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GIS-BASED TECHNIC FOR ROADSIDE-SLOPE STABILITY ASSESSMENT: AN BIVARIATE APPROACH FOR A1 EAST-WEST HIGHWAY, NORTH ALGERIA

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Abstract: This paper presents a GIS-based method for landslide susceptibility (LS) assessment using slope-movement inventory and field data. The study has been carried out along A1-Highway (A1-H) in Hanif region as this road section is threated by several types of mass wasting. This hilly zone is known by their landslides sensitive terrains in the North of Algeria. The terrain data are collected from a Géologic map, satellite imageries, digital elevation model, rainfall data, field suveys and ancillary data. In this paper Frequency Ratios (FR) based on bivariate statistical method are evaluated by comparing the observed landslides to their controlling factors. The product of the linear summation of the FR values was a landslide susceptibility index (LSI) map. It was categorized using the natural breaks classification method. The resultant LS zonation map delineates the area into five hierarchic zones. The results confirms that the angle of the slope, plays the most role in wasting especially in road sides. The LS can be used for preliminary land use planning and hazard mitigation purpose. By means of this map the current route of the A1-H can be improved to cross less susceptibles zones.

Keywords: *Landslide susceptibility, Frequency ratio, Bivariate statistics, Mountain, Geotechnic.*

INTRODUCTION

Mass wastiongs are geomorphic processes affecting the terrain landscape, leading to several disturbances. The caused damages are varied and may involves life injuries or economic losses (Gadri et al. 2015; Zahri et al. 2016; Mouici et al. 2017). The phenomenon results from the concomitance of a wide range of natural and anthropogenic processes involving geological, geomorphologic and environmental factors (Hadji et al. 2013). In Hanif region (surrounding Pk 235 to 245 of A1-H), many potential landslides

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are identified around roads, which some of them may causes serious disruption of traffic on the strategic A1-H (Fig. 1). The LS assessment of this terrain is very interesting for engineering geologists and civil engineers (Chingkhei et al. 2013). The most used assessment approaches are deterministic, heuristic and statistic techniques (Aleotti and Chowdhury, 1999). Based on geotechnical parameters; deterministic approaches are typically related to slope stability studies, expressed in terms of the safety factor (Achour et al. 2017). Whereas, heuristic approaches are usually made by a direct geomorphic mapping based on specialists' opinion; doubtful being subjective (Kouli et al. 2010). On the other hand, statistical approaches analyzes the relation between landslide-controlling factors and landslides distribution (Hadji et al. 2017). Analytical Hierarchy Process (AHP), Artificial Neural Network (ANN), fuzzy logic and Weight of Evidence techniques (WoE), etc. could be also employed (Pradhan and Lee 2010; Hadji et al. 2014a). The FR method is one of the most widely adopted methods for LS assessment. This bivariate method quantify LS through calculating the weight values of each class of individual landslide-related factors. This technique was chosen because it have privileged accuracies compared with other methods (Pradhan 2010). It uses FR model based on the bivariate statistics between landslide locations and each associated factors (lithology, lineaments, slope angle, slope aspect, elevation, rock strenth, drainage network and precipitations) (Sivakami and Sundaram 2014). The ratio is that of the area where the landslide occurred, to the total area. In this type of approaches remote sensing (RS) is very useful to determine landslide features. For the processing, the application of Geographic Information System (GIS) is an essential tool in the data analysis and LS assessment. The main objective of this study is to evaluate the susceptibility to landsliding of the terrains crossed by the A1-H in Hanif region, and the proposition of an alternative route. The study passes trouth four steps *i*) Landslides inventory and thematic layers are prepared from geologic map, satellite images, digital elevation model; rainfall measurements, field investigation and other related data in GIS platform; *ii*) The subcriteria of all parameter are calibrated using FR technique; *iii*) LS zonation map is prepared through the summation of the categorized layers; *iv*) The performance of the susceptibility analysis is evaluated by using a receiver operating characteristic (ROC) curve. This methodology have an effective role in the planning of roads schemes in mountainous regions.

