Risk Assessment of Vegetation Degradation Using GIS

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ABSTRACT

The entire land in the Southern Iran faces problems arising out of various types of land degradation, of which the vegetation type forms one of the major ones. The Payab basin (522,470 ha), which covers the lower reaches of Mond River, was chosen for a test risk assessment of this type. The different kinds of data for indicators of vegetation degradation were taken from the records and published reports of Iran governmental offices. A new model was developed for assessing the risk of vegetation degradation. Taking into consideration nine indicators of vegetation degradation, the model identifies areas with 'Potential Risk' (risky zones) and areas of 'Actual Risk' projecting the probability of the worse degradation in future. The preparation of risk maps, based on the GIS analysis of these indicators will be helpful for prioritizing the areas to initiate remedial measures. A hazard map for each indicator was first prepared in GIS by fixing the thresholds of severity classes of the indicators. The risk classes were defined on the basis of risk scores arrived at by assigning the appropriate attributes to the indicators and the risk map prepared by overlaying some nine hazard maps in the GIS. Areas under actual risk were found to be widespread (93%) in the basin and when the risk map classified into subclasses of potential risk with different probability levels the model would project a statistical picture of the risk of vegetation degradation.

Keywords: Actual risk, GIS, Indicator, Potential risk, Vegetation degradation.

INTRODUCTION

Iran lies within the arid and semi arid climatic belt, in the climatic conditions of which land degradation processes are known to progress more speedily and pervasively. Compared with other countries in the Middle East, the present status of land degradation in Iran is alarming, as about 94% of arable lands and permanent pastures are estimated to be in the risk process of degradation (FAO, 1994). This includes the large proportion of land that has already been affected by vegetation degradation and which forms one of the major types of land degradation in Iran (FAO, 1994). That is why developing a model, such as the present one, for assessing the risk of vegetation degradation sounds as extremely important.

Vegetation degradation results in reduction in the biomass, leading to decline in the vegetative cover. In contrast to deforestation, which has been defined as "the clearance of forest for agriculture or other purposes", vegetation degradation refers to "either the temporary or permanent reduction in the density, structure, species composition or productivity of vegetation cover" (FAO/UNEP, 1984). The definition reveals that the reduction implied is not only in the quantity of biomass but also in its quality; for instance increasing of bush over rangelands, and the loss of palatable pasture grasses as well as their replacement with non-palatable species. Vegetation degradation is a major factor contributing to soil erosion along with loss of soil organic matter, but it is assessed as an individual type of land degradation in some methods of

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assessment of desertification hazard (FAO/UNEP, 1984). Other studies like GLASSOD (Oldeman *et al.,* 1991) and ASSOD (Van Lynden and Oldeman, 1997) do not consider vegetation degradation as an individual type of land degradation, which is thought as one of the disadvantages of these models.

Degradation of the vegetation and soil, due to cultivation, grazing, and collecting of fuel in many regions of Iran reached a stage when one would believe it was beyond any repair. Firewood provides fuel for the rural population and wood cutting continues unabated exposing the soil to more deleterious erosion. The erodibility of soil occurs more in slopy areas but this problem is faced with, all over the basin as the forest and rangelands are encroached upon to increase the areas under cultivation, especially dryland cultivation. This replacement has been fast in the recent decade. Plowing of natural vegetation on slopes, depletion of mountain forest and overgrazing have subjected vast areas to the influence of water and wind erosion causing irreparable damage to the economy. Recorded data and documents (Jamab, 1999) reveal that such deforestation has instigated vegetation degradation causing frequent flood conditions ever since.

Feng *et al.* (2006) analyzed the present status of eco-environmental degradation in the source region of the Yellow River supported by GIS and RS, as well as field investigation and indoor analyses. Results indicated that within the last half century, the desertification and environmental degradation in this region are mainly attributed to human activities under the background of regional climate changes. To control and manage the degradation in the environment of this region, great efforts should be made to use land resources rationally, develop advantageous animal agriculture and protect the natural grassland.

Liu *et al.* (2009) analyzed vegetation degradation in western Beijing mountainous areas. The coverage image in 2005 was subtracted from the image in 1979, with the degradation image estimated. There was difference observed in vegetation degradation in these areas, and as a result of increased residential area and sand/ stone disturbance, the vegetation degradation was recorded as the most serious.

