Impact of climate change on landslide in the High Central Atlas of Morocco - Confirmation of the results of soil mechanics by X-ray diffraction: Case of Tabaroucht-Ouaouizerht. Azilal

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ABSTRACT

This research work is focused on the study of the gravitational instabilities of the Tabaroucht slide, in the Ouaouizerht-Tagleft basin of the Central High Atlas of Morocco and on the role of geological, hydrogeological and mechanical factors in triggering landslides. The purpose of this scientific approach is to identify the direct and indirect causes of this risk in a context of climate change. The approach of the study is both quantitative (calculations) and of course qualitative by field verification and validation from historical data. At the end of this work, the various geological, hydrogeological and mechanical factors were defined in the landslide to determine the triggering factors. The results show that the geological nature, the slope, the vegetation cover are the indirect factors of the landslide, and that the impact of climate change on hydrogeology and local hydrology are the main natural direct factors of such landslides. we can also include the anthropic action that affect the stability of slopes in the phase of equipment works or mining and quarrying materials. This study improved the understanding of gravity instability for possible solutions to the problem. The geochemical and mineralogical

analyzes focus on the 5 samples from the parts forming the two slopes in order to detect the nature and the crystallography of the sediments favoring the risk of sliding of the masses. The objective of this mineralogy is to confirm the elements forming the main clay that has been detected by the geotechnical tests including Methylene blue.

Keywords: Landslide, Climate change, Geochemical, Central High Atlas, Morocco

1. INTRODUCTION

Rainfall-induced shallow landslides are one of the most common and dangerous natural hazards, mainly because of their high temporal frequency, resulting in significant economic deaths and damage each year [1]. In recent years, the concern has grown because the effects of climate change could exacerbate the impact of landslides. Due to the thermodynamic effect, a warming atmosphere results in higher moisture content in the air, which can in turn increase the frequency and intensity of heavy rainfall [2]. A landslide is a type of mass waste process that acts on natural and man-made slopes. It is the movement of a mass of rock, debris, or earth falling down under the influence of gravity [3-4]. Landslides involve flowing, sliding, falling or spreading, and many landslides present a combination of different types of motion, at the same time or during the life of the landslide. Landslides are present on all continents and play an important role in the evolution of landscapes. In many regions, they also pose a serious threat to the population [5]. The synthesis report of the Intergovernmental Panel on Climate Change (2014) provided assessments of the risks of flooding, and concluded that the number of people exposed to floods is expected to increase worldwide [6]. In Morocco, the reduction of fluvial inputs downstream of dams resulting in insufficient recharge of groundwater, freshwater circulation and sediments, dilution of pollution and affecting the hydrodynamic equilibrium of ecosystems [7] . Rainfall regimes vary from region to region while remaining dominated by a large irregularity in space and time, seasonally and interannual. The alternation of sequences of years of strong hydraulicity and severe drought sequences, which may last for several years, is a hallmark of climatic and hydrological regimes [8]. Climate change induces a modification of the hydrological cycles having a direct impact on the piezometric regime of the natural slopes and thus on their stability conditions. In particular with regard to active landslides in fine-grained soils [9]. And this is the case of landslides in the Central High Atlas of Morocco that affect most of the geologically unstable slopes and especially the paved track between

Ouaouizerht and Tabarroucht taking the regional road RR302. Point geochemistry and mineralogy is the study of the distribution of chemical elements, their distribution in rocks, minerals, water and land gases, their origin, their nature and their behavior during geological processes [10-11].

2. MATERIALS AND METHODS

The landslide is located about 12 km south-east of Ouaouizerht, is at an altitude between 1200 1400 m, its latitude is [32,11835N] and its longitude is [-6,25350E]. It is a slope with a possible landslide, the overall slope varies between 55% and 60%, by the contours and the scale, and verified by the compass. From a geological point of view, the area is formed by calcareous deposits, marls, clay-silts, and reddish breccias and also Jurassic basaltic flows in places. The age of the formations dates from Jurassic (Bathonien). The Cretaceous formations outcrop, in particular, in the plateaus and basins in the northwest in the Ouaouizerht basin. In this study, he has mapped, at different scales, to deduce the value of the slope conditioning the problematic by a topographical bottom (mathematical demonstration by the tangent arc) and confirmation by the compass by the measurement of the dip of the great slope. Fig.6.

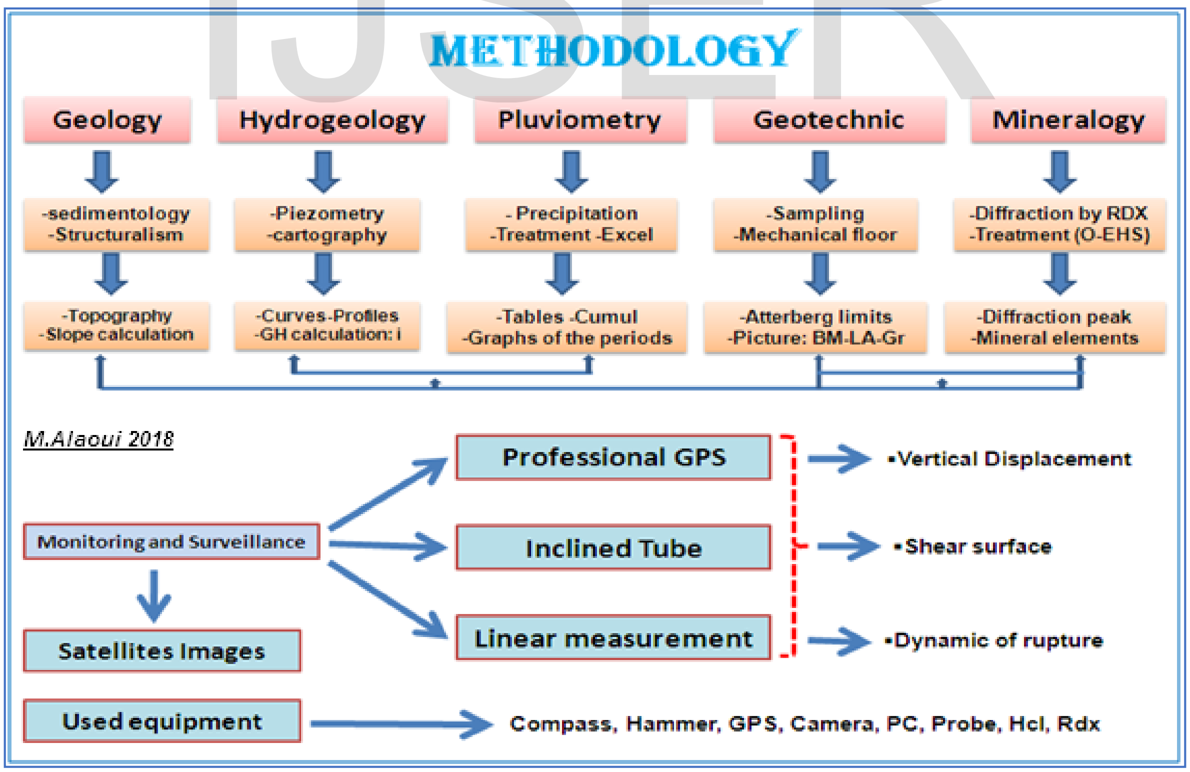

Figure 1: Organization chart of the used methodology

Of the slipped part. An analysis of the geological maps and the field research were carried out to give a precise idea of the hydrographic network which can intervene in a direct or indirect way on the evolution of the hazard in the time and the space. The directions of the faults and breaks with slight folds in the limestones and the marl, by the projection of the orientations in a framework of Schmidt, one can little deduce the constraint of the tectonic deformation to confirm the major accidents of the atlasic orogenesis which gave place to this mountain range. (Laville Model.1985).