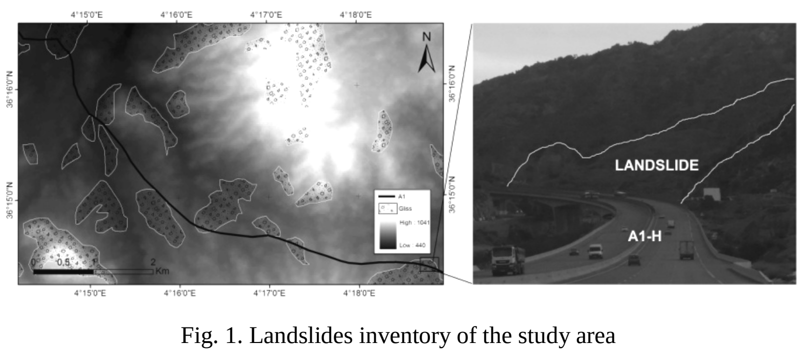

Fig. 1. Landslides inventory of the study area

2. STUDY AREA GENERAL SETTING

The study area is located in the North of Algeria, as a part of Hanif municipality, Bouira province. The region is predominantly mountainous, with an acute slopes, high precipitations and a developed hydrographic network. It shows a topography with an altitude of 1041 masl. The study site is located along the A1-H (PK 235 to 245) at some Kilometers South of RN5 national road, and covers a total area of 32.845 km^2. The extent of this study area lies between 36°14'12" to 36°16'36"N Latitude and 04°14'78" to 04°18'92"E Longitude (Fig. 2).

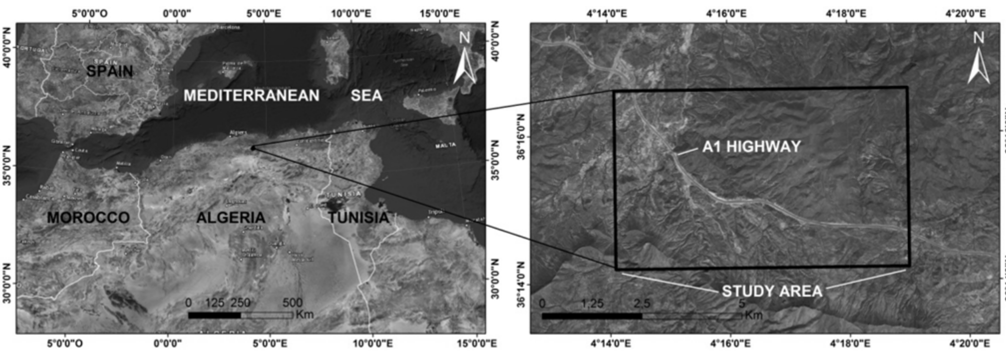

Fig. 2. Geographic location of the study area

Climatic condition of this region is semi-arid, having cold and humid season from October to March. with an average rainfall recorded around 775mm. In the study area, the surface geology consists predominantly of weathered marls, clays, limestones rock, and quaternary sedimentary including conglomerate, silt, and gravel; widely recognized to be sensitive to weathering and vulnerable to landslides (Hadji et al. 2014b; 2016). The soil deposits are mainly found in the Sahel valley and gravel terraces composes the mountain slopes.

The A1-H, (called also East-West highway) is one of the largest public works projects in the world (14 billion Dollars). The most sections of this six-lane highway road are completed. The Route (more than 1200 km) cross the North of Algeria from the Tunisian border in the east to the Moroccan border in the west. This unique highway in Algeria desserves several Algeria's coastal cities.

METHODOLOGY

During the course of this study, different thematic maps/layers corresponding to the causative factors implicated in the occurrence of landslides were prepared in GIS domain using ArcGIS 10.3 software. They were compared with the landslides inventory map realized by satellite images interpretation and and field Survey. A Digital Elevation Model (DEM) type Shuttle Radar Topography Mission (SRTM) (with 30 meter of spatial resolution) sourced from the United States Geological Survey (USGS) has been used for the preparation of various topographic and hydrographic parameters such as slope (Fig. 3a), aspect (Fig. 3b), elevation (Fig. 3c) and Streams (Fig. 3d). Using the same web portal orthorectified Landsat image, was downloaded for land survey. It was used for the delignation of landslides features (Fig. 1).