Often all the woody plants, not leaving even the small sub shrubs, have been cut and disappeared around the villages. It has a simultaneous effect on livestock grazing. As a result, the encroachment into the marginally hilly areas that formerly formed the best grazing lands has turned into a high risk land use (Pueyo *et al.*, 2006). At the same time, overgrazing in the remaining parts of rangelands gets accelerated by the ever increasing population of the livestock on rangelands. Grazing pressure seems to have become much more intensive within the past couple of decades than it was before (Todd, 2006). Pasture production is affected by livestock. Stocking volume and grazing method are the two most important management variables affecting herbage production, seasonal pattern of production, herbage quality, as well as botanical composition (Chaichi and Tow, 2000). Proper 'rangeland management', based on grazing (carrying) capacity is urgently required. The implementation of management strategies is, of course, very difficult to introduce because of the socio-economic disposition of the rural population. Rangeland destruction makes herdsmen turn to more tolerant species of livestock; sheep are substituted for cattle, and while goats replacing sheep. Total numbers of the livestock in the Payab basin in 1996 were: 13,411 sheep, 113,046 goats, 7,276 cows, 369 camels, and 3,340 other livestock species (Research Institute of Planning and Agricultural Economics, 1998). These figures show that the dominant animal at present is goat, as it tolerates and survives hard conditions.

The risk assessment of vegetation degradation was done in the present paper on the basis of nine indicators. Attempt was made to focus on the vegetation degradation of natural plants of rangelands and forests

and not on the agricultural systems. The thresholds (class limits) for the severity classes of these indicators were established and subsequently the risk map of vegetation degradation prepared in the GIS, and deployed in the model.

MATERIALS AND METHODS

The Payab Basin (Study Area)

The Payab basin, which extends over the lower reaches of the Mond River, is bounded between Lat. 27°, 44´ to 28°, 51´ N and Long. 51°, 09´ to 52°, 25´ E. It lies in the Bushehr Province, Southern Iran (Figure 1) covering an area of nearly 522,470 ha of which about 45% forms the plains. The main rivers are Mond River in its lower reaches, and its tributaries Shur and Baghan (Figure 2). The main city within the basin is Khormuj. The population of the entire basin is estimated at about 200,000 of which nearly one third are urbans. The rural population is engaged mostly in agricultural activities including cattle raising. The land use map published in 1998 by the Ministry of Agriculture, Iran, shows only 5 % of the plains of Payab basin as irrigated agricultural lands, the remaining plains (95%) being under dry-land farming, natural vegetation cover as well as bare lands. About 53% area of the entire basin is under natural vegetation cover (37% rangeland and 16% forest). The natural vegetation cover of this basin is of a low density (canopy less than 25%). The natural vegetation cover reflects the climatic and soil conditions but is affected also by anthropogenic activities like encroachment for cultivation and grazing. At higher elevations, on most mountainous parts of the basin, rangeland is replaced by xeromorphic open forests dominated mostly by *Zizyphus spina-christi* and then *Pistacia spp*. There is no woodland with canopy of more than 25% within the basin.