Regarding rainfall, the closest data station to Landslide G2 is at an altitude of 800m, so the meteorological approach is useless for our site at 1300m. To analyze and interpret the direct effect of the rains on this landslide, we used cumulative precipitation between 2003 and 2018 from a landslide site [G1] in the same region 55 km to the southwest de Tabarroucht [G2], we also have the same plant cover. Therefore, we could consider these data as local rainfall at 90% certainty at 1300m altitude.Fig.3

The mineralogical method consists in bombarding the sample with X-rays, and in looking at the intensity of the X-rays which is diffused according to the orientation in space. Fig. 12. [Bragg-Brentano Diffractometer or Device]

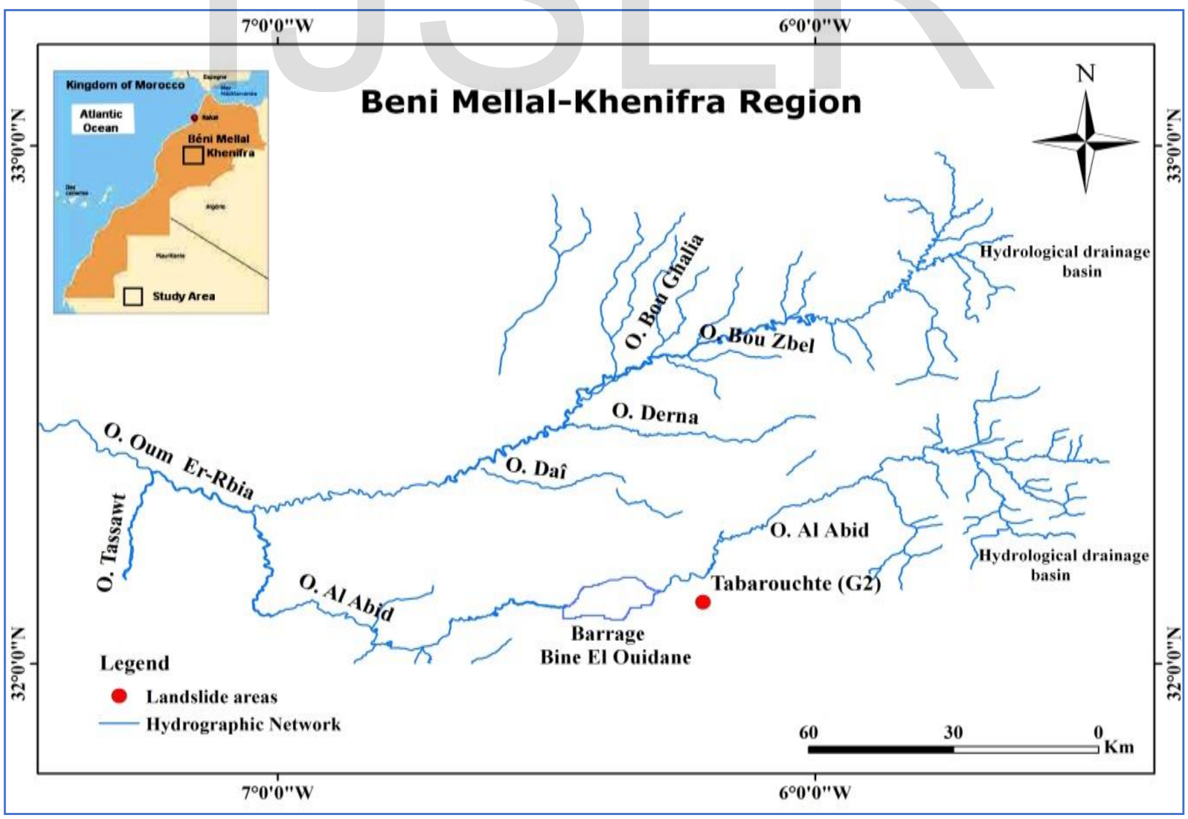

Figure 2: Geographical location of the site and location of hydraulic structures upstream

Anybody, including wood, is subject to the action of different external forces, including those of compression, traction and shear (Panshin and Zeeuw 1980). From the combination of these three forces originates the bending force. In geotechnical study, the resistance of a body to different external forces determines its mechanical strength (De la Cruz, 2006).

3. RESULTS

1.3. HYDROGEOLOGICAL AND RAINFALL STUDY OF SLIDING FIELD

From a hydrogeological point of view, a series of flow measurements were carried out to find out about the arrival of water from above, especially the origin of the water at the foot of the slopes in dry periods, between 2014 and 2018, at the level of the source that outcrops in the marl. The underground flow is controlled by a hydraulic gradient "i" between the bowl and the slip zone. In this respect, the arrival of water at the slope is one of the issues that impede the stability of the land and pushes the geotechnician to think of adequate solutions for a good comfort of the hazard. Fig.3 and Fig.4.

