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Erosion Hazard Index Methodology (EHIM) for Streams Erodibility Assessment (Ardabil-Province)

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Abstract

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An erosion hazard index methodology (EHIM) was developed for assessing stream erosion. The index of stream erosion is designed as a management tool. Assessing stream erosion involves consideration of a range of aspects of streams and a value judgment about a desirable state. The assessment of the erosion indicators of streams was based on a state-wide assessment of physical stream condition. A scale from 0 to 100 was chosen as a basis for ranking where an erosion hazard index (EHI) of 100 indicates the very extensive possible erosion state and one of zero the stable or no erosion possible erosion state. In the EHIM five steps are necessary for calculation: to measure and select of basic and additional indicators, to calculate sub-EHI_i for all selected indicators, to determine weighting factors for all selected indicators, to calculate a synthetic EHI using the sub-EHI_i and weighting factors for all selected indicators and final step: to assess stream erosion based on synthetic EHI values. The EHIM was applied to a 378 number of Ardabil Province (NW of IRAN) for assessment and comparison purposes. Length of stream erosion (LE) was selected to serve as a basic indicator, while erosion susceptibility of lithology (LESi), length of streams with lateral erosion (LLAE), length of streams with bed erosion (LB), the plant cover and human impacts (LAHE), pasture lands (LPE) and their relationships and discharge of floods ($Q_{2.33}$) were used as additional indicators. The results suggest that the EHIM is a valuable relatively uncomplicated methodology with simple principles, ease of calculation, reliable and intuitive results. As a practical planning tool, it can be widely used for the quantitative assessment and comparison of stream erosion states for a series of different streams or more complicated stream systems .However, planning for river management systems is complicated by a variety of uncertainties but this paper presents the development of a simple assessment model for river management under uncertainty. **[Talaei et al. Erosion Hazard Index Methodology (EHIM) for Streams Erodibility Assessment (Ardabil-Province). International Journal of Agricultural Science, Research and Technology, 2012; 2(2):89-97].**

Key words: Erosion hazard index; Quantitative assessment; Stream condition; River indicator

1. Introduction

The main purpose of the study is to propose a new method for assessing streams on the basis of theirs erosion characteristics (i.e. Erosion hazard index methodology), that can be used to solve some of environmental problems and select management methods and specially type of erosion control works. Measures of stream condition can assist in adaptive management approach and can be used to aggregate a large volume of data and will be useful in communications to the public and higher level management or funding agencies. They can also be used by managers to get an overview of problems in a particular region or at a national scale to assist in decision-making about the allocation of funding and resources. There is increasing interest in the use of decision support system to assist in managing the environmental condition of waterways (Anderson, 1993). Decision support systems can assist the evaluation of management scenarios by predicting likely changes to stream condition. Measures of stream condition could be useful in validating these predicted changes. Those aspects of stream condition that can be measured will be a useful guide to those parts of the river system that are worth modeling. Assessment of stream condition can help provide information to quantify more accurately the environmental consequences of decisions. This information can then feed into negotiations about environmental, economic and social costs and benefits. As a case study, this new methodology is applied to the assessment for the erosion status of 378 Ardabil province streams.

A number of national and international programs (Baker, 1977) have been established to address measuring stream condition in terms of the components of river and stream condition and the intended use, for instance: "protecting and assessment the chemical, physical, biological, habitat, ancillary and hydrological of water quality is the primary goal of the Clean Water Act passed the United States Congress in 1972 (Barmuta et al, 1992; Cooper et al., 1994; Carlson, 1977; Costa, 1974; Department of the Environment Sport and Territories, 1994), "Estuarine Health Index" (Dury, 1973; Division of Water Resources, 1992), "Riparian, Channel and Environmental Inventory" (Gupta, 1975), "State of Environment Report, Victoria, Australia" (Gupta, 1983), "Environmental Condition of Victorian Streams" (Jackson and Anderson, 1994; Ladson and White, 2000; Michell, 1990), "State of the Rivers Project, Queensland, Australia" (Nanson and Hickin, 1986; Odgaard, 1987), "Index of Stream Condition" (Baker, 1977), "State of the Environment" (Office of the Commissioner for the Environment, 1988), Australian River Assessment System (Melissa et al., 2000) and "Water erosion hazard assessment of the Lort and Young Rivers catchment" (Holmes et al., 2010). An Integrated planning for studying and recognition of the characteristic of the river and ephemeral streams in Ardabil Province–NW of IRAN- supported by the Soil Conservation and Watershed Management Institute (Talaei et al., 2006). However, the lack of consensus in criteria for assessment has led to two major problems in the use of present methods to assess river erosion hazard. First, it is extremely difficult to assess the actual erosion status of a river and stream system; and secondly, it has been difficult to make comparisons of erosion hazard status among different river and streams.