The hydrological units (Figure 2) were decided on the basis of 'water divides', each unit differing in the total area covered, and in having one or more plains used for agriculture. These units do not differ much in the kinds of water resources, kinds of cultivation, and their socio-economic culture. The climate of the basin is controlled and affected by the low latitude and varied elevations. About 99% of the
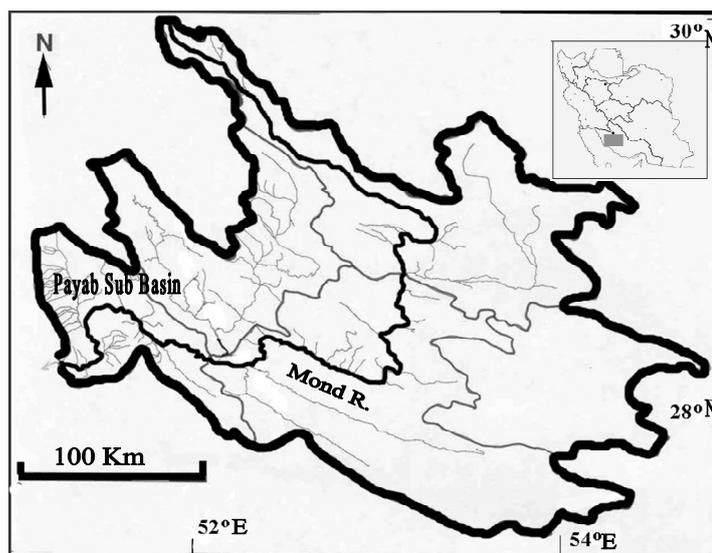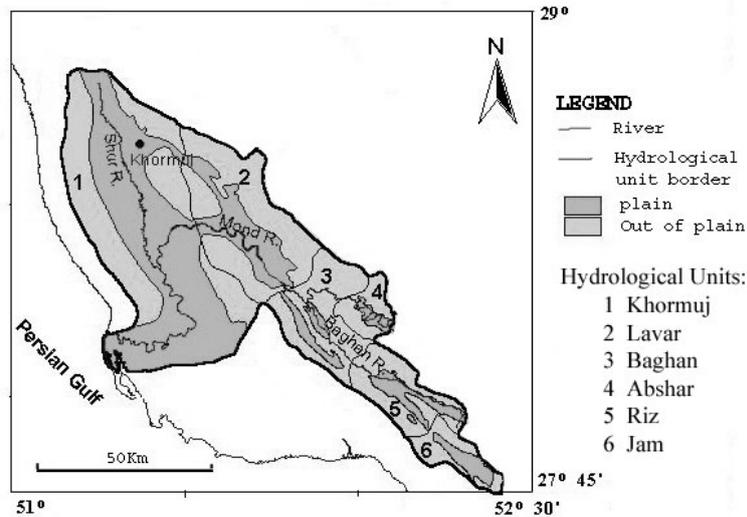

Figure 1. The Payab Basin.

Figure 2. Map of hydrological units with their plains in the basin.

basin lies in the arid to very arid climate. The day temperatures rise very high, reaching a maximum of close to 50ºC, during the summer months of July, August and September. The winter temperatures are low, with often cooler nights (close to 0ºC) during January and February. Rainfall varies between 180 and 260 mm annually; more in the northern and in the eastern parts. The main precipitation occurs in winter and in early spring. The summer is dry and hot, with autumn and spring also among semi arid seasons. Generally, after every few years severe drought conditions threaten the basin (Jamab, 1999)..

Risk Map Preparation

The model for risk assessment of vegetation degradation uses two types of data, namely, 1) numerical data and 2) thematic maps. The data are deployed for the GIS analysis using ARC VIEW 3.2 software. All such relevant data were obtained from the local and main offices and institutes of the Ministries of Agriculture and Energy and as well from Meteorological Organization, Statistics Center of Iran, and processed, using the GIS technique. The sources for the maps are indicated in Table 1. The thematic maps were digitized and

Table 1. Published maps digitized for the present GIS work.

Map	Scale	Publishing organization	Year published
Hydrological units	1:250000	Research Institute of Planning and Agricultural Economics (RIPAE), Ministry of Jahad-e-Agriculture, Iran	1998
Climate	1:250000	RIPAE	1998
Annual rainfall	1:250000	RIPAE	1998
Area of city and its suburbs	1:250000	RIPAE	1998
Land type (Unit)	1:250000	Research Institute of Soil and Water, Ministry of Jahad-e-Agriculture, Iran	1998
Land use	1:250000	RIPAE	1998

some numerical data like density of rural people related to each hydrological unit or to attributes like soil suitability within land units were considered to further prepare different hazard maps.

The assessment of the risk of vegetation degradation was attempted by first identifying the main indicators (Table 2) of vegetation degradation in the study area and then establishing the thresholds (class limits) of severity for indicators to arrive at the hazard map for each indicator in the GIS. The recommendations appearing in some literature mentioned against each indicator (Table 2) as well as the statistically suitable parameters of local conditions (Indicators 5 and 6) and official reports of the study area (Indicators 1, 2, 3 and 9) for some indicators have also been taken into consideration in determining thresholds for the five classes of severity for each indicator.

The hazard maps were prepared following

fixing of the thresholds of the five classes of severity (ratings scores between 1 and 5) for each indicator. In order that the effect of all the indicators gets projected in the risk map, the overlays of the individual hazard maps, derived from nine indicators, were analyzed simultaneously. The severity of risk assigned to each polygon was assessed by summing up of all the attributes (rating scores) of indicators used in the GIS. The following equation shows the weighting given for each indicator:

Equation (A): Risk score for vegetation degradation= [(Potential of biomass production+Vegetation cover+Rural population density+Pressure of livestock)×2]+[Expansion of agricultural activity over lands suitable for natural resources+Village density+Climate+Coefficient variation (CV) of annual rainfall+ Land suitability for vegetation cover]

Table 2. Indicators used in the GIS model of risk assessment for vegetation degradation.