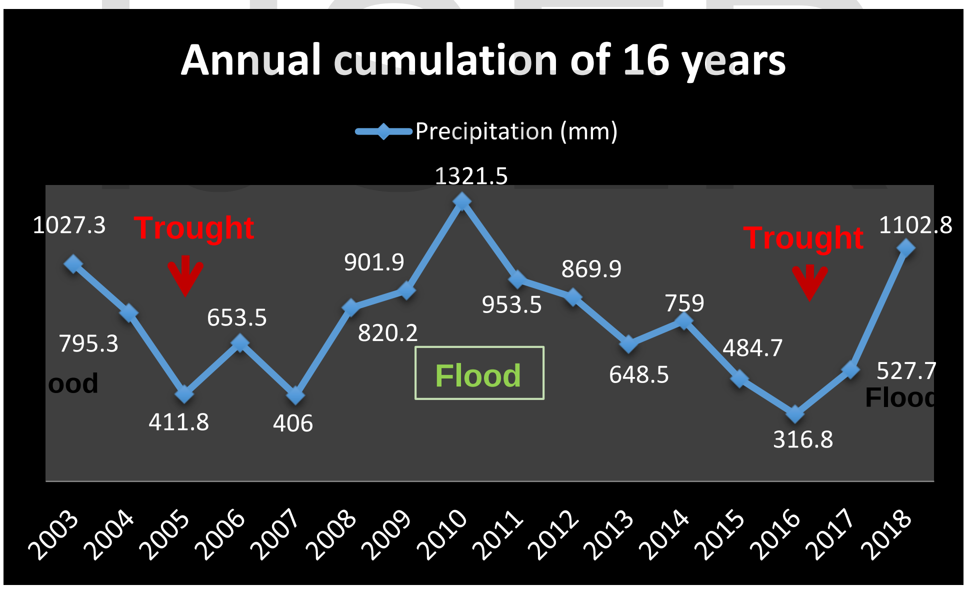

Figure3: Rainfall data from a second landslide site (G1) (1250m above sea level) located 55 km as the crow flies southwest of Tabaroucht (G2)

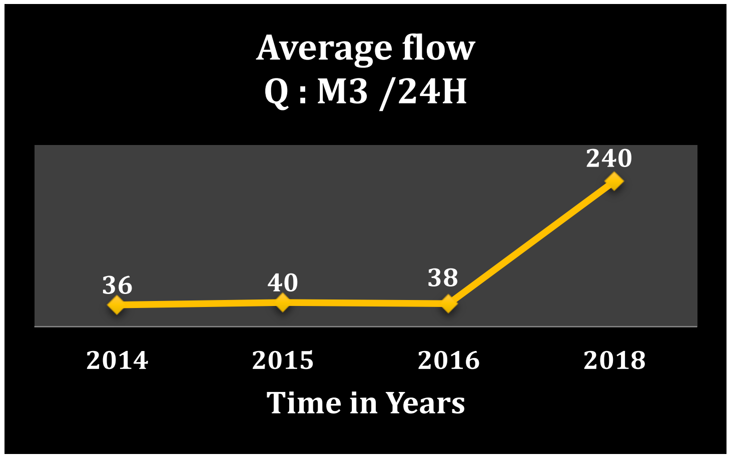

Figure 4: Groundwater flows at the source level between 2014 and 2018

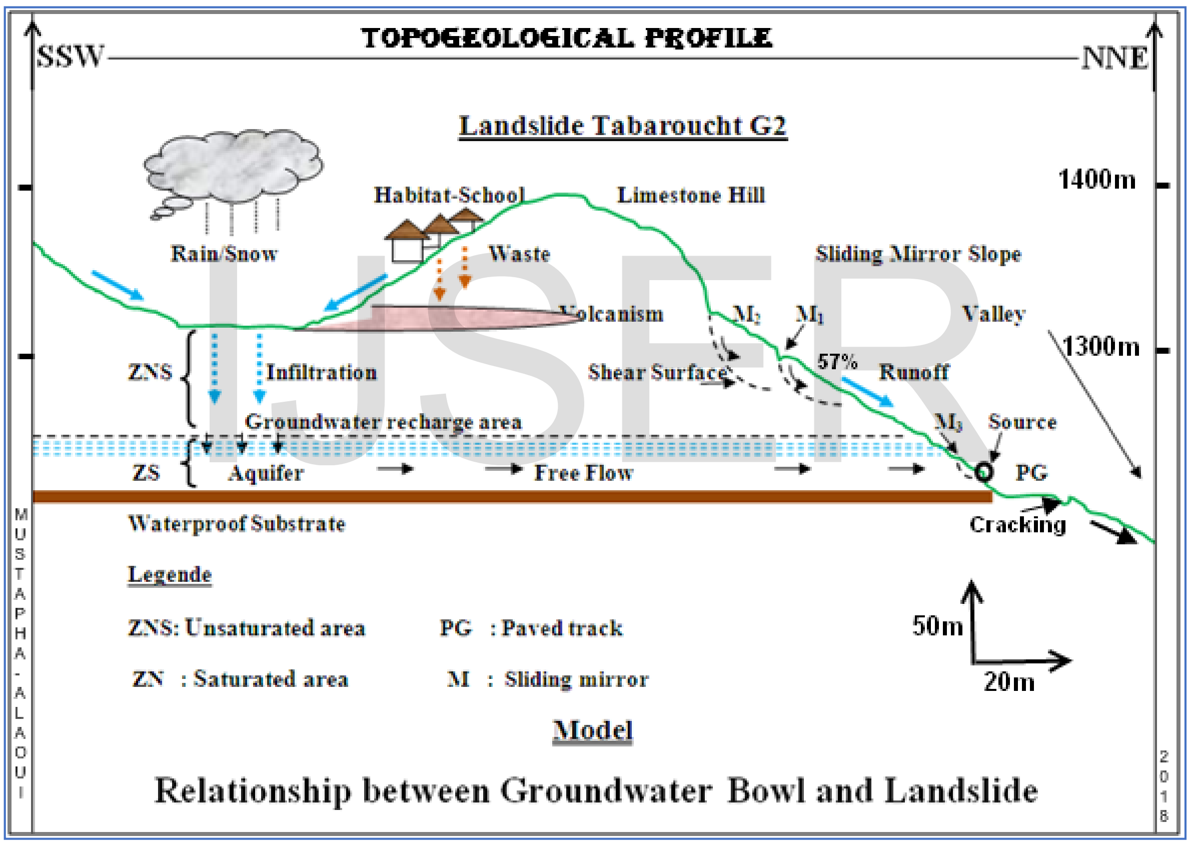

Figure 5: Topogeology of the sliding valley with types of soils and sediments characterizing the valley and location of the slopes at risk

According to Darcy's law, underground flows are controlled by a hydraulic gradient "i" of each porous medium. While 2018 was the rainiest year in the past 10 years, the average flow was increased Fig.5. Knowledge of groundwater inflow is one of the most effective actions to prevent, stabilize or slow down a landslide. The study of the feeding mode of the water table is essential to intervene in an adequate way.

This demonstrates the importance of the hydrogeological study for understanding the evolution of landslides, but also for controlling the corresponding risk. Most of the aquifers in this area are fed by rain and snow slit precipitated on the ridges between 1300m and 1800m, and fine rains in the presence of a porous limestone-dolostone substratum with impervious volcanism at the base. The monitoring of the aquifer measurements showed that the arrival of water at the foot of the slope during the dry period has a direct impact on the instability of the slide. The region consists of two different aquifers at varying altitudes, the collection of local rainfall data is essential to know the hydrodynamic regime.