2. Materials and methods

Ardabil province, an area of some 17953 Km^2, is situated in the North-West of IRAN. It is located between longitude 47˚ 03 to 48˚ 55 east and latitude 37˚ 45 to 39˚ 42, north. The area drains into the Aras and Qezel Owzan river systems. Watersheds of this area have a number of 378 rivers and ephemeral streams. Their mean width ranged between 0.5 and 80 m, with length ranging from 0.1 to 145 km. Their average discharge varied from 0.1 to 155m^3/s. The measured parameters and collected data, according to the topographical maps (1:50000), included various physical forms (e.g. erosion and sedimentation), water quality (e.g. SD, pH, TDS, N, P, Si, COD, etc.) and plant cover (e.g. type of floristic and species). The mathematical principals used in this article are based on Xu et al. (2005) studies.

Design and calculation of erosion hazard index (EHI)

In order to quantitatively assess the erosion status of a stream, an erosion hazard index (EHI) needed to be developed. A scale from 0 to 100 was chosen as a basis for ranking where an EHI of 100 indicates the very extensive possible erosion state and one of zero the stable no erosion possible erosion state. In order to facilitate verbal descriptions of erosion status, the EHI was further divided into five groups with ranges as: 0–20, 20–40, 40–60, 60–80, 80–100 corresponding to five erosion states, "No or only spot erosion", "Moderate, affecting parts of reach", "Significant", "Extensive" and "Very Extensive ", respectively.

The EHI is then calculated according to the following equation (Xu et al., 2005):

$$EHI = \sum_{i=1}^{n} \omega_i SubEHI_i \tag{1}$$

Where EHI is a synthetic erosion hazard index, Sub-EHIi the *i*-th sub- erosion hazard index for the *i*-th indicator, n the number of indicators considered in assessment, and ωi the weighting factor for the ith indicator. It can be seen from Eq. (1) that the synthetic EHI depends on the various Sub-EHIi and the weighting factors for each indicator.

Assessment indicator selection

In authors previous studies, a set of approaches to measuring stream indicators including the physical, chemical, biological and general-system aspects of stream conditions have been proposed (Baker, 1977). There are at least seven components of stream condition that can be identified the literature: Water quality, physical habitat, riparian quality, aquatic biology, physical form, aesthetics and hydrology. The choice of indicators is also important. Suitable indicators of stream condition should follow some principles (Platts et al., 1987; Rankin, 1995). The final choice of indicators depends on the local conditions and specific objectives. To obtain an overall value of condition, indicators must be scored against some standard, a defined desirable state which may be the natural condition.

For erosion hazard index methodology (EHIM), assessment indicators are composed of basic and additional indicators. Additional indicators, although important, have a less close relationship with stream erosion hazard status. Stream erosion's hazard status can be evaluated on the basis of the basic indicators; with the assessment offered by the additional indicators considered as remedies for the results indicated by the basic indicators.

In most stream conditions, the indicators having the closest relationship with erosion hazard status are length of stream erosions (LE to meter or kilometer). The higher the LE or percentage of erosion ratio ($\frac{LE}{SL} \times 100$) a stream has the worse the stream's erosion state (SL: length of stream to meter or kilometer). Based on above principles and data availability for the Ardabil streams, LE was selected as the basic indicator. Lithological erosion susceptibility (LES), i.e. rock and sedimentary formation, length of streams with intense lateral (LLAE) and bed (LB) erosion, the plant cover and human impacts on erosion (LAHE) and discharge of floods (Q2.33) were then selected as additional indicators.

