plans and projects are difficult to rank because many important criteria are unquantifiable and non-comparable [8]. Thus, due to some critical uncertainties and complexities there is a general but conservational tendency to replacing laboratory and field measurements and observations (actual recorded data) by subjective (mental data) and objective (hybrid data) models [7, 9, 10].

Applications of AHP and subjective models are extending in land use planning, watershed and natural hazards integrated management and environmental pollution mitigation projects. For instance, application of AHP in prioritization of possible land uses [11], agricultural research projects [12], national park management plan projects [13], and integrated management of watersheds in the US [14]. Further examples include watershed management strategies in Brazil [15], natural resources and environment [16], landslide hazard zonation [9, 17, 18], desertification hazard management plans [19], air pollution mitigation strategies and project assessment [8], in the development of spatial decision support systems for identifying priority site area selection between watersheds and within sub-watersheds for watershed management schemes and expert knowledge for sub-watershed priority, management option selection [20], and production system allocation in micro-watershed in India [21].

The main purpose of this paper was to determine the potential land degradation hazard zonation (proving the present status of hazard) by a numerical subjective model and prioritization of land degradation hazard integrated management plans (alternatives) using the AHP method under the data and decision uncertainty in the Gorgan semi-arid coastal plain of Iran on the direction of national and provincial sustainable development strategies.

2 STUDY AREA

The Gorgan semi-arid plain (including two other local and more arid plains, known as Agh-Ghala and Gomishan) is located in the northern part of Golestan province, southeast Caspian lowland desert region, Iran (Fig. 1). The study area of 5693 km^2 (26% of the total province) extends from the Albourz forest covered mountain range in the south to the Turkmenistan boundary (southwestern margin of Kara-Kum Desert) in the north, and from the Caspian Sea in the west to hilly undulated lands in the east.

Due to different types of topography (mountain to lowlands), climate (dry sub-humid to arid with annual precipitation of 630–220 mm and annual temperature of 16–18°C, (both inversely change toward the north), lithology (from pre-Quaternary rocks to Quaternary marine, alluvial and aeolian sediments and soils) and vegetation (from dense deciduous forest to mild steppe), the region presents a unique geo-ecological sharp gradient. Furthermore, this region provides a complex mosaic for land use planning (from tropical to boreal crops) and natural hazards (from desertification to sea and river floods) integrated management [22].

Land degradation has been associated with the Gorgan plain throughout its human occupancy, but has accelerated mainly during catastrophic climatic changes (Caspian Sea level fluctuations), human misuse, overuse of natural resources, and poor management of the environment [23]. The landscape of the Gorgan plain (in fact, the former beds of the Caspian Sea) is a mid-latitude coastal desert, characterized by a mosaic of geomorphological features of mild desert and land degradation. This includes salt pan, playa, badland, puffy soil, patterned ground, seasonal mobile sand dunes (as small nebka and sand ridge), stabilized coastal paleo-dunes (as large barchan and parabolic), and >150 archeological hill sites composed of artificial and natural origins (as sand dunes and mud volcanoes) with different civilization artifacts of 6400 years BP [24, 25]. Hence, the area can be viewed as a small regional laboratory “Golestan province and southeast Caspian Sea coast desert type” (in comparison with the central deserts of Iran) for development and calibration of desertification and

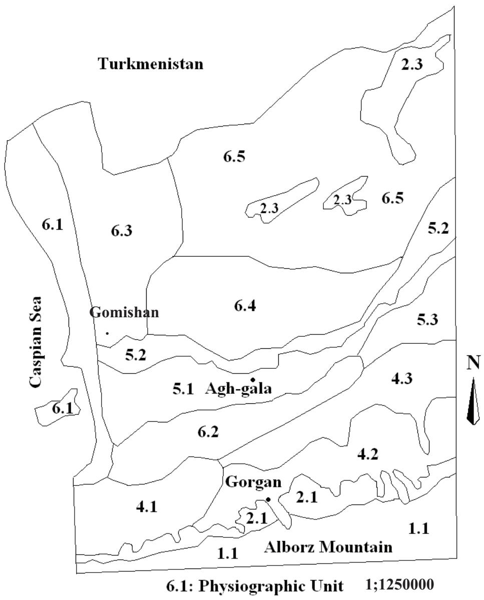

Figure 1: Physiographic unit map.

land degradation hazard zonation models. For developing local Caspian desertification action plans, Gorgan plain (mainly Gomishan coastal region) has been selected as a hot spot area of Iran [1].