2.3. GEOLOGICAL AND GEOTECHNICAL STUDY OF SLIDING

2.3.1. SLOPE CALCULATION AND CORRESPONDING ANGLE

According to the classic formula for calculating the slope:

$$\mathbf{Tan}\,\boldsymbol{\alpha} = \boldsymbol{h/d}\ \boldsymbol{TA/OA}$$

(h): difference in altitude (TA)

(d): distance between Talwegs and the crest of the embankment (OA)

The value of h = 1400-1280 = 120 m and the value of d = 210 m, so the slope calculated from the topographic Map is Tan = 120/210 = 57%. While the Average dip of the line of great slope measured by a compass on ground varies between 45° and 55°. Fig.6

In mathematics, the tangent arc of a real number is the value of an oriented angle whose tangent is worth that number. The tangent arc of a number x is the angle y (expressed in radians or degrees) of the following interval] -π / 2, + π / 2 [whose tangent is x. Where slopes are concerned, we have the following mathematical equation:

$$\forall x \in R \quad y = \text{Arctan}\,(x) \iff x = \tan y \text{ avec } y \in]-\pi/2, +\pi/2[$$

In our case of computation, the angle [y] or [α] must belong to the following interval] 0, + π /2[, because one always works in natural slopes with natural slopes and positive values. From where Arctan [0.57] = 31° it means that Tan 31° = 0.57 or Tan 31° = 57%.

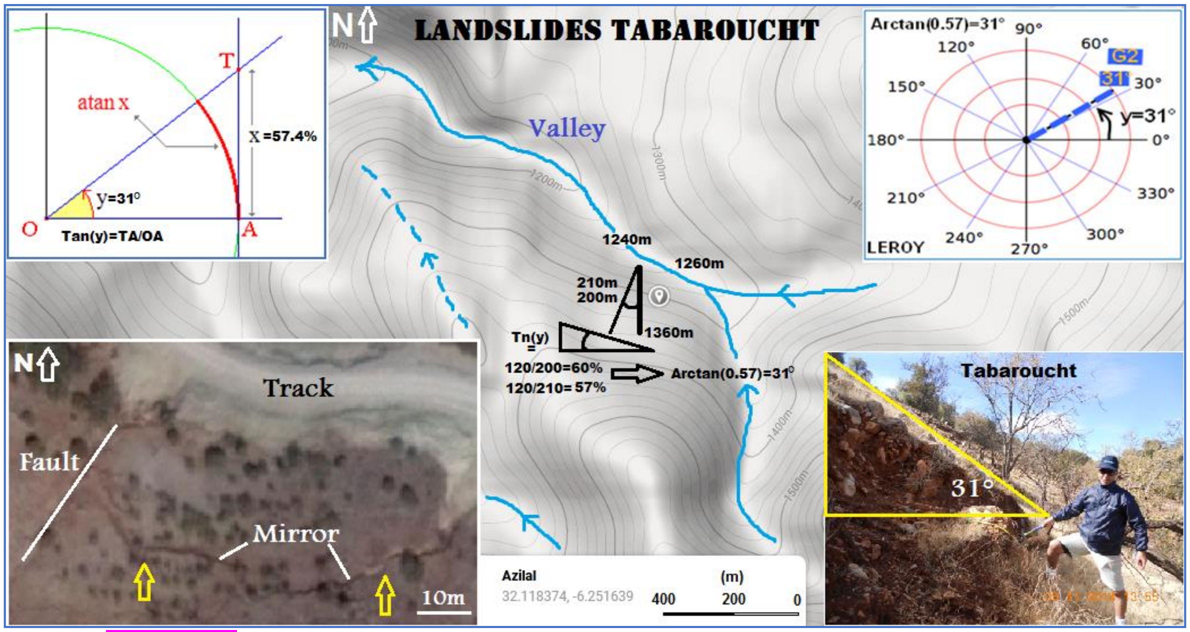

Figure 6: Geometric model for calculating the slope and corresponding angle

2.3.2. EVOLUTION OF MIRRORS FOLLOWING THE DEGRADATION OF THE FLORA

Unstable soil has different consequences on the forest: it can lead to partially buried trunks, uprooting of trees, and most often "curved" trees; on a moving ground, the tree tends to bow in the direction of movement. A curved tree thus makes it possible to estimate the direction or directions of a landslide, as well as the amplitude of the movement (angle of inclination α), (Braam et al., 1987b).

Intervals (m)	[0-20]	[20-40]	[40-60]	[60-80]	[80-100]
Mirror 1(cm)	250	230	190	150	85
Mirror 2(cm)	190	145	80	60	45

Tableau 1: Measuring variations of mirror planes in space

The giant holm oak maintains the land in permanent stability by is highly developed root system, it is called the cement of the Atlas. Measurements of the nests that have been made from East to West have shown that the persistence of these green oak specimens has been able to maintain the slide in permanent stability. Fig.7.

The mirror M2 has a significant value between [00m and 60m], it has passed from 190cm to 80 cm, and between [80m and 100m] its evolution is almost calm. As for the mirror M1 its evolution in space is almost normal, because the values are close and not spared.Fig.8

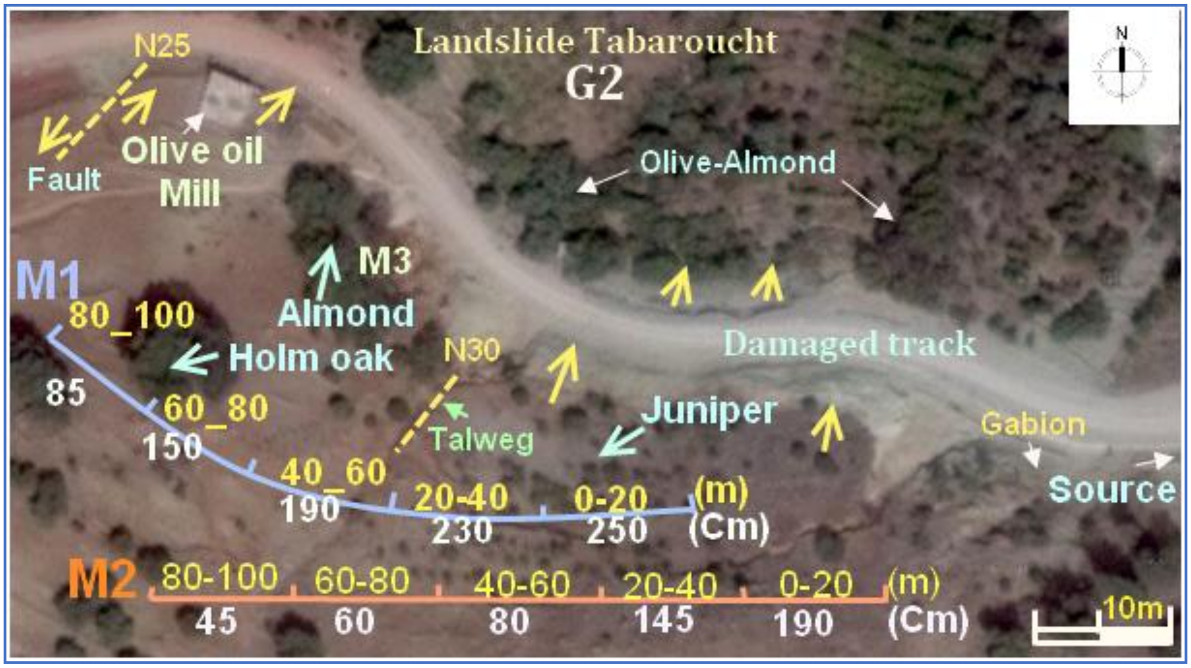

Figure7: Aerial view of mirrors in linear displacement.