Calculating Sub-EHIi

In terms of the EHIM, EHI (LE) is considered to be highest (100) when the LE is also highest. The distribution of LE is a log normal, Figure1.

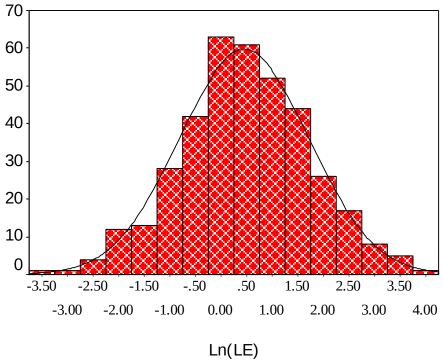

Figure 1. Histogram shows of a log normal distribution of Ln (LE) in the Ardabil stream systems. (N=378, Std. Dev. =1.26 and mean=0.45)

Therefore, EHI (LE) can be calculated by the following equation (2) (Pizzuto, and Meckenburg, (1989):

$$\mathrm{EHI(LE)} = 100 \times \frac{\mathrm{Ln}(\mathrm{LE}_x) - \mathrm{Ln}(\mathrm{LE}_{\min})}{\mathrm{Ln}(\mathrm{LE}_{\max}) - \mathrm{Ln}(\mathrm{LE}_{\min})} \quad (2)$$

Where EHI (LE) is the Sub-EHI for the basic indicator, LE; LE x the measured LE value; LE min the measured minimum LE value when EHI (LE) is 0; LE max the measured maximum LE value when EHI (LE) is 100.

By rearranging terms, Eq. (2) can be restated in the following format:

$$\mathrm{EHI(LE)} = 10 \times (a + b\mathrm{Ln}(\mathrm{LE}_x)) \quad (3)$$

Where a b is constants determined by LE_{min} and LE_{max} and computed by the following equations (Xu et al., 2005):

$$a = -10 \times \frac{\mathrm{Ln}(\mathrm{LE}_{\min})}{\mathrm{Ln}(\mathrm{LE}_{\max}) - \mathrm{Ln}(\mathrm{LE}_{\min})} \quad (4.1)$$

$$b = 10 \times \frac{1}{\mathrm{Ln}(\mathrm{LE}_{\max}) - \mathrm{Ln}(\mathrm{LE}_{\min})} \quad (4.2)$$

According to measured data for the 378 Ardabil Province streams, LE_{min} is 0.035 (Km) and LE_{max} is 50 (Km). By inserting these values into Eq. (4.1 and 4.2), we find that a = 4.614 and b = 1.377. The expression for calculating the EHI (LE) for the Ardabil streams can then be obtained as:

$$\mathrm{EHI\ (LE)} = 10 \times (4.614 + 1.377 \times \mathrm{Ln}\ (\mathrm{LE}_x)) \quad (5)$$

Eq. (5) indicates that calculation of EHI (LE) can be deduced from the measured LE data by logarithmic expression of the differences between the extreme values. The relationship between EHI (LE) and LE is shown in Figure 2.

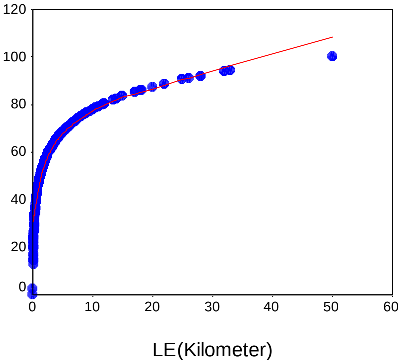

Figure 2. Relationship between length of stream erosions (LE) and EHI (LE) in Ardabil streams. LE_{min} is the measured minimum length of stream erosion values when EHI (LE) is 0, and LE_{max} the measured maximum LE value when EHI (LE) is100.