3 MATERIALS AND METHODS

This research was conducted in two successive phases.

Phase 1: Land degradation potential hazard mapping using available data and a subjective model (expert opinion) as follows:

- Identification of physiographic or general geomorphological units (macro and micro units as mainly photomorphic units) at semi-detailed or regional scale (1:250,000).
- Development of a simple regional four-class hazard assessment model based on five key desertification processes (salinization, ponding (water logging), water erosion, wind erosion, and vegetation deterioration) dependent on five natural and anthropogenic basic factors (topography, climate, parent material, hydrology, and land use).
- Determining relative importance (weighting) of key processes on desertification potential hazard in each map unit using field knowledge and expert experience as a subjective scoring method (0–4 ratio scale) according to available tabular and map data [26, 27]. Each single criterion evaluation provides a ranking of hazard classes and management plans.
- Preparation of desertification hazard choropleth map as a basic document for plans and project prioritization and selection.

Phase 2: AHP and expert system demonstrate a solution for the standard three-step hazard management procedure: 1, critical area identification; 2, best management practice selection; and 3, comprehensive hazard control plans [28].

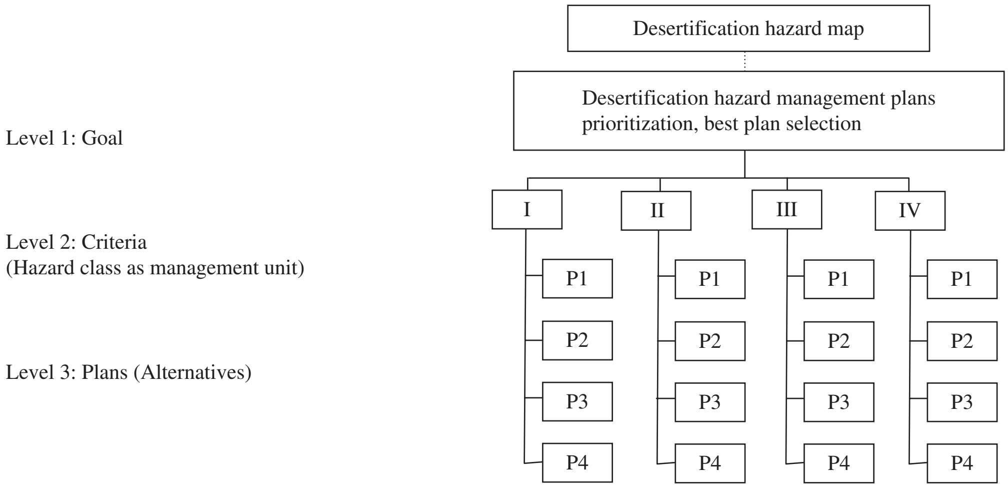

Figure 2: Decision hierarchy for desertification hazard management plan prioritization.

The AHP determines the priority of each alternative by analyzing the judgment matrices and their eigenvalues and eigenvectors. Both subjective and objective judgments are combined in an integrated framework based on ratio scales from simple pair-wise comparisons [15] and prioritization of desertification hazard integrated management plans (alternatives) using the AHP technique as follows:

- Identification of hazard management work units as desertification hazard class zones (hazard map unit) as a key criterion for management plan prioritization (managerial needs of each hazard class).
- Selection of hazard management plans and strategies consisting of four effective plans: drainage and surface flow water collection (P1), shrub plantation and green belt creation (P2), soil physicochemical improvement (P3), and protection and preservation (P4).
- Prioritization of plans (options) in each hazard class zone via pair-wise comparison (AHP, Expert Choice, version 11) mainly with respect to two critical criteria, including plans implementation cost and applicability (effectiveness), and calculation of local (partial) weights of plans [15].
- Prioritization of hazard classes with respect to managerial needs (goal) and calculation of their local weight as a new criteria and work using AHP. It must be remembered that in spite of classified numerical values, there is no distinct mathematical relationship between hazard classes. In addition, class IV is not four times class I [9].
- Calculating global (total) weights and rank management plans in the study area by multiplying weights of plans and classes as matrix of ranked values to assist decision-makers [20]. The decision hierarchy structure of the research phases including hazard map and AHP is shown in Fig. 2.