Seismic data was supplied by the Research Center in Astronomy, Astrophysics and Geophysics (CRAAG). The seismic map of the study area is not used in the moeling, because it is single area and will not change the results. And meteorological data provided by the National Meteorological Office (ONM) was used for the generation of precipitations map (Fig. 3e). Lithology (Fig. 3f) and lineaments (Fig. 2g) were digitazed from existing geologic map, whereas the rock cohesion data was obtained from laboratory tests (Fig. 3h). All these maps were rasterized in 30m resolution grid.

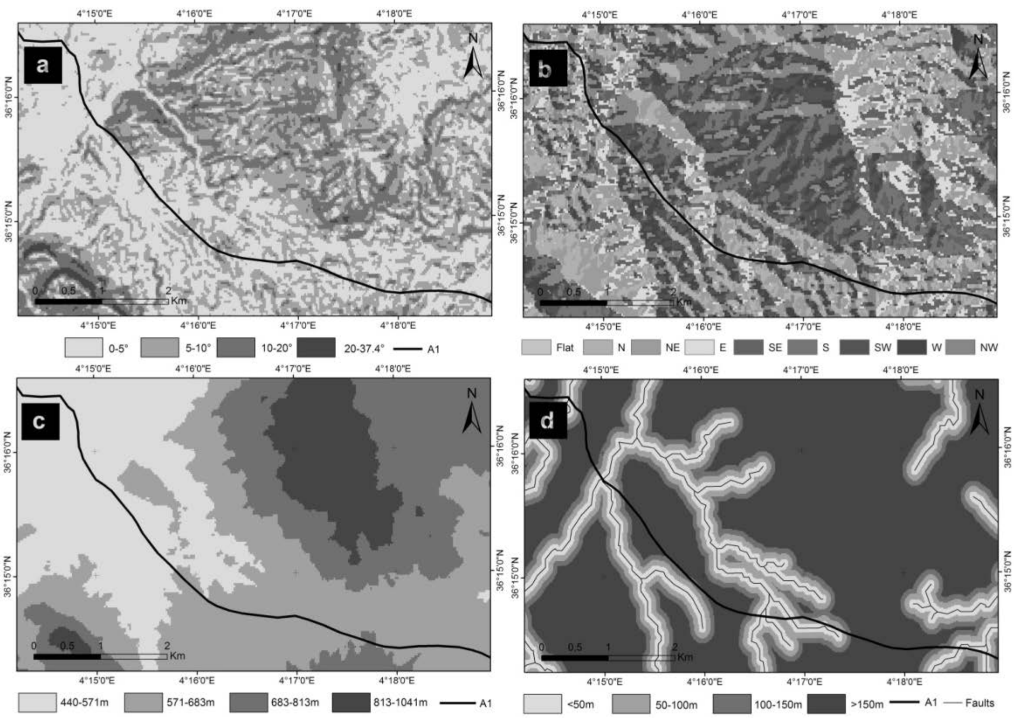

Fig. 3. a – Slope map; b – Aspect map; c – Elevation map; d – stream proximity map