3. Results and discussion

Calculating EHI (LES)

It is clear that rock type influences stream erosion; and rates of stream erosion can vary on different geologic materials. According to measured data of lithological, stream erosion characteristics for the 378 Ardabil streams, there are direct mutual relationship between stream erosions with erosion susceptibility of different litology. The unconsolidated sediments of Quaternary period and sedimentary rocks such as Marls and Claystone related to Miocene are very susceptible against basic and intermediate igneous rocks, also sandstones, limestone and siliciferous dolomites are resistant. For two classes of geologic materials susceptibility, erosion hazard index were assessed as EHI (LES2) – EHI (LES3); corresponding to rock and sediments erodibility states: low to moderate; high and very high respectively.

The positive relationship between length of stream erosions (Ln (LE)) and the length of different lithology with low to moderate erodibility state (Ln (LES2)) is shown in Figure3. The following expression can be obtained by means of regression analysis:

$$\text{EHI (LES2)} = 10 \times (4.614 + 1.377 \times (-0.658 + 0.602 \times \text{Ln (LES2)})) \tag{6}$$

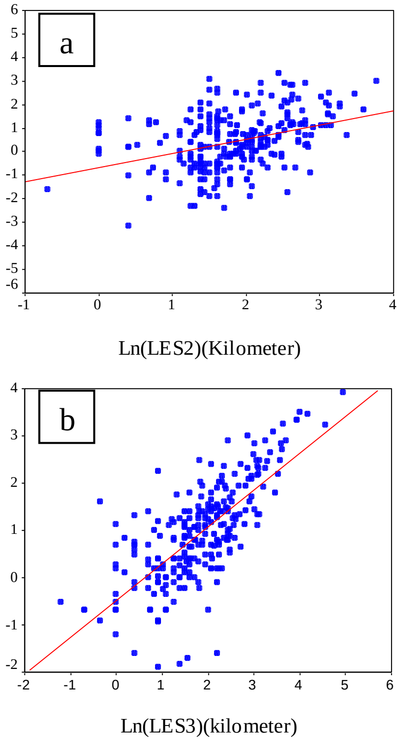

Figure 3. Relationship between length of stream erosions and the Length of different lithology a) with low to moderate erodibility state (LES2), b) high and very high erodibility state (LES3) in Ardabil streams.

The relationship between (Ln (LE)) and the length of different lithology with high and very high erodibility state (Ln (LES3)) is shown in Figure3b. The graph shows that length of stream erosions increases with greater length of high erodible rock and sediments. Now the equation of a straight line can be written in the form:

$$\text{EHI (LES3)} = 10 \times (4.614 + 1.377 \times (-0.477 + 0.799 \times \text{Ln (LES3)})) \tag{7}$$

In which a= - 0.477 and b= 0.779 are parameters determining the line. Thus the equation determines straight line graphed in Figure 3 b.

Calculating EHI (LLAE) and (LB)

The graded streams of this area can be deepening their channel by down cutting while part of their energy is also widening the valley by lateral erosion. Almost 19% of stream lengths of our area were accompanied by lateral and bank erosion (LLAE); and bank erosions are dominated as compared with bed erosion in its length. The relationship between (LLAE) and (LE) is shown in Figure 4a.

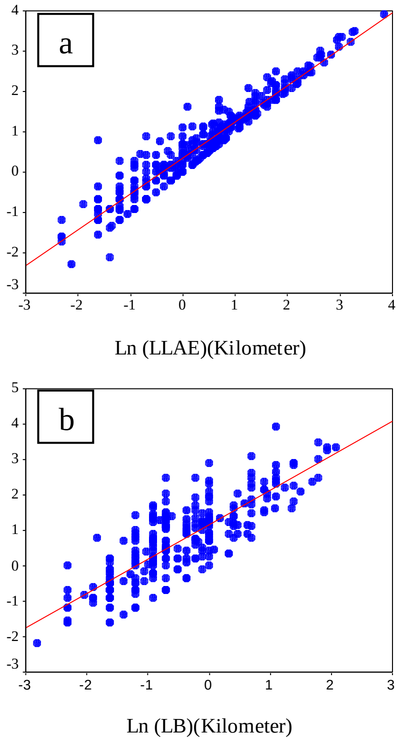

Figure 4. Relationship between Length of stream with intense erosion (LLAE) (a), bed erosion and the total length of bank erosion (LE) (b) in Ardabil streams.