Indicators	Class limits and their score				
	None (1)	Slight (2)	Moderate (3)	Severe (4)	Very severe (5)
1) Potential of biomass production (kg ha^{-1}) (Ref: Le Houerou and Le Hoste,1977; FAO/UNEP,1984; Kharin, 1986; Kumar, 1992)	≥1000	650 - 999	350 - 649	100 - 349	<100
2) Pressure of livestock ^{a} (Ref: FAO/UNEP, 1984)	≥ 5	1.5 – 5	1.0 – 1.5	0.5 – 1.0	< 0.5
3) Vegetation crown cover, % (Ref: FAO/UNEP, 1984)	≥ 70	50 - 69	25 - 49	10 - 24	< 10
4) Expansion of agricultural activity over lands suitable for natural resources (Ref: Ahmadi *et al.,* 2001)	Natural resource lands (without any changes)	Irrigated lands with low limitations	Irrigated lands with limitations, or dryland cultivation with low limitations	Dryland cultivation with high limitations	Dryland cultivation with very high limitations
5) Rural population density (per sq. km) in hydrological units	< 1	1 – 4	5 – 19	20 – 34	≥ 35
6) Village density (per sq. km) in hydrological units	0	0 - 0.02	0.02 - 0.06	0.06 – 0.09	≥ 0.09
7) Climate	Sub humid and humid	Slightly semi arid	Semi arid	Arid	Very arid
8) Coefficient Variation (CV) of annual rainfall in hydrological units (Ref: Ahmadi *et al.*, 2001)	<20	20 – 29	30 – 39	40 – 49	≥ 50
9) Land suitability for vegetation cover	Very good	Good (suitable)	Medium	Low	Poor or very poor (Unsuitable soils)

^{a} Pressure of livestock= Potential of Carrying Capacity (PCC)/Actual density of livestock.

The attributes×2 indicate their relative importance in assessing the severity of risk. On the other hand, the indicators of less impact were given weighting (1).

The risk score in each polygon denotes the cumulative effect of all the indicators. It was used to classify the five severity classes (Table 3) ranging from 'none' to 'very severe' in the risk map. For example, if the risk score is 13 (Table 3), the risk will be classified under 'none' severity class, implying that the attributes of each of the indicators used (Table 2) for assessment of the risk of vegetation degradation have the value 1, showing the least hazard. The risk score 65, on the other hand, would imply that each indicator will have a value of 5, implying maximum hazard. Any score with a value of multiple of 13 (26, 39, 52) defines the severity class, the thresholds of the severity classes being defined by scores like

19.5, 32.5, 45.5 and 58.5.

In the present assessment following a classification of the severity classes, areas with agricultural activity were considered as a mask and excluded in the GIS from the risk map (Figure 3), since vegetation degradation was considered, in the present work, for areas under natural vegetation cover. The correction for this section was done for severity classes as follows:

a) If the agricultural activity is under irrigation farming, → 2 classes were lowered for these lands.

b) If the agricultural activity is under dryland farming, → 1 class was lowered for these lands.

This classification facilitated the production of a risk map that shows only different degrees of vegetation degradation, but doesn't show where the risk of

Table 3. The severity classes of Risk Map produced in the GIS.