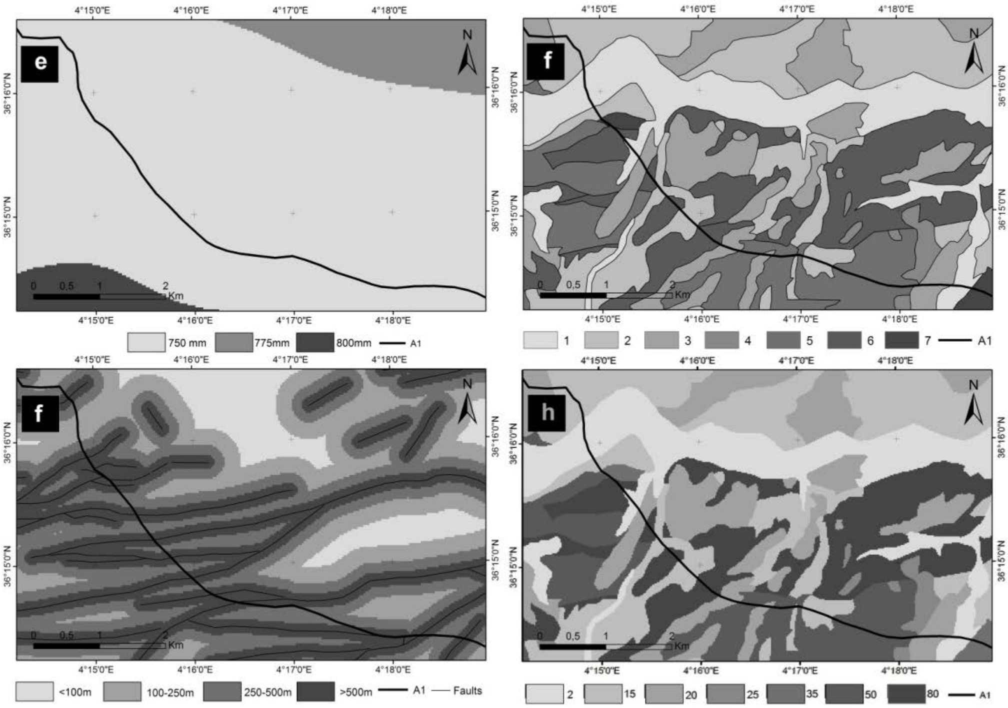

Fig. 3. e – Precipitation map; f – Lithologic map (Legend of the lithologic map: 1 – Solatanian-Rharbian (q^{5-6}): Silt, gravel and alluvial sand. 2 =Amirian-Tansiftian (q^{3-4}): Silt, gravel and torrential sands. 3 – Pliocene ($p\text{-}q^1$): Brown conglomerate with pebbles; Limestones and calcareous crusts. 4 – Saletian (q^2): Conglomerate and torrential sandstones, Calcareous crusts. 5 – Middle-Albian (n^{6b}): Alternating clays, Sandstone and marl past. 6 – Lower-Albian (n^{6a}): Alternating clays with sandstone beds with quartizoids, marl and limestone.7 =Upper Albian (n^7): Marls with aleurolites clays); f – Fault proximity map; h – Cohesion parameter map of the study area

In the study area, 26 slope failure are identified (in characteristics and boundaries) and confirmed by field investigation (Fig. 1). The dismantled landslides were identified using old dated satellite images. Among these landslides, eight are in frontal contact with the A1-H. Planar and rotational slides are the common typologies. The largest slope area is about $796000m^2$, it measured 1855m in length and 21.4^o in angle. These landslides indicates a slide of weathered rock of natural slope failure resting over the bed rock. The landslides data is randomely divided into 3/4 and 1/4 subset. The first three quarter are used to determine the LS; whereas the remaining quarter is used for the validation.

The FR model is calculated from the statistical relation between landslides and the attributed factors. The ratio calculates for subcriteria of parameter the landslides occurrence probability to the non-occurrence probability for a given attribute, (Eq. 1). And then the frequency ratios were summed to calculate LSI (Eq. 2), (Yilmaz 2010):

$$FR = (D_i/\sum^n D_i)/(A_i/\sum^n A_i) \quad (1)$$

$$LSI= \sum^n FR \quad (2)$$

(D_i – area of landslides in the i^{th} category, A_i – area of the i^{th} parameter category, n – number of the parameter). Roc curve was used for the validation. LSI has a continious interval and represents various LS levels. Natural breaks classifier was used to divide the interval into five classes. All the spatial data sourced in the study are given in the table 1, and the flow chart of the working process in figure 4.