$$\text{EHI (LLAE)} = 10 \times (4.614 + 1.377 \times (0.359 + 0.895 \times \text{Ln (LLAE)})) \tag{8}$$

Bed erosion evidences have been recorded approximately in 5.2% of stream length by repeatedly and periodically field controls during 2001 to 2005, which were significant in comparison with other erosion features in particular lateral erosion. There are positive of relationship between bed erosion length (LB) and the length of total erosions in Ardabil streams, the relationship between (LB) and (LE) is shown in Figure 4b. The following expression can be obtained by means of regression analysis:

$$\text{EHI (LB)} = 10 \times (4.614 + 1.377 \times (1.163 + 0.969 \times \text{Ln (LB)}) \tag{9}$$

Calculating EHI (LLAE/LE) and (LB/LE)

The positive relationship between LE and (LLAE×100/LE) is shown in Figure5a. The following expression can be obtained by means of regression analysis:

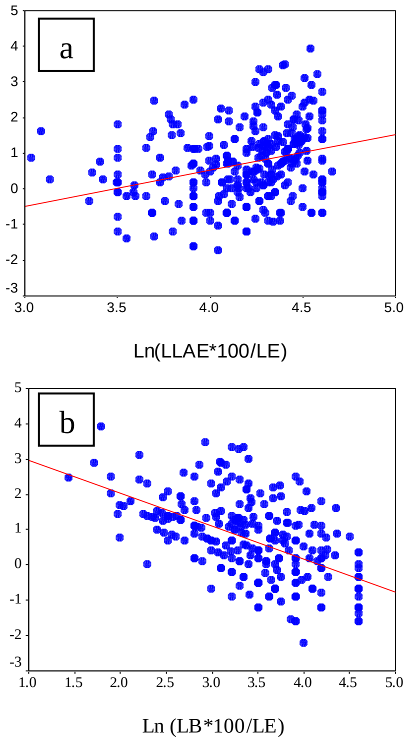

Figure 5. Relationship between the length of stream with erosion (LE) and, the (LLAE×100/LE) (LILE×100/LE) ratio in Ardabil streams.

$$\text{EHI (LLAE/LE)} = 10 \times (4.614 + 1.377 \times (-0.704 + 0.319 \times \text{Ln (LLAE} \times 100\text{/LE)))} \quad (10)$$

The negative relationship between LE and LB*100/LE is shown in Figure 5b. The following expression can be obtained by means of regression analysis:

$$\text{EHI (LB/LE)} = 10 \times (4.614 + 1.377 \times (3.903 - 0.932 \times \text{Ln (LB} \times 100\text{/LE)))} \quad (11)$$

Calculating EHI (LAHE) and (LPE)

The plant cover of indicated river and streams has been divided to 2 groups: Plantation and farmlands and pasture lands. Finally, three sub-erosion hazard index (Sub-EHIi) calculated, for each of these classes of plant covers and human impacts, erosion hazard index were assessed as EHI (LAHE) and EHI (LPE) respectively.

There are quadratic regression kind of relationship between reach length of stream with agriculture and human activities (LAH) and (LAHE)×100/(LAH) ratio in Ardabil streams; as LAHE is length of bank streams with agriculture landuse and human activities that have been affected by erosion processes. The rate and intensity of erosion in stream bank in this area is strongly influenced by agriculture and human works Figure 6a. The graph shows that percent of stream length with erosion, e.i. (LAHE)×100/ (LAH) ratio, increases with longer length of plantation and farmlands, and greater human impacts, i.e. (LAH).