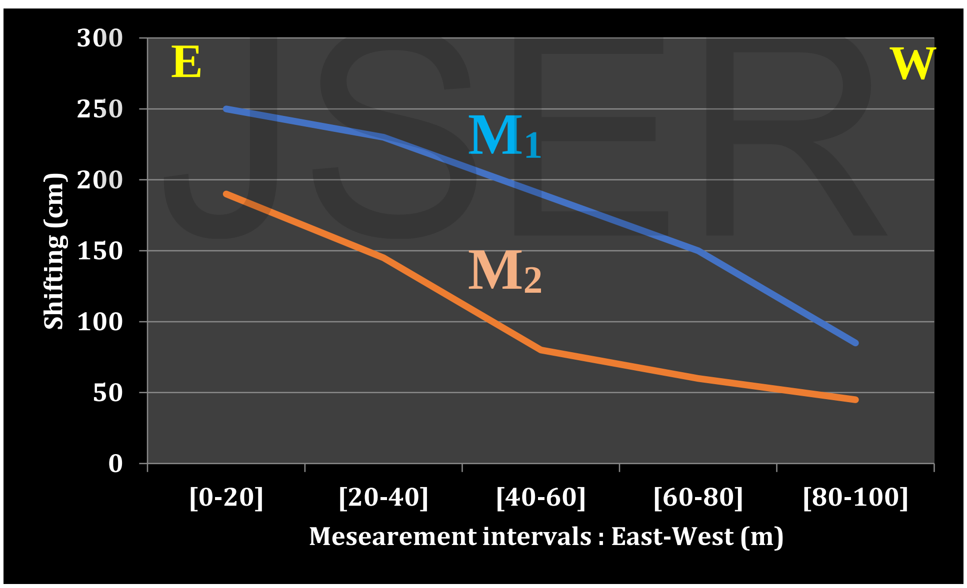

Figure 8: Cinetic of mirrors planes in space

2.3.3. SEDIMENTOLOGY AND LITHOLOGY OF THE RISK AREA

The geological formations of this region are purely Jurassic spreading from the Lias to the Dogger with sandstone plateaus and clay from the continental Jurassic in North. More towards the west, the fracture mirror decreases in value, due to the presence of a giant Holm Oak forest, which grounds the soils in geomorphological instability. Fig.9-Fig.10.

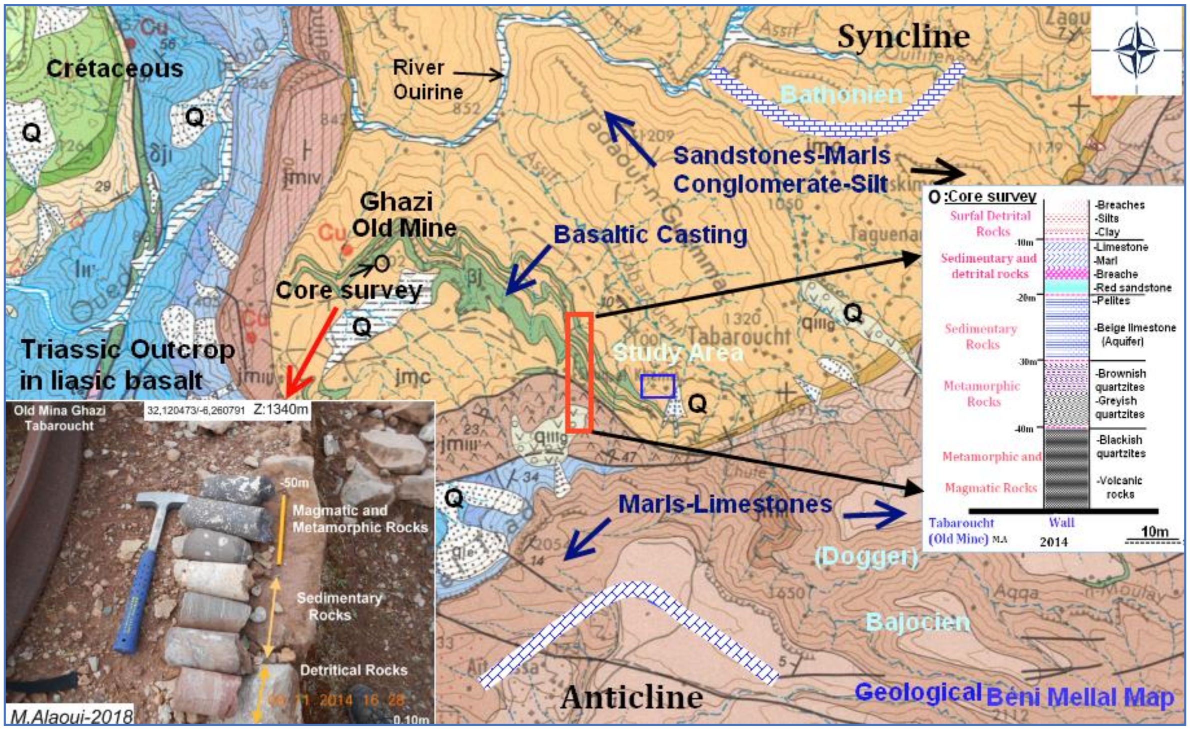

Figure 9: Map and geological context of the studied area

It is a slope oriented [NNE-SSW] to [North-South], with slopes varying from 55% to 65%, with a less dense vegetation and very limited root system, especially, almond, juniper and some shrubs. The Talus is crossed by a torrent, from an N30 fault, which drains the waters upstream. This type of soil has a bad behavior, especially in the presence of water. [Béni Mellal geological map] (Edition1982).

A geological and geotechnical exploration of the substratum's forming the sedimentary series of this part will be very effective to know the origin of the direct factors of such a movement of ground. The geomorphological and structural data will allow us to qualify the intensity of the hazard and its impact on the natural and human environment with significant material damage. Between 2014 and 2018 the magnitud of the slide increased which led to the total destruction of the building. The aquifer of the aquifer at the base of the slope is almost multiplied by 6, giving a large flow (from 38 m^3 / d to about 240 m^3 / d).

