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### RESEARCH ARTICLE

#### IMPACT OF CLIMATE CHANGE ON THE LANDSLIDE IN THE CENTRAL HIGH ATLAS OF MOROCCO: CASE OF TIT N'ZIZA, EL KSIBA.

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#### Abstract

This research work is focused on the study of the gravitational instabilities of the Tit N'Ziza, El ksiba landslide in the Imhiwach-El Ksiba area 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 in order to determine the triggering causes. 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 has improved the understanding of gravity instability for possible solution to the problem.

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#### Introduction:-

Shallow rainfall-induced landslides are one of the most common and dangerous natural hazards, mainly because of their high temporal frequency causing, each year, some deaths and significant economic damage (Melchiorre and Frattini, 2012). 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 a higher moisture content in the air, which can in turn increase the frequency and intensity of heavy rainfall (Trenberth, 1999). 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 (Cruden and Varnes 1996; Hungr, Leroueil and Picarelli, 2013). Landslides involve flowing, sliding, falling, or expanding movements. 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 (Petley, 2012). The synthesis report of the Intergovernmental Panel on Climate Change (2014) provided flood risk assessments, and concluded that the number of people exposed to floods is expected to increase

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worldwide. In Morocco, the reduction of fluvial inputs downstream of dams, resulting in a deficiency in groundwater recharge functions, freshwater circulation and sediments, as well as dilution of pollution affecting the hydrodynamic equilibrium of ecosystems (Zeino-Mahmalat and Bennis, 2012). Precipitation patterns vary from region to region but still dominated by strong irregularity in space and in time, seasonal and interannual basis. Alternating sequences of years high runoff and severe drought, which may last several years, is a prominent character of climatic and hydrological regimes (Bzioui, 2006). 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, regarding the active landslides in fine grained soils (Rianna et al. 2014). 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 track between two cities Ouaouizerht and Tabaroucht.

### **Materials and methods:-**

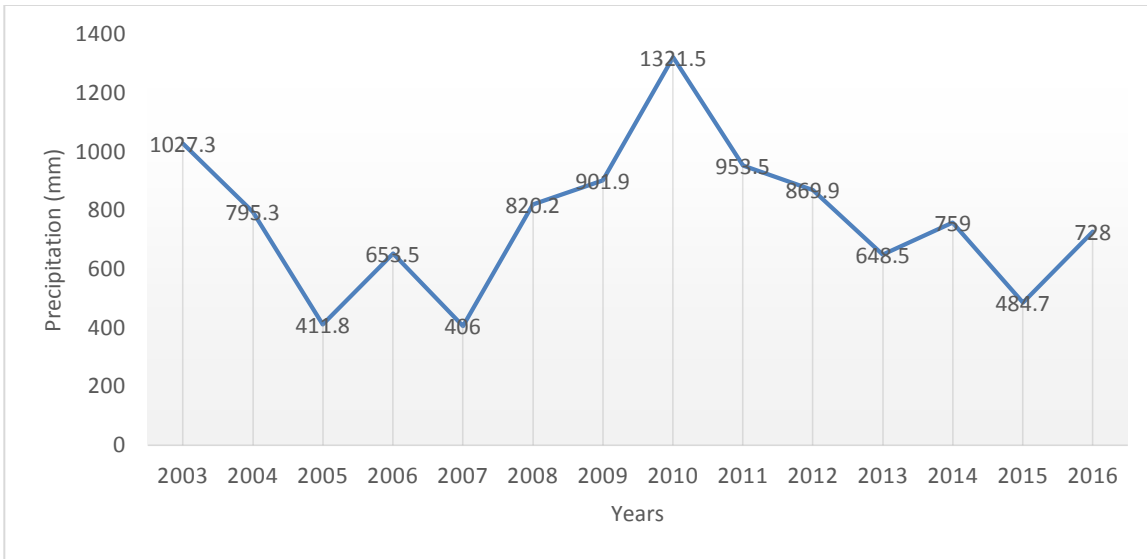
The slip is located about 3 km southeast of Imhiouach, with an altitude between 980 and 1150 m, latitude 32.566667 ° N and longitude -5.9666667 ° E. This is an embankment with a possible landslide. The overall slope varies between 55% and 65%, by contour and scale, and verified by compass measurements. From a geological point of view, the area is formed by limestone deposits, marls and clays and also basalts in places. The age of the formations dates back to the Triassic Jurassic (-140 Ma). The Cretaceous formations outcrop, in particular, in the plains to the North in contact with the Paleozoic (Discordance) and North-west of the site. In this study, a cartography was made at different scales to deduce the value of the slope, conditioning the problematic by a topographical background (mathematical demonstration by the arctangent) and confirmation by the compass by measuring the dip of the great slope of the slipped part. An analysis of topographic maps and field research was done to give us a precise idea of the hydrographic network that can intervene directly or indirectly on the evolution of the hazard in time and space. Structural data were used to determine the tectonic regime of the study area. The directions of the faults and some slight folds were manifested in the sandstones within the marls by the projection of the orientations in a canvas of Schmidt, to deduce the stress of the tectonic deformation and confirm the major accidents of the atlasic orogeny that gave rise to this mountain range. From a hydrogeological point of view, a series of piezo-metric measurements was carried out in order to know the level of the aquifer upstream of the site, in particular, to know the origin of the waters at the foot of the slopes during the dry period, between May and October. It was deduced the piezo-metric level. According to Darcy's law, underground flows are controlled by the hydraulic gradient of each porous medium.