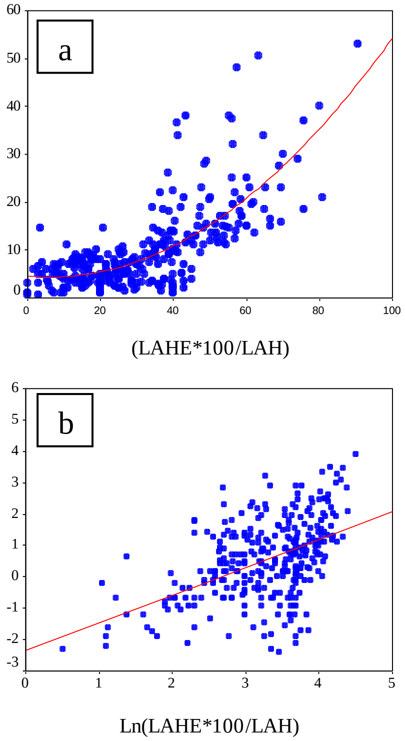

Figure 6. a) Relation of stream erosion with plantation, farmlands and human activities, (LAH): length of stream with agriculture and human activities; (LAHE) ×100/ (LAH): length of bank streams with agriculture landuse and human activities ratio, multiplying by 100. b) Scatter diagram for length of river with erosion (LN (LE)), and length of bank streams with agriculture landuse and human activities ratio (Ln (LAHE) ×100/ (LAH)); as percentile. This diagram corresponds to increasing degree, or strength, of Linear (Ln) relationship.

The scatter diagram for 307 points obtained from the database is shown in Figure6b. An inspection of scatter diagram shows that there is a tendency for values of Ln (LAHE) ×100/ (LAH) to be associated with values of Ln (LAH). Now the equation of a straight line can be written in the form:

$$\text{EHI (LE)} = -2.348 + 0.883 \times \text{(Ln (LAHE} \times 100\text{/LAH))} \quad (12)$$

The combination of Eq. (5) with Eq. (12) yields Eq. (13) for calculating plantation, farmlands and human activities on stream erosion condition , EHI(LAHE), as:

EHI (LAHE) = 10 × (4.614 + 1.377 × (-2.348 + 0.883 × (Ln (LAHE × 100/LAH))) (13)

The results showed, that the reaches in length accompanying of bank erosion evidences have been significantly decreased by increasing of range and forest cover in stream bank; Also, there was significant correlation between pasture and forest density with stream erosion values. Characteristics of natural plant covers and their density have important roles in controlling erosion quantity and it's intense in stream systems. Lower rates of bank erosions have been recorded on streams with natural riparian covers, Figure 7a; In fact, the fastest bank erosion rates identified in Ardabil stream systems with pasture riparian covers have been measured on the low density, Figure 7b.

The negative relationship between length of bank erosion (Ln(LE)) and (Ln(LPE) × 100/(LP)) ratio is shown in Figure8; i.e. LPE: the length of streams with bank erosion and pasture riparian covers, LP is the length of streams with and without bank erosion; and it has pasture riparian covers. The following expression can be obtained by means of regression analysis:

EHI (LPE) = 10 × (4.614 + 1.377 × (1.131 - 0.274 × (Ln (LPE × 100/LP))) (14)

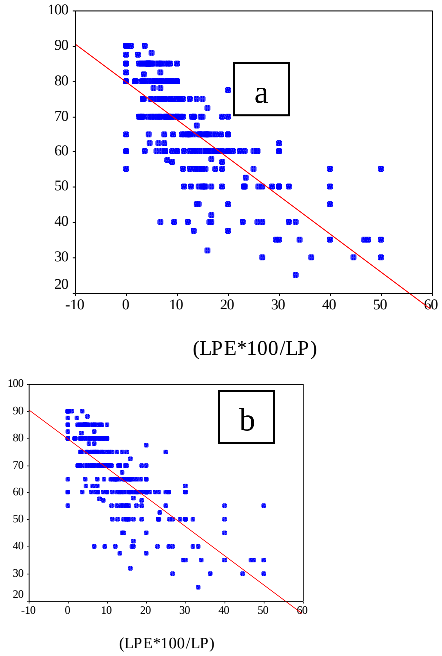

Figure7. Relationship between erosional lengths of streams with: a) pasture riparian covers, b) the density of range plants