3.1 Assumptions

For the hazard management plan prioritization three basic assumptions were defined:

1. From class I to class IV, difficulty, cost, and managerial needs and priority are increased non-linearly.

2. The cost of implementation and effectiveness of the proposed plan(s) criterion(s) are the most important among the development plan prioritization.
3. From plans 1–4, difficulty, cost of operation, and limitation of land use are increased non-linearly, and areas vulnerable to desertification/land degradation hazard were identified for implementing best management practices.

4 RESULTS

Based on the variety, the results obtained were presented by desertification hazard zonation, and management plans prioritization as follows:

4.1 Hazard zonation (mapping)

The final hazard map contains all four classes of the regional model with different frequency and key process combination (Table 1). The spatial succession of hazard classes derived from the sharp gradient of desertification key factors and processes shows a regional pattern and hazard intensity increases from the south (class I in forest covered mountain) to the north (class IV in steppic and gentle low coastal plains) with the exception of fossil sand dunes (as productive islands) over the vast low plains (Fig. 3).

Table 1: Scoring of key processes effect and desertification hazard class by physiographic units.

Map unit	Area (%)	Processes effect score S	P	Ew	Ed	Vd	Hazard number	Hazard class	Current land use	Land use compatibility
1.1	4.6	0	0	2	0	2	4	I	1, 7	2–3
2.1	5.1	0	0	3	1	4	8	II	1, 3	2
2.3	3.5	2	2	4	3	3	14	III	2, 4	3
4.1	5.27	1	3	3	2	2	12	III	3, 5	4
4.2	7.21	1	3	3	2	2	11	III	3, 5	4
4.3	6.15	1	3	3	2	2	11	III	3, 4, 5	3
5.1	8.43	2	3	3	2	2	12	III	3, 4, 5	4
5.2	3.16	2	3	2	3	2	12	III	3, 4, 5	3
5.3	2.02	2	3	2	3	2	12	III	3, 4	4
6.1	7.9	4	4	3	3	3	17	IV	2, 6, 7, 8	3
6.2	8.75	3	4	3	2	3	15	IV	3, 4	3
6.3	9.8	4	3	3	3	4	17	IV	2, 6	3
6.4	9.15	3	4	3	3	3	16	IV	2, 4	3
6.5	19.15	4	4	3	4	4	19	IV	2, 4, 6	3
Study area	100	2.07	2.79	2.86	2.36	2.71	12.79	III	All	3
Area weighted	100	2.63	3.01	2.99	2.55	2.97	14.15	III	All	3

Process scoring: 0 = None, 1 = Slight, 2 = Moderate, 3 = High, 4 = Very high.
Dominant present land use: 1 = Forest, 2 = Range, 3 = Irrigation, 4 = Dry farming, 5 = Urban, 6 = Barren, 7 = Protection/recreation, 8 = Fishery.
Present and possible (future) land use compatibility class: 1= None, 2 = Low, 3 = Moderate, 4 = High.

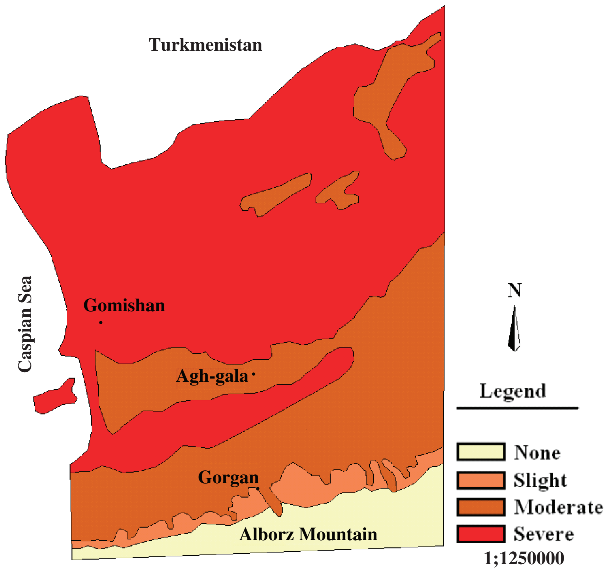

Figure 3: Land degradation hazard map.