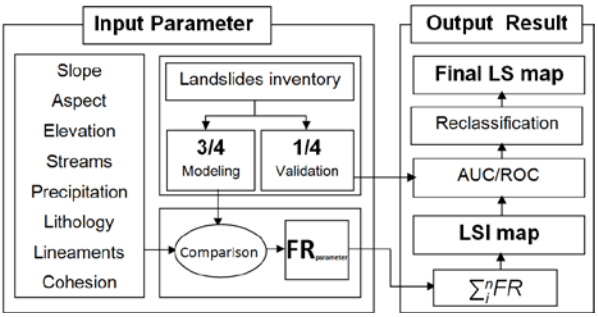

Fig. 4. Flow chart of the study methodology

Table 1. Source and spatial processing of the the study parameters

Parameters	Technique	Source	Classes
Lanslides inventory	Visual interpretation (Landsat 8) + field checking	https://earthexplorer.usgs.gov/	26
Slope	ArcGIS 10.3/ Spatial analyst tools/Surface (DEM).	(SRTM V-2) (DEM) 30m resolution https://earthexplorer.usgs.gov/	4
Aspect			9
Elevation	ArcGIS 10.3/ Spatial analyst tools/Reclass (DEM).		4
Drainage	ArcGIS 10.3/Spatial analyst tools/Hydrology (DEM).		4
Geology	ArcGIS 10.3/Editor	Geologic map of Beni Mansour (N°90)	7
Lineaments			4
Rock Cohesion	Laboratory tests	Laboratory of public works	7
Precipitation	ArcGIS 10.3/Spatial analyst tools/Interpolation (IDW)	rain measurment (ONM)	3
Seismic data	ArcGIS 10.3/ Analysistools/Clip	Seismic map CRAAG	1

RESULTS AND DISCUSSIONS

The modeling of the retained thematic maps/layers in a GIS environment leads to the generation of a global susceptibility index map (Fig. 5a, b). The model was validated by its comparing with 1/4 of the identified landslides. The Area Under the Curve (AUC) shows a good correlation (AUC=0.82), (Fig. 5c).

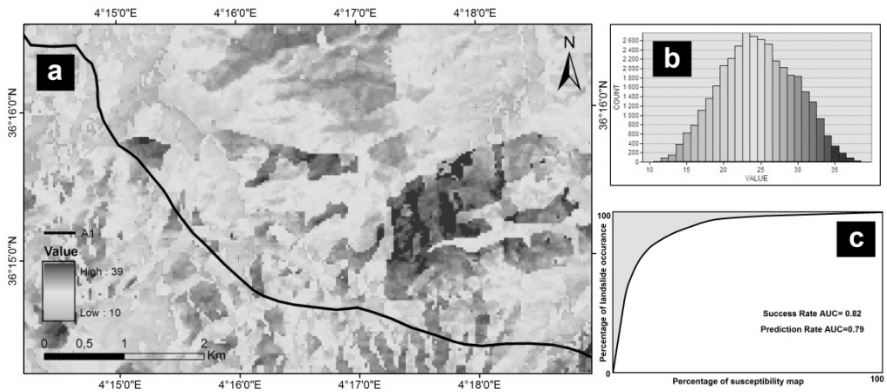

Fig. 5. a – Landslides susceptibility index map of the study area; b – histograme of the index distribution; c – AUC of Roc curve for the model validation

The catalog of the retained model for individual parameters and their subclasses is given in table 2. It shows the degree of correlation between landslides and conditioning factor classes. The greater ratio value (FR > 1) indicates a higher relationship between landslides occurrence and the given factor's classes, while a lower ratio value (FR < 1) indicates a less probability of landslides occurrence, (Ozdemir and Altural, 2013).

The results demonstrates that areas with slope gradien >20° have a very high probability to landslides occurrence with (FR_{20}=4.876). This is explained by that accute slopes have a high frequency of landslide than gentle ones, because of higher shear stress associated with high gradient. Slope aspect bounded for (N, NE, E and NW) have rational connection with landslides occurrence (FR_{NE} = 1.321), these sides are more watered by rain. FR is high in area where elevation exceeds 800m (FR = $1.791_{>813}$). FR shows its maximum value in marls with aleurolites clays formations; their unstable character makes them very favorable to landsliding (FR = 3.059_{n7}). Soil that has already been weekend by moisture losses its retainability under the influence of rainstorms. The ratio between landslides and fault proximity is high for distances values < 100 m ($FR_{<100}$ = 1.275). This indicates that faults has a seismic character or drains water. The distance from rivers less than 50 m has a stronger relationship with landslides ($FR_{<50}$ = 1.492). This is due to the torrential nature of streams and high velocity of runoff. The relationship between precipitations and landslides occurrence indicate that they correlates with high values of rain (FR_{750} = 1.944). This confirm that precipitation is the principal trigger factor of landslides in the study area. Finaly, FR increases in area with mediocre geotechnical characteristics (cohesion) (FR_{35} = 6.485). This mechanical parameter is a contributing factor to the landslides occurrence.