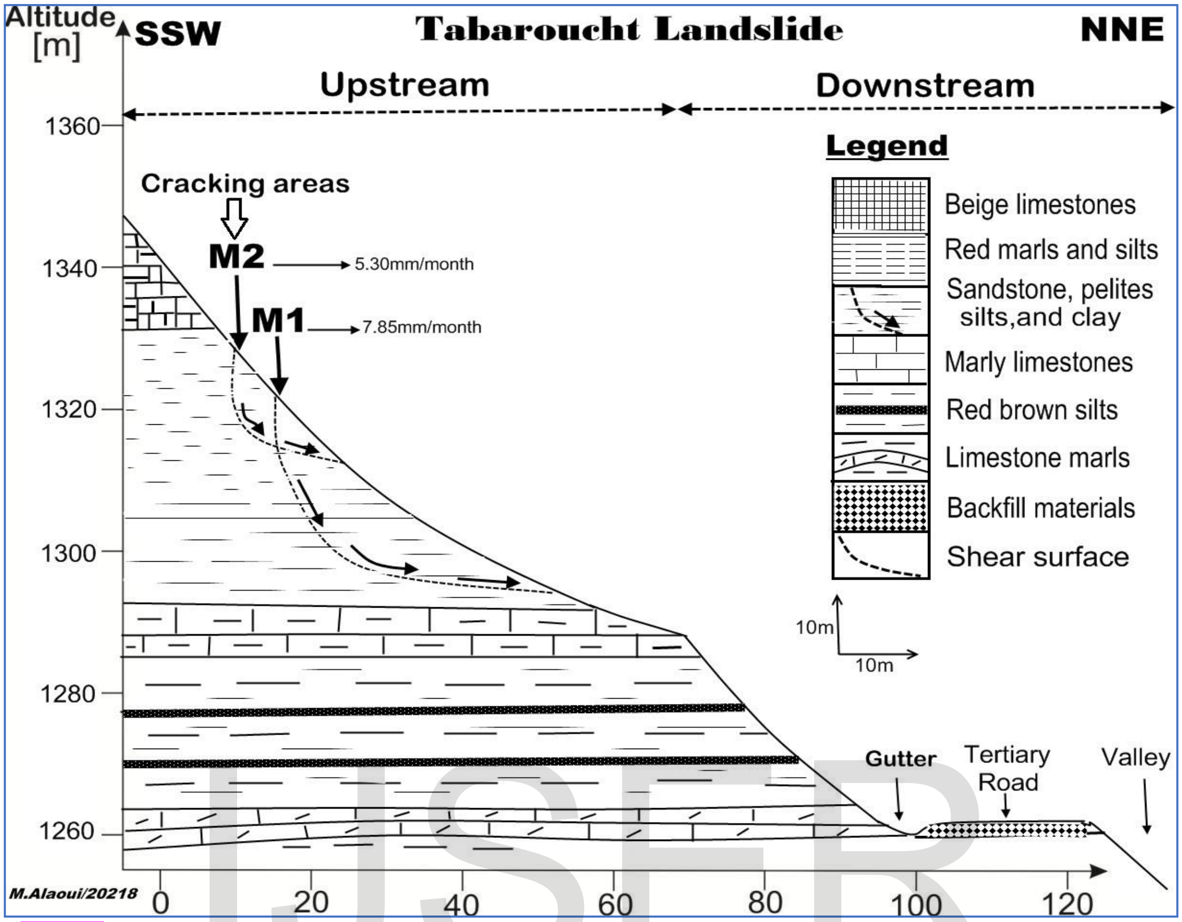

Figure10: Geological section with Kinetics of the movement of M1 and M2 of the landslide area between [2014-2018]

A follow-up of the measurements of the mirrors during the study period showed us that after the heavy precipitation experienced in the region in 2010, the displacement was remarkable and brutal, particularly at the level of the bead of feet on the slope. The M1 and M2 mirrors were triggered and aggravated after the November 2014 floods in Morocco. The relative speed of movement of the two mirrors is between 5.30mm / month and 7.85mm / month, so our sliding is called slow. (LCPC- Guide). Fig.10.

The mission of November 2014 and that of April 2018 is a geomorphological follow - up in time and space.A follow-up of the measurements of the rupture plans during the period [2014-2018], and by Google Map showed us that after the floods of November-December 2014 and 2018, the displacement was remarkable and brutal notably on the level of the slope to upstream (The main index of this shift is the downstream movement of the mill, but the rains of 2018 were very intense which completely destroyed the building. Fig.11.

Figure 11: **Evolution of the mirror following the various factors of instability G2**

3.3. GEOTECHNICAL AND SOIL MECHANICS

Fourteen samples were taken from both banks to determine the geotechnical characteristics of the soil in question. Manual surveys were carried out along the road (20Km) from which soil samples were taken. The latter were subjected to identification tests.Soil mechanics is essential to know the type of soil that reacts with these local climatic conditions. Based on the Atterberg limits, especially the "IP" Plasticity Index and the % of fine clay/silts to determine the essential factor for the poor behavior of these soils (Table 2).

Survey	Plasticity Índex	% of fine clay-silt
PK1	14	56
PK2	16	58
PK4	18	61
PK6	18	64
PK7	15	56
PK9	14	65

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PK11	**17**	**51**
PK13	**16**	**35**
PK14	**17**	**41**
PK15	**14**	**44**
PK16	**15**	**45**
PK17	**16**	**54**
PK18	**13**	**27**
PK20	**14**	**36**
Average	**14,30**	**49,50**