Table 2: Area frequency and physiographic units of desertification hazard classes.

Hazard class	Area (%)	Physiographic units	
		Micro	Macro
I – None	4.6	1.1	1
II – Slight	5.1	2.1	2
III – Moderate	35.7	2.3, 4.1, 4.2, 4.3, 5.1, 5.2, 5.3	2, 4, 5
IV – High	54.6	6.1, 6.2, 6.3, 6.4, 6.5	6
Study area (III)	100	All	All

Frequencies of the hazard classes area from class I to IV are 4.60%, 5.10%, 35.70%, and 54.60%, respectively, and the average hazard class of study area is of class III (on the boundary of class IV) with hazard number of 14.29, and area-weighted average class is also of III with hazard number of 14.15 (Tables 1 and 2).

The relative importance of five key desertification processes is nearly different by macro and micro physiographic units, and in global (study area) as Ew > P > Vd > Ed > S for un-weighted and P > Ew > Vd > S > Ed for weighted equations due to the difference in surface area frequency of the map units (Tables 1 and 3).

Among the physiographic units (unit and type) the lowest (4) and highest (19) hazard numbers belong to forest-covered rocky mountains, and lowlands and marshy coastal plains units, respectively (Tables 1 and 3).

Table 3: Desertification hazard classes by physiographic macro units (type).

Physiographic type	Area (%)	Micro units	Hazard Number	Hazard Class	Process important succession
1 – Rocky mountain slope (Forest covered)	4.6	1.1	4	I	Ew = Vd > S = P = Ed
2 – Rock/sediment hill-slope	5.1	2.1	8	II	Vd > Ew > Ed > P = S
3 – Pediment plain/alluvial fan	18.6	4.1, 4.2, 4.3	11.33	III	Ew > P > Ed = Vd > S
4 – Gentle plain/river terrace	13.6	5.1, 5.2, 5.53	11.66	III	P > Ed > Ew > S = Vd
5 – Lowlands and coastal plain	54.6	6.1, 6.2, 6.3, 6.4, 6.5	16.80	IV	P > S > Vd > Ed = Ew
6 – Sand dunes (fossil)	3.5	2.3	14	III	Ew > Vd = Ed > P = S
Study area	100	All	12.79	III	Ew > Vd > P > Ed > S
Area weighted	100	All	13.94	III	Ew > Vd > P > Ed > S

Table 4: Weights, priorities and the final ranking of hazard management plan alternatives.

Class		I (0.125)		II (0.235)		III (0.306)		IV (0.336)		Global weight and rank	
W&R		w	r	w	r	w	r	w	r	W	R
Plans	P1	0.483	1	0.315	2	0.136	3	0.066	4	0.198	4
	P2	0.315	2	0.483	1	0.315	2	0.136	3	0.295	2
	P3	0.136	3	0.136	3	0.483	1	0.315	2	0.302	1
	P4	0.066	4	0.066	4	0.066	4	0.483	1	0.206	3

w, local weight; *r*, local priority rank.

4.2 Hazard management plan prioritization

The local weight and rank of management plan (P1–P4) implementation priority with respect to the hazard classes are different between and within classes. Also, priority weight and rank of hazard classes with respect to managerial needs (goal) show a nonlinear difference (Table 4). Average local priority of management plans with respect to the hazard classes that was calculated by rank scoring method is P2 > P3 > P1 > P4 (plan 2 = 12 + plan 3 = 11 + plan 1 = 10 + plan 1 = 7) = (40, more simple). Their global priority in the study area is P3 > P2 > P4 > P1 (P3 = 0.302 + P2 = 0.295 + P3 = 0.206 + P1 = 0.198) = (1.00, more complex) equations (Tables 4–6).