Table 2. Frequency ratio of terrain arameters

Parameter	N°	Class	Conditioning Factor Pixels Nber	Conditioning Factor Surface Km²	Conditioning Factor Surface %	Landslides Pixels Nber	Landslides Surface Km²	Landslides Surface %	FR	Density
Slope angle (°)	1	<5°	18445	14.163	43.12	1249	0.958	16.02	0.371	0.068
	2	5-10°	16286	12.491	38.03	3405	2.611	43.67	1.148	0.209
	3	10-20°	7666	5.886	17.92	2791	2.140	35.80	2.00	0.364
	4	>20°	396	0.304	0.92	352	0.270	4.51	4.876	0.888
Aspect	5	Flat	497	0.382	1.16	0	0	0	0	0
	6	N	6122	4.701	14.31	1353	1.037	17.35	1.212	0.412
	7	NE	6453	4.955	15.08	1554	1.192	19.93	1.321	0.241
	8	E	4343	3.334	10.15	843	0.646	10.81	1.065	0.194
	9	SE	3829	2.940	8.95	515	0.395	6.60	0.738	0.134
	10	S	5142	3.948	12.02	595	0.456	7.63	0.635	0.116
	11	SW	5635	4.327	13.17	812	0.623	10.41	0.790	0.144
	12	W	4836	3.713	11.30	707	0.542	9.07	0.802	0.146
	13	NW	5918	4.544	13.83	1418	1.087	18.19	1.314	0.240
Elevation (m)	14	440-571	12573	9.654	29.39	2392	1.834	30.68	1.044	0.190
	15	571-683	14973	11.497	35.01	2589	1.985	33.20	0.949	0.173
	16	683-813	10679	8.200	24.96	1331	1.021	17.07	0.684	0.125
	17	813-1041	4550	3.494	10.64	1485	1.139	19.05	1.791	0.326
Lithology	18	q^{5-6}	7794	5.984	18.22	910	0.698	11.67	0.640	0.117
	19	q^{3-4}	11069	8.499	25.88	2039	1.564	26.15	1.011	0.184
	20	Pq^{1}	8741	6.712	20.43	2525	1.396	32.38	1.585	0.288
	21	q^{2}	678	0.520	1.58	49	0.038	0.628	0.396	0.072
	22	n^{6b}	5817	4.466	13.60	531	0.407	6.810	0.501	0.091
	23	n^{6a}	8182	6.282	19.13	1467	1.125	18.81	0.984	0.179
	24	n^{7}	495	0.380	1.16	276	0.212	3.54	3.059	0.556
Distance faults (m)	25	<100	14939	11.471	34.92	3471	2.662	44.52	1.275	0.219
	26	100-250	13736	10.547	32.11	2585	1.982	33.15	1.032	0.188
	27	250-500	9539	7.324	22.31	1414	1.084	18.13	0.813	0.148
	28	>500	4561	3.502	10.66	327	0.251	4.20	0.393	0.072
Distance rivers (m)	29	<50	5525	4.242	12.92	1503	1.152	19.28	1.492	0.270
	30	50-100	5946	4.565	13.90	1197	0.918	15.35	1.104	0.200
	31	100-150	4958	3.807	11.59	882	0.676	11.31	0.976	0.177
	32	>150	26346	20.230	61.59	4215	3.232	54.06	0.878	0.159
pita-tion	33	750	2243	1.722	5.24	795	0.610	10.20	1.944	0.354
	34	775	36314	27.883	84.89	6078	4.661	77.95	0.918	0.167
	35	800	4218	3.239	9.87	924	0.708	11.85	1.202	0.219
Cohesion	36	2	7794	5.984	18.22	1224	1.475	24.68	1.354	0.117
	37	15	11069	8.499	25.88	430	0.330	5.51	0.213	0.184
	38	20	8741	6.712	20.43	533	0.409	6.84	0.334	0.288
	39	25	678	0.520	1.58	104	0.080	1.33	0.841	0.072
	40	35	494	0.380	1.16	584	0.448	7.49	6.485	0.557
	41	50	5817	4.466	13.60	1122	0.860	14.39	1.058	0.091
	42	80	8182	6.282	19.13	3100	2.377	39.76	2.078	0.179

LS map divides the study area to five hierarchic susceptibility classes (Fig. 6). It shows that the high susceptible zones are the most prone to landslides activity which demonstrates weathered steep slopes, denudation processes and destabilizing road earthworks, etc. The majority of landslides have occurred close to streams and hence, the incipient erosion taking place in the hills is one of the reasons for slope failure. The fractured substratum with marl affinities promotes the instability. As the landslides affecting the roadside slopes of A1-H making a severe traffic disruption to the East of Algeria; it is paramount to promulgating a management rules taking into consideration the specificities of the terrains represented in the susceptibility map.