Table 2: Analysis and results of soil mechanics (IS/R.D.E)*

3.4. GEOCHIMIC AND MINERALOGICAL STUDY

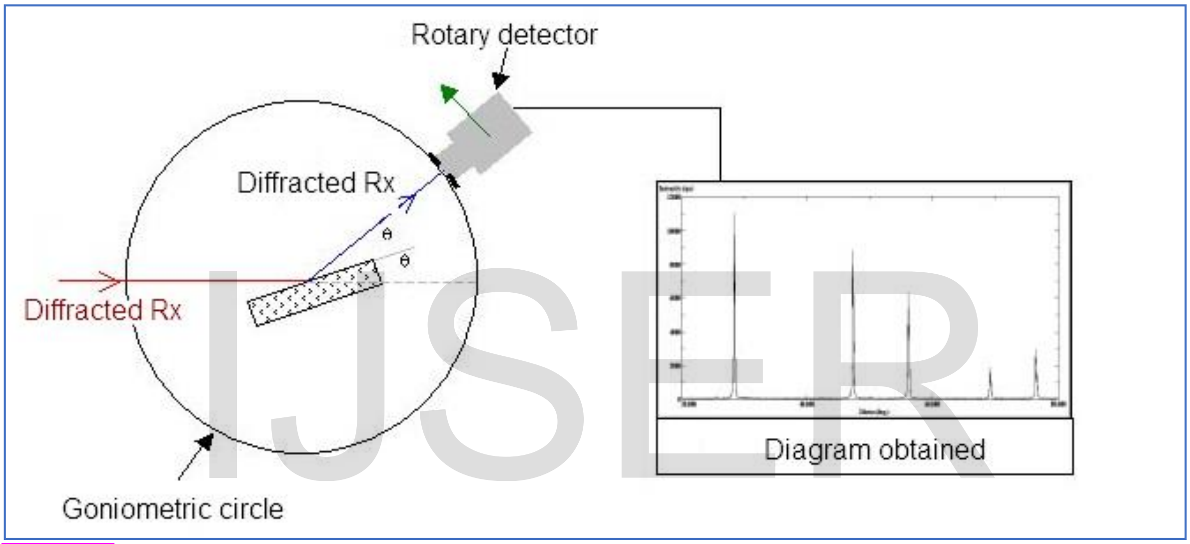

Figure 12: Simplified diagram of the principle of X-ray diffraction. (Eric Boucher)

Several previous studies around the world have shown that clay minerals of smectite, montmorillonite, bentonite, illite, vermiculite, kaolinite, or sepiolite have adsorption capacities of heavy metals in effluents and contaminated waters.

A. Qlihaa et al, March 2016. X-ray diffraction (XRD) provides a diffractogram which is a set of lines that manifest the X-ray reflections on the plane of organization of elements (Al, Si, O, OH) in the crystal lattice. Some lines mark X-ray reflection on the surface of each leaflet; they measure the reticular distance "d" between two surfaces. P.Quantin. J. Bertaux-Alian Wang & Brad Jolliff: Washington University in St. Louis ***"Journal of Raman Spectroscopy"***.

After XRD analysis and Expert High Score treatment, the talus1 samples showed an identical peak with the diffraction angle 2 (θ) = 30 ° of the crystals of the X-ray bombarded powder (A. Belayachi). Two dominant minerals, SiO2 CaCO3 at the mirror M1.cela means that the main substratum is marno-clay to clay-limestone. As for sample E2.

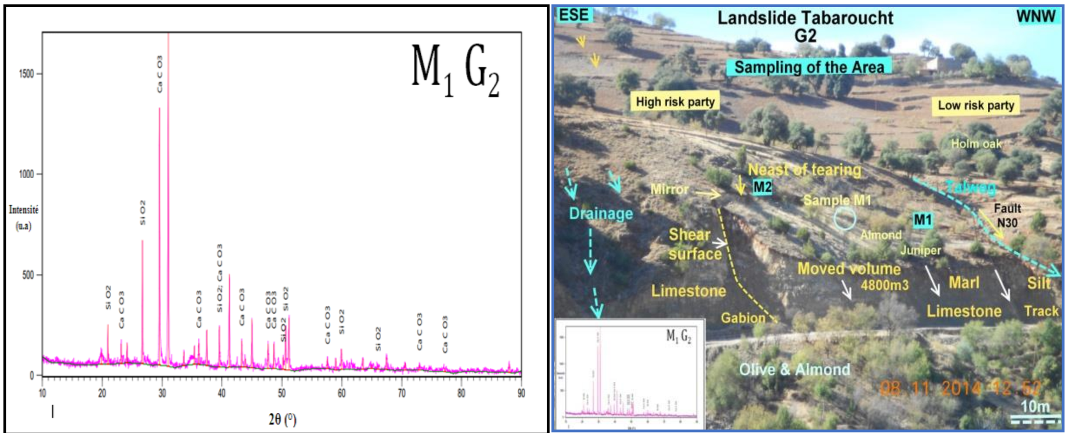

Figure 13: Results and geochemical location sampling(L.P.M/FST)

Slampes	1	2	3 M_1	4 M_2	5 M_3
GPS	32,11846	32,11846	32,11828	32,11833	32,11878
Coordinates	6,25280	6,25192	6,25357	6,25377	6,25409
Altitude(m)	1290	1285	1321	1324	1311
Type of soil	Clay-Marl	Clay-Marl	Clay-Marl	Clay-Marl	Clay-Marl
Mineral chemistry	//	//	CaCO3-SiO2	//	//

Table 3: Crystallography and mineralogical results

4. DISCUSSION

Slope is a key element in land movements. The average descent of this slope is 57% with a dip of 45° to 55° measured by the compass, between the mirror and the foot, promotes instability of the materials after rupture of the cohesion of the particles especially after heavy precipitation. The geological nature and type of sediment are two critical triggers. In our case, the marl-siltous series and the permeable altered basalts favor a bad behavior of the soil by migration of the bead towards the track bringing some trees with weak roots. Muddy flow develops during the rainy months due to an overweight of particles caused by the water content which reduces the interstitial force [μ]. When the slope exceeds 60% where the angle of inclination is more than 30 ° the risk of a landslide increases, (Ahmed Slimi and Jean-Pierre Larue 2010)

Precipitation and its distribution over time play a key role in most mass movements. Drainage of rainwater at 1400 m converts towards the heart of the slope by runoff in showers and infiltration in soft rain generates a mechanism of clear instability by an evolution of the mirrors and an increase of the volume in movement in muddy flow. At 1600 m altitude a green oak forest with good roots that maintain the land. At 1200 m a forest with various shrubs is in continuous instability due to poor soil behavior. (Veronica Ochoa Tejeda & Monique Fort 2011).

Soil mechanics tests, in this case the [IP] plasticity index exceeds 14, 30 so the soil is moderately plastic. The fine clay-silts are between 45% and 55% tells us about the existence of a large clay fraction in these sediments. Based on the liquidity limit [WL] and the plastic limit [WP] to deduce the IP by the following formula:

$$[\boldsymbol{IP}] = [\boldsymbol{WL}] - [\boldsymbol{WP}] = \mathbf{14{,}30}$$

$$\%\boldsymbol{fine} = \mathbf{49,50}$$

$$\mathbf{10} \leq \boldsymbol{IP} < \mathbf{18} : \textbf{Moderately Plastic}$$

$$\mathbf{25} \leq \%\boldsymbol{fine} < \mathbf{65} : \textbf{Clay material}$$

The action of the Man here is obviously clear, certainly the work of the tracked carried out by the rural commune strongly put the embankments, where the route passes, in movement of the materials towards the bottom. The degradation of the forest, especially for domestic and economic use (Coal and wood) could influence the quality of the inter-rivers and the watersheds by favoring an intense runoff which aggravates the hazard.

The estimated 4800m^3 are mobilized by a geological regime characterized by an overall average slope of 60%, a measured dip that exceeds 45°, and an aquifer, even in summer, at the base of the slope favoring the decohesion of materials and increasing the viscosity of the bead in feet.