According to statistical tests (chi-square) among the analyzed variables, differences in hazard classes, weights, surface areas, and priority weights of the plans are significant at the 0.01 and 0.05 probability levels, respectively.

Table 5: Valuation and comparison of global priority of hazard management plans.

Score		4	3	2	1
Rank		1	2	3	4
Class	I	P1	P2	P3	P4
	II	P2	P1	P3	P4
	III	P3	P3	P1	P4
	IV	P4	P3	P2	P1
Study area	III	P3	P2	P4	P1
Calculations		P1 = 4 + 3 + 2 + 1 = 10		P2 = 3 + 4 + 3 + 2 = 12	
		P3 = 2 + 2 + 4 + 3 = 11		P4 = 1 + 1 + 1 + 4 = 7	

Table 6: Final hazard management plans priority ranking.

Rank	1	2	3	4	Implementation
Local	P2	P3	P1	P4	More simple
Global	P3	P2	P4	P1	More complex

5 DISCUSSION

The synergetic effect of different temporal and spatial combination of desertification key factors and processes with "equifinality mechanism" has promoted different desert landscapes and land degradation hazard intensity in the Gorgan area that are the same as whole margin areas of the Caspian Sea [1]. The spatial pattern of hazard zones shows the effects of distance to positive (mountain and forest) and negative (desert and sea) sources on desertification potential hazard intensity. However, there are some local exceptions to the effects of human historic and present destructive and constructive activities [1, 2, 5].

Following the spatial distribution and succession of hazard classes, the implementation and conducting level of proposed management plans intensifies toward the north (hazard source) and imply gradual or graded hazard mitigation planning and measures.

Local and global priority differences in the proposed plans can be related to the effect of contributing of hazard class relative weight in calculation of global weight. In global priority, the implementation and execution of proposed plans seems to be more difficult and complex than local priority due to cost, time and probable legal requirements as explained by De Stiguer *et al.* [6].

In general, with respect to the land uses and land degradation hazard in the Gorgan area the hazard zones of class IV (54.60%) are of first priority for mitigation with plan priority equation of P4 > P3 > P2 > P1. Meanwhile, the hazard zones of class I (4.60%) with equation of P1 > P2 > P3 > P4 can be temporally considered as "no project, no plan, no action" option, as resulting in plan 2 > plan 1 > plan 3 in the Paraguacu River Basin [15].

6 CONCLUSIONS

There are forms of land degradation that are often overlooked, except by those who are directly affected, even though they are frequently very visible. Selection of the best plan, implementation and monitoring of the plan are important steps in integrated land and hazard management. This should be considered with real or detailed knowledge and warning of ineffective anti-desertification measures and failures of combating, as experienced after 50 years in north China [6].

In land use planning and natural resource mitigation, projects and plans are difficult to weight and rank, because many important criteria are unquantifiable and non-comparable. Well-developed subjective models and the AHP method provide a useful tool not only for scoring and weighting of options and decision making under uncertainties but also for proving the nonlinear relationship between the hazard class that is essential in determining mitigative needs and plan selection.

With respect to game theory and spatial diffusion of hazard from main sources to marginal lands, hazard zones of class IV are of first priority for mitigation. Meanwhile the hazard zones of class I can be temporally considered as "no project, no plan" option in benefit of the other relatively three intense hazard zones.

There are some arguments to determine which land degradation or desertification hazard class is the first priority and requires the most management attention and best plan. For example, the highest class (hot spots, damaged and irreversible areas) or the lowest class (bright spots, in front, margin and reversible areas).

In many of the reviewed references, the priority of management plans (alternatives) of natural resources and natural hazards have been evaluated only in a single geographic region (as basin, sub-basin, province, site and any map or work unit) and without respect to land capability or natural hazard classes. To achieve the real land use planning and sustainable development, the priority of proposed management plans or options must be evaluated with respect to the natural resources capability and natural hazard intensity classes as the critical comparing criteria in each of the map units or management units.

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