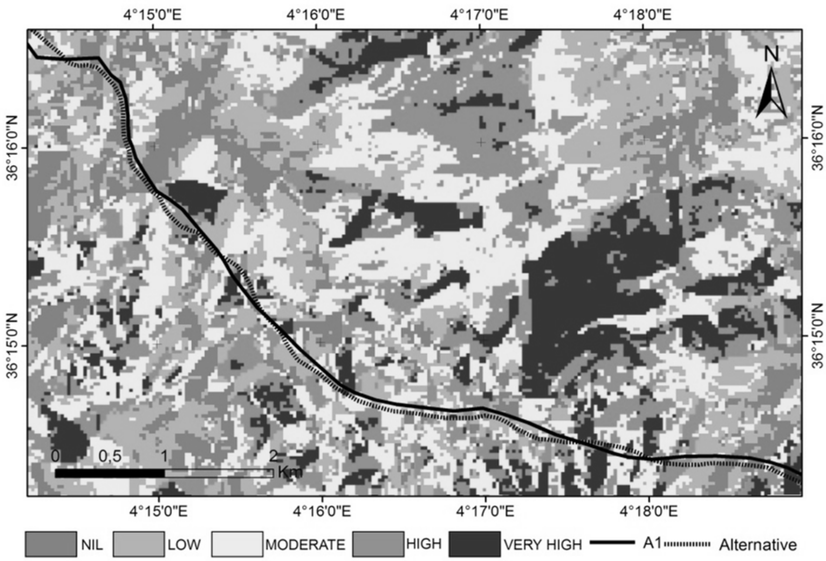

Fig. 6. Landslides susceptibility (LS) map of the study area

The table 3 shows the percentage of different classes for the LS map. The extraction by using the mask of the road confirms that the route is very exposed to sliding. A possible change of course may reduce the exposure of this section of A1-H.

Table 3. Count, area and percentage of the class of LSmap , A1 and Alternative route

	Nil			Low			Moderate			High			Very High		
	Pixels	area	%	Pixel	area	%	Pixel	area	%	Pixel	area	%	Pixel	area	%
LS map	4525	4.09	12.45	9885	7.59	23.11	12483	9.58	29.18	9285	7.13	21.71	5795	4.45	13.55
A1	76	/	19.69	99	/	25.65	94	/	24.35	83	/	21.50	34	/	08.81
Altern.	115	/	30.03	113	/	29.50	71	/	18.54	65	/	16.97	19	/	04.96

CONCLUSIONS AND RECOMMENDATIONS

In this paper, a GIS-based FR model for LS assessment has been developed for estimating the potential slope instability along A1-H.

Slope, lithology and geotechnical properties are the main landslides causing factors. The field analysis reveals that steep slopes have contributed more landslides than gentle ones. During the construction of A1-H the slope declivity accentuation has increased the gravitation intensity induced shear stress in soils. The stability of the terrain close to A1-H was disrupted specially where it is affected by the erosion of the bank of the road support.

This methodology provides an comprehensive approach for the practical assessment of LS in a wide area even in road neighboring. Unstable areas could be quantified more accurately by making an overall assessment taking into account all concerned parameters. The result of the analysis was found that 30.16% of the A1-H pavement is distributed in high and very high susceptibility zone. A new route trace based on the LS map reduces rigorously the road exposure by 30% to only 21% and avoiding the very high prone area.

as recommendations; areas in which landsliding activity is known, are to be planned so as to not worsen their actual status. If the natural drainage is disrupted and slope modified, landslide could be immediately triggered.

The A1H pavement needs urgent mitigation measures as slope stabilization, stream structures correction, surface and subsurface drainage control works, etc. unless urgent action plans are implemented; the roadside slopes will deteriorate further to a disturbing situation. The study shows that GIS, which can manage and visualize several types of data, can help the decision making process for road planning in mountanious regions. As prospect of this research some issues could be remarked. the number of input data can be varied for LS assessment and the integration of surficial formation data involved in the landslide genesis can improve the quality of results.

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