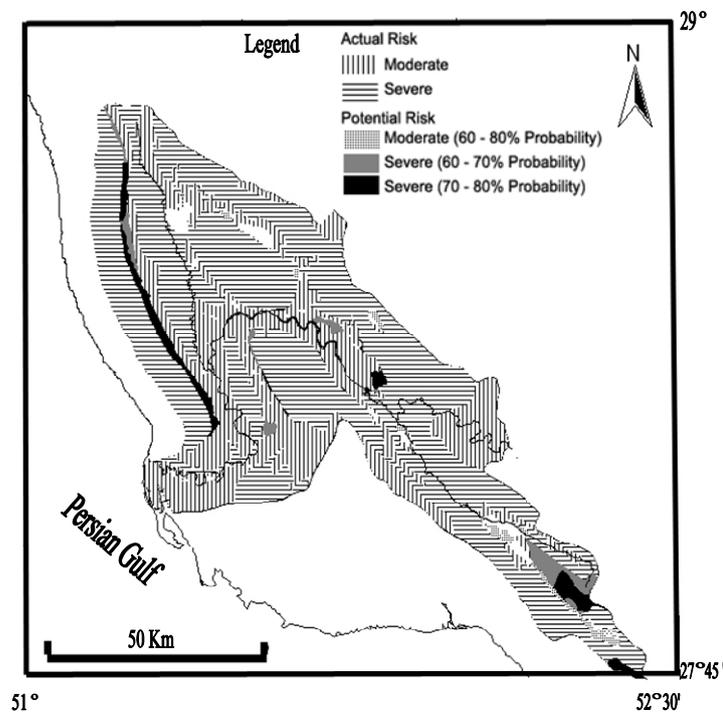| Class	None	Slight	Moderate	Severe	Very severe
Risk score	13 -19.5	19.6 – 32.5	32.6 – 45.5	45.6 – 58.5	58.6 - 65

Figure 3. Risk of vegetation degradation in the Payab basin.

vegetation degradation would be higher in the 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 vegetation degradation. The areas under potential risk were recognized using the following criteria:

Equation (B): Potential risk area= Areas where the risk class determined> Present status of hazard.

The potential risk areas (Figure 3) include areas that for the moment show a state of degradation, lower than the risk classes predicted. For example, areas under 'moderate' potential risk suffer already from slight to no degradation, but show moderate vulnerability towards worse conditions. On the other hand, the degradation may be prevented with the choice of a judicious land use and appropriate land management techniques. To show a statistical picture of the level of risk, the final risk scores were converted into percentages and applied in calculating the probability of potential risk, using the following equation:

Equation **(C):** *% Probability of risk in potential risk areas = [(X − 13)/52]×100*

Where, *X*: The risk score in each polygon, 13: the least score (0% probability) and 52: The numeric difference between the highest *vs.* the least scores. Therefore, in this equation it is tried to stretch the risk scores between 0 to100.

The 'Actual risk' areas (Figure 3) include areas that presently show a state of degradation equal to the risk class predicted. For example areas under 'severe' actual risk already show the evidence of severe degradation; implying lesser vulnerability in the immediate future as compared with the areas under potential risk. The indicators show that these areas bear a lesser chance of further degradation unless the degradation is imposed by either adverse anthropogenic activity or by drastic climatic changes. In Equation (B), the present status of hazard is determined by considering the attributes of the per cent of vegetation crown cover (indicator 3, Table 2).

RESULTS

The risk map (Figure 3) shows only those areas of moderate to severe 'actual' and 'potential' risk, excluding all the under 'slight' and 'none' risk classes. Using the present model, Tables 4 and 5 show the areas under 'potential risk' with their probability levels and the areas under 'actual risk':

From Figures 3 and 4, the most obvious conclusion drawn is that in the Payab basin a larger proportion (64.5%) of land is under 'severe risk' of vegetation degradation than

Table 4. Probability (in %) for areas under potential risk of vegetation degradation in the Payab basin.

Risk class	Probability	Areas under risk
Moderate	60-80%	Few scattered parts of all the hydrological units (except Abshar), especially on the plain areas of Riz and Jam units along the Baghan River and its branch in Jam.
Severe	60-70%	Few scattered parts in the hydrological units of Riz, Lavar and Khormuj, especially on the hilly and plateau areas of Riz.
Severe	70-80%	Dominant, more on the hills to the west of Khormuj plain, and on the hills of Jam unit.

Table 5. Areas under actual risk of vegetation degradation in the Payab basin.

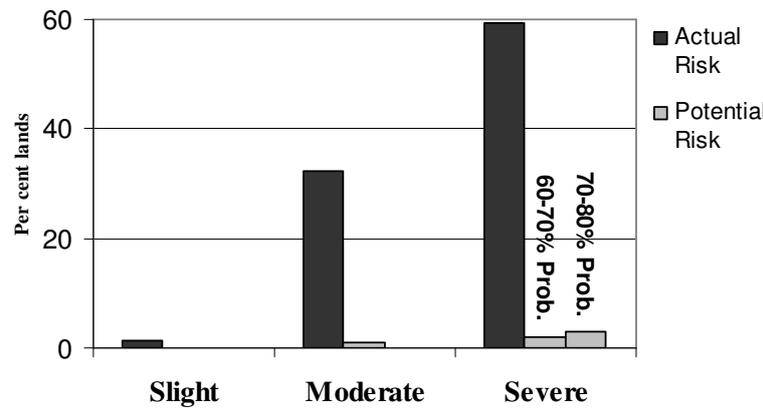| Risk class	Areas under risk
Moderate	Moderate risk areas occur in most parts of the Abshar unit, plains of Lavar and Khormuj and in parts of the Riz and Baghan plains.
Severe	Covering most of the mountainous and hilly areas. Also some areas along the course of Shur and close to the Mond River in the Khormuj plain show severe risk.