According to Cornell's 1951 table, the plasticity index is 14.30, so our clay is a Kaolinite. The exchange cation is <Ca> for an IP = 11, as shown by the X-Ray diffraction graph we have [CaCO3-SiO2] is dominant in our clay material.

$$\boldsymbol{V} = \boldsymbol{L} \times \boldsymbol{l} \times \boldsymbol{h} = \mathbf{80} \times \mathbf{30} \times \mathbf{2.00} = \mathbf{4800}\boldsymbol{m}^{\mathbf{3}}$$

During the three years of study in this zone, the state of the track presented more cracks, from where the surface of rupture is limited just along the slip to 2.5m of thickness, so we

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can qualify our sliding of the deep. The present case of slope movement is a mass migration of earth, especially, in rainy periods of the year. The root system of the existing flora is unable to maintain the soil in permanent instability. The drainage system carried out by the municipality, segued in concrete, and downstream is insufficient for a collection of rainwater far from the embankment in danger.

5. CONCLUSIONS

The major factors of a landslide are different from one zone to another, in case of slip of our study; the agents triggering these hazards are divided into two categories, direct and indirect factors. The geological nature, the slope, the vegetation cover are the indirect factors of the landslide, but also the impact of climate change on hydrogeology and local hydrology are the main natural direct factors of such landslides, one can also include the anthropogenic action which affect the stability of the slopes in the phase of the equipment works or the quarries and mines exploitations as well as the seismic magnitudes which vary between 3 and 5 Richter.

Direct factors:

Rainfall: The altitude of 1400 put to give during these last years, variable rains. The snowy peaks between November and April condition the supply of aquifers and sources upstream.

Geology: The formations between the Lias and the Quaternary, characterized, in particular, by the marls, the clays and the silts favor the good conditions for the instability of the slopes, as well as the presence of a fault network with different directions which has generated areas of weakness (faults) for the drainage of flood waters.

Groundwater: The presence of an aquifer system in the basin to the south and south-east of the slope aggravates the situation, especially after the supersaturation of the aquifers.

Slope: this is the primary factor of mass movement downstream, especially when the slope belongs to the great slope of a watershed, such as the case of landslide of this zoned. 60% and an angle of inclination exceeding 30°.

The anthropic action: In order to improve the conditions of the distant inhabitants and to encourage the rural Geotourism the passage of the roads proves essential. The passage of the paved road between the regional road 302 and Tabaroucht caused rupture zones which reacted in movement.

Indirect factors:

Degradation of the flora: The use of wood by the population is a scourge that ravages the Moroccan forests, which causes a huge loss of trees and their root system (10 Billions of trees per year worldwide [Nat Geo]). Therefore lose ground instability is highly likely.

The seismic factor: Magnitudes recorded in this region since 2003 up to the present day, oscillated between [3.2] – [4.6] Richter, which has, perhaps, increased the risk especially on the new pull-out nests.

Vehicle traffic: the traffic of medium-weight vehicles, in particular those of the transport for the weekly souks, has an indirect impact on the evolution of tension cracks at the level of the pull-out nests of such a slip.

In the case of landslides, active techniques are preferred to passive methods. Indeed, once a landslide involving large amounts of materials is initiated, it is difficult to control the consequences, example of Colombia April 2017 with more than 254 missing.

Since it is a transport of deep materials [2m-10m] Benouis 2010, so the appropriate solutions will be expensive and effective for such a risk. Good drainage at aquifer level is essential, especially by subhorizontal drains. Rock fill of creep areas, especially reinforced gabions, is an adequate remedy in critical periods. The relative speed of the plans is between 4 and 14mm / month, so called slow (Guide LPC)

References

1. Melchiorre, C. y Frattini, P. Modellingprobability of rainfall-inducedshallowlandslides in a changingclimate, Otta, Central Norway. Clim Chg, 2012, *113*, 413– 436. **DOI.** https://doi.org/10.1007/s10584-011-0325-0. .D.E. Benouis 2010. Étude d'un glissement de terrain par différentes méthodes. Université Saadi Algérie,

2. Trenberth, K. Conceptualframework for changes of extremes of the hydrological cycle withclimate change. Clim Chg, **1999**, 42, 327–333. Available online: http://www.cgd.ucar.edu/staff/trenbert/trenberth.papers/ClimChg42_327-339.pdf (accessed on 14 September 2017)

3. Cruden D.M. ; Varnes D.J. Landslide types and processes in Turner & Schuster, Landslides, Investigation and Mitigation, Special Report 247, National AcademyPress : Washington, D.C. USA ; 1996 ; pp. 240-241

4. Hungr, O. ;Leroueil, S. ; Picarelli, L. The Varnes classification of landslide types, an update. Landslides, 2013, 11, 167–194, DOI. http://dx.doi.org/10.1007/s10346-013-0436-y.

5. Petley, D. Global patterns of loss of life fromlandslides. Geology. 2012, 40, 927–930. DOI. http://dx.doi.org/10.1130/G33217.1.

6. IPCC – Intergovernmental Panel on Climate Change, 2014. Climate Change 2014 : Synthesis Report. Contribution of Working Groups I, II and III to the FifthAssessment Report of the Intergovernmental Panel on Climate Change, Geneva, Switzerland pp. 151. ISBN : 978-92-9169-143-2.

7. Zeino-Mahmalat E. ; Bennis, A. Environnement Et changement climatique au Maroc : diagnostic Et perspectives. Konrad-Adenauer-Stiftung : Morocco, 2012 ; Available online :http://www.kas.de/wf/doc/kas_31546-1522-1-30.pdf?120705170939 (accessed on 01 Novembre 2017)

8. Bzioui, M. Rapport National 2004 Sur Les Ressources En Eau Au Maroc. UN Water/Africa (2006), African water development report 2006, Econ. Comm. for Afr., Addis 2004. Available online : http://www.albacharia.ma/xmlui/bitstream/handle/123456789/30433/0178Rapport%20national%202004%20sur%20les%20ressources%20en%20eau%20au%20Maroc%20(Novembre%202004).pdf?sequence=1 (accessed on 04 Novembre 2017)

9. Rianna, G, Zollo, A. Tommasi, P. Paciucci, M Comegna, L. Mercogliano, P. (2014). Evaluation of the Effects of Climate Changes on Landslide Activity of Orvieto ClayeySlope, ProcediaEarth and Planetary Science, 2014,9, 54 – 63**. DOI.** https://doi.org/10.1016/j.proeps.2014.06.017

10. A. Qlihaa 2016: Caractérisation physico-chimique d’une argile Marocaine [Physico-chemical characterization of a morrocan clay], S. Dhimni*, F. Melrhaka, N. Hajjaji, A. Srhiri Laboratoire de Matériaux, Electrochimie et Environnement

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