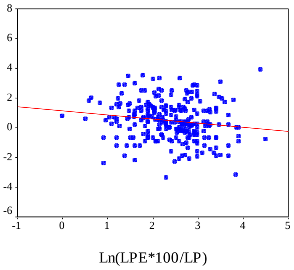

Figure 8. Relationship between length of bank erosion (Ln (LE)) and (Ln (LPE) × 100/ (LP)) ratio

Calculating EHI ($Q_{2.33}$)

There is normally a tendency for kinetic energy to increase in a discharge resulting from the entry of numerous tributary streams into main rivers and the occurrence of foreseen floods in ephemeral and intermittent channels. The role of floods in the erosion of stream channels has been one of the most controversial topics in fluvial geomorphology. Nearly every experienced fluvial geomorphologist can cite examples where major floods have produced surprisingly little channel change (Ramm, 1994), very temporary effects (Tilleared, 1986), where spectacular adjustment has occurred or to increase migration rates (Talaei et al., 2006; Young et al., 1995; Yoder and Rankin, 1994). The effectiveness of flood erosion depends on the exceedence of a resistance threshold in bed or bank materials, including vegetation, by the stream power per unit area generated during flood flow. The influence of flood discharge in stream erosion was estimated according to simplified method. The flood discharge with 2.33 years of recurrence interval is calculated by:

$Q_{2.33}$= 0.516$A^{0.596}$, R=-0.95; (for the watersheds of northern area (Ramm, 1994) (15)

$Q_{2.33}$=0.0012A+ 1.477, R=-0.93; (Calculated for the watersheds of southern area) (16)

Q= Specific discharge expressed in lit/s/Km^2; A= Watershed area in Km^2. The flood discharge with 2.33 years of recurrence interval (in m^3/s) for each stream.

It can be seen that flood discharge and length of stream erosion are middingly correlated Figure 9. The relationship between flood discharge and length of stream erosion is particularly good consideration the fact that the bed and bank of streams are eroded during a flood and this erosion has taken place during a period of smaller return periods flood (2.33 Year- floods).

The positive relationship between Ln (LE) and Ln ($Q_{2.33}$) can be represented by means of regression analysis, and as a result, the EHI ($Q_{2.33}$) is defined by the following formula:

$$\text{EHI } (Q_{2.33}) = 10 \times (4.614+1.377\times(-0.316+0.637\times \text{Ln } (Q_{2.33}))) \quad (17)$$

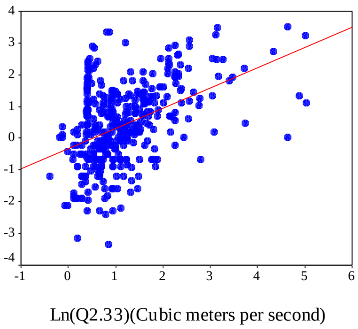

Figure 9. Relationship between length of stream erosion (Ln (LE)) and flood discharge with 2.33 years return periods (Ln ($Q_{2.33}$)).

Determining weighting factors (ω_i)

The method of relation-weighting index can be used to determine the weighting factors for assessment indicators, i.e. the relation ratios between LE and other indicators can be used to calculate the weighting factors for indicators. The equation is as follows:

$$\omega_i = \frac{r_{i1}^2}{\sum_{i=1}^{m} r_{i1}^2} \quad (18)$$

Where ω_i is the weighting factor for the i-th indicator; r_{i1} the ratio between the i-th indicator and the basic indicator (LE), and m the total number of assessment indicators, here $m = 14$.

The correlation ratios between the basic indicator (LE) and other indicators are shown in table 1. The calculation of the weighting factors can be done using Eq. (18) and the corresponding correlation ratios.