Figure 4. Percent land under different risk classes of vegetation degradation in the Payab basin.

the risk from other classes. The actual severe risk areas in the Payab form 60% of the total land, where there is hardly any vegetation cover.

Total land under moderate to severe 'potential risk' forms only 6% of the Payab basin, but indicates those areas as still under greater threat of vegetation degradation. Such lands are widespread in the plains of Jam and Riz and a big narrow strip in western part of Khormuj plain where agricultural activity and encroachment into the rangelands is greater than in other areas in the basin. Among areas under potential risk, those forming the severe risk class occupy to a greater extent in the Payab basin (5%), showing a greater risk in getting into the 'severe' class. Overall, the areas under 'potential risk' in the Payab basin bear a lower proportion (6%) as compared with the areas under 'actual risk' (93%). A 1% of total lands is classified under 'none class' showing no degradation.

DISCUSSION

The estimates done on the basis of observations on the current status of vegetation degradation like current crown cover (indicator 3, Table 2) reflect only what has happened so far. Risk assessment, on the other hand, is based on modeling, calculations and predicting the potentially

adverse situation that may arise in 10 to 50 years from now (Bridge *et al*., 2001). Most studies so far done in the world (e.g. Kumar, 1992) have based their estimation on the 'present status' of vegetation degradation. There exists also confusion in the use of the term "risk assessment" among many scientists (e.g. Filho *et al*., 2001) who actually estimated only the current state of land degradation and not the risk.

The vegetation degradation assessment, based only upon the present status of degradation, is inadequate to predict areas under risk. It requires a comparison between the present status and data showing the state of vegetation degradation in the past to find the trend of degradation. It is almost difficult to find trend of hazard because of a lack of such data of the previous decades. The present model using different indicators of vegetation degradation tries to solve this problem since it finds the severity of degradation using cumulative effect of all the indicators and then comparing it with the present status of degradation.

As regards the present work, the risk assessment of vegetation degradation attempts to demarcate areas of greater probability of reaching the worst step of degradation e.g. a change from moderate to its severe state, in the meantime assessing the probability (risk) of this adverse change. This kind of classification, using two

categories of 'actual' *vs.* 'potential' risk, and its subclasses based on the percent probability in the risk map is the first attempt of its kind in defining areas with higher risks of degradation. Preparing such risk maps may prove to be useful for regional planners, and policy makers for agricultural and environmental strategies, not only in the semi-arid and arid conditions of Southern Iran but also in other countries facing similar problems. The model can be made applicable for other countries only after limited modification of some of the indicators, based on the local conditions. The GIS analysis not only facilitated the model development but also allowed for an evaluation of spatial correlation as well as risk map production.

The risk assessment map (Figure 3) also facilitates the prioritization for planning the reclamation and conservation of natural vegetation cover as against the degradation causes. The highest priority areas would be those under severe and moderate potential risk. Such lands are not extensive, covering only some 6% of the lands in the basin. The second priority areas would be those under 'moderate actual risk'. Such lands cover some 32% of the Payab basin. The last priority areas are those under 'severe actual risk'. Such lands are extensive and cover some 60% of lands in the Payab.

To control vegetation degradation, some governmental laws should be passed. Management strategies can be undertaken by the local governments to enforce the following existing laws for natural resource conservation:

(1) Remedial measures for soil degradation types

One of the most important measures against vegetation degradation is to find the kind of such limitations as erosion, salinity and the compaction state the soil belongs to. Proper measures can then be undertaken to substantially reclaim the vegetation cover.

(2) Natural resources management

The anthropogenic activity like deforestation, encroachment into rangelands for cultivation, mining and urbanization seriously harm the natural vegetation cover. The unavoidable need for food, fuel and construction materials in rural areas or by the nomads has led to immense felling of trees and as well the destruction of the vegetation cover. All these activities have to be controlled by local natural resources offices as based on the capacity of natural vegetation cover and land use planning.