Table 1. Statistical correlation ratios between LE and other indicators

Relative indicators	**Ln(LE)-Ln(LE)**	**Ln(LE)-Ln(LES2)**	**Ln(LE)-Ln(LES3)**	**Ln(LE)-Ln(LLAE)**	**Ln(LE)-Ln(LB)**
Number of stream reach	378	257	245	339	263
r_{ij}	1	0.375^{**}	0.727^{**}	0.957^{**}	0.820^{**}
r_{ij}^2	1	0.140	0.528	0.915	0.672

Relative indicators	**Ln(LE)-Ln(LLAE*100/LE)**	**Ln(LE)-Ln (LB*100/LE)**	**Ln(LE)-Ln (LAHE*100/LAH)**	**Ln(LE)-Ln (LPE*100 /LP)**	**Ln(LE)-Ln($Q_{2.33}$)**
Number of stream reach	339	263	307	261	374
r_{ij}	0.192^{**}	$-.0534^{**}$	0.491^{**}	-0.156^{*}	0.446^{**}
r_{ij}^2	0.036	0.285	0.241	0.024	0.198

** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed).

Results for the 378 Ardabil stream systems are presented in table 2. EHI values range from 2.74 to 73.94, covering a stream erosion status range from "No erosion or only spot erosion" to "Extensive erosion". Of the 378 streams, 97 were within the "Moderate" erosion hazard status range, 203 were classified as in a "Significant" erosion state, and 54 were in the "Extensive" erosion category. Only 24 streams were considered to be in a "No erosion or only spot erosion" erosion state.

Table 2. Classification results for the 378 Ardabil stream systems

Criteria to determine stream erosion ratings used by EHI	Frequency	Percent	Cumulative Percent
No erosion or only spot erosion	24	6.3	6.3
Moderate, affecting parts of reach	97	25.7	32.0
Significant	203	53.7	85.7
Extensive	54	14.3	100
Total	378	100.0	

Discussions

The choice of suitable indicators and their weights is critically important in the erosion hazard status assessment of a specific stream or river using EHIM. There are some principles that should be followed. For the Ardabil province streams, length of stream erosion (LE) was selected as the basic indicator; while, erosion susceptibility of lithology, the length of streams with lateral erosion especially length of stream banks with intense erosion, length of streams with bed erosion, the plant cover and human impacts, pasture lands (LPE) and their relationships and discharge of floods ($Q_{2.33}$) were used as additional indicators. With increasing erodibility state or condition, i.e. length of stream with erosion, outcrop area of susceptible rock and soils, clearing bank vegetation, the artificial modifications to the streams and human activities, erosion hazard index (EHI) is of course increased. The results from the case studies indicate that the EHIM can be used to solve the two problems mentioned in Section 1. The method offers a numerical scale from 0 to 100 allowing the quantitative assessment and comparison of erosion hazard state for single or multiple river or streams. It can describe continuous changes in a river's erosion hazard state. Further, the criteria for different erosion hazard states can also be obtained using EHIM. The combination of EHIM with field observations offers a comprehensive approach that can be utilized in both relative and absolute diagnosis as well as in the prediction of river erosion hazard state. The EHIM can be used for the absolute and relative assessment of both single river and different river and streams. The EHIM can be used for predicting the changes of erosion hazard index following the changes in environmental conditions, if river models are either validated or designed with a dynamic structure. Any approach to measuring river and stream conditions will be constrained by resources and the availability of data and skilled people.

4. Conclusion

The technique presented here represent a approach to measuring the overall erosional conditions of river and streams. There are decisions about weighting of indicators and calculation techniques and methods and the way the results is to be reported. The erosion hazard index methodology (EHIM) has been proposed for assessing river and stream erosional hazard. The method can easily make the quantitative assessment and comparison of erosional hazard states for single and different rivers by offering a numerical scale from 0 to 100. The EHIM was successfully applied to the assessment and comparison for a series of Ardabil province river and streams with satisfactory results. The EHIM is a valuable method with the advantage of uncomplicated principle, handy calculation, reliable and intuitive results. It is expected that the EHIM can be widely used for the quantitative assessment and comparison of erosional hazard states for single and different rivers and streams.

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