(3) Grazing based on carrying capacity

Grazing pressure seems to have become more intensive on the vegetation cover than before. Grazing with heavy stocking has had multiple adverse effects on agro-ecosystems through defoliation of plants and consequently influencing their growth, strength as well as proper regeneration processes. Besides, it has reduced the diversity of plant species and their vegetation crown cover and along with the volume of biomass. Through reduced vegetation, the factors of crown cover, and water infiltration rate decreases while wind/water soil erosion go on the increase (Mwendera and Mohamed Saleem, 1996; Le Houerou, 1996; Asadu *et al.*, 1999; Taddese, 2001). Facing these kinds of problems, 'rangeland management', as based upon grazing capacity is dearly compulsory.

(4) Consideration of land suitability and capability

The land suitability and capability for agricultural and natural resource purposes was prepared for each land unit. Any strategy for development of these areas under agriculture, pasture and/or forest can be undertaken by taking into consideration the sort of such information.

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CONCLUSIONS

Preparation of a Risk Map is seen as a prerequisite for planning environmental conservation. For the entire Southern Iran, highly threatened by vegetation degradation, it is the need of the day. The Payab Basin model is the first attempt of its kind for defining the risk of vegetation degradation and can be made applicable to other areas in Iran and elsewhere. This model has been applied for a regional scale but if the data of indicators for larger scales are available, it can be used to assess the risk for smaller areas too. The main results achieved from the present paper are: The hazard maps of nine indicators processed in the risk assessment model give a far better opportunity to distinguish the severity classes of the risk of vegetation degradation. The indicators are related to vegetation cover, anthropogenic activity, soil characteristics and climatic factors. The model for assessing the vegetation degradation should provide proper emphasis to the local geographic conditions and land use practices. The model based on the statistical parameters helps to identify the areas under actual and/or potential risk and their sub classes based upon per cent probability. The areas under 'actual risk' in the basin are more extensive (93% of the total land), as compared with those under 'potential risk'. Considering both actual and potential risk areas it is concluded that the areas under 'severe risk' bear a greater spread (65%) as compared with the other classes, indicating bad conditions of environment in such areas. The remedial measures should be undertaken by selecting the priority areas. Areas under moderate and severe potential risk (indicated in the risk map) will be the areas needing immediate attention. Remedial measures for reducing vegetation degradation and to diminish the effects of degradation have been suggested.

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ارزیابی ریسک زوال پوشش گیاهی با استفاده از GIS

م. مسعودی

چکیده

کل اراضی جنوب ایران تحت تاثیر مشکلات ناشی از اشکال مختلف تخریب خاک می باشد که زوال پوشش گیاهی یکی از مهمترین این اشکال میباشد. حوضه پایاب (۵۲۲۴۷۰ هکتار) حوضه بالادست رودخانه مند بوده که برای ارزیابی ریسک این شکل تخریب انتخاب شد. داده های مختلفی برای محاسبه شاخصهای تخریب از گزارشات چاپ شده و اطلاعات تهیه شده از ادارات مختلف ایران گردآوری گردید. یک مدل جدید برای محاسبه ریسک زوال پوشش تهیه گردید. با در نظرگیری نه شاخص زوال پوشش گیاهی مدل مناطق با ریسک بالقوه (مناطق ریسکی) را از مناطق با ریسک بالفعل را تشخیص و همچنین میزان احتمال تخریب بیشتر در آینده را معین کرد. تهیه نقشه های ریسک بر پایه تجزیه و تحلیل های GIS و این شاخصها کمک کننده برای تشخیص مناطق اولویت دار و شروع

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اقدامات حفاظتی و احیایی میباشد. یک نقشه خطر برای هر شاخص در GIS بر پایه حدود کلاسهای خطر شاخص ها تهیه گردید. کلاسهای ریسک بر اساس مقادیر ریسک بر گرفته از توصیفهای شاخص ها مشخص و نقشه ریسک پس از روی هم گذاری نه نقشه خطر در GIS تهیه گردید. اراضی با ریسک بالفعل گسترش بیشتری با ۹۳٪ در منطقه دارد و هنگامی که نقشه ریسک به زیر کلاسهایی بر اساس میزان سطوح احتمال طبقه بندی گردید، مدل تصویری آماری از ریسک زوال پوشش گیاهی به نمایش در آورد.