### **Results:-**

#### **Hydrogeology sliding study:-**

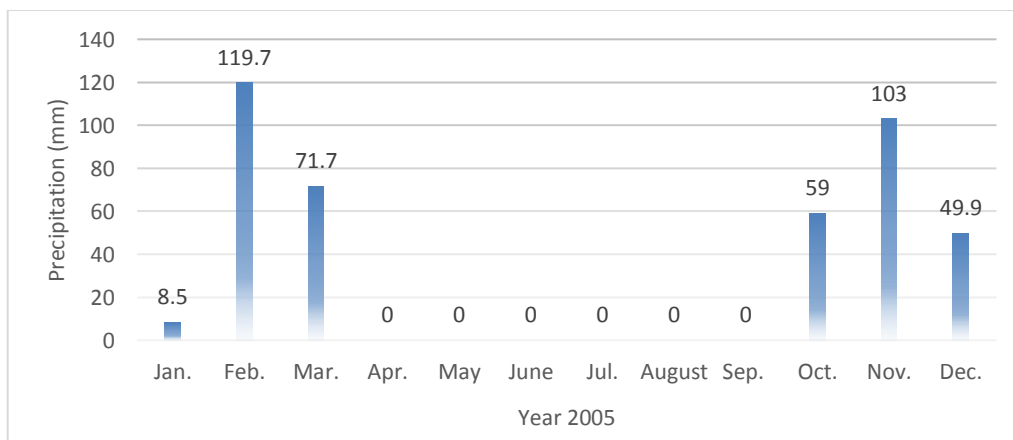
##### **Precipitation:-**

The El Ksiba weather station shows that during the period 2003 to 2016, the average monthly precipitation varies between 30 mm and 120 mm, and the annual average varies between 400 mm and 1400 mm, but with a significant interannual and seasonal irregularity. The cool season receives the majority of the precipitations, not to mention the showers during the end of the spring and the end of the summer of each year (Example: the rain of June 23, 2014 and fall of the temperature). The dry season, which extends from mid-May to mid-October, promotes decohesion and cracking of marl-clay soils (Fig.1).



**Fig 1:-** Average annual precipitation with location of landslides by rainfall period over 14 years.

The year 2005 presents a dry period a little long which lasted almost seven months, with an annual cumulative of 411.5 mm, a monthly average of 34.3mm (Fig. 2). While 2010 remains the rainiest year in the last fourteen years with a total of 1321.5 mm, a monthly average of 110.13mm.



**Fig 2:-** Rainfall at different regimes of the year 2005

While the year 2010 was the rainiest during these 14 years, where the dry period did not exceed 4 months (Fig. 3). The rainy years had an impact on the dynamics of land movements throughout the Kingdom, including the site at risk. The rainiest month was February of the year 2010 with 350 mm. In that time, the region experienced deadly floods, such as that of the Ait Chkounda Valley and Ait Hamou Abdeslam. The 2010 rains affected weak structures such as faults and breaks, which led to strong runoff at the watershed and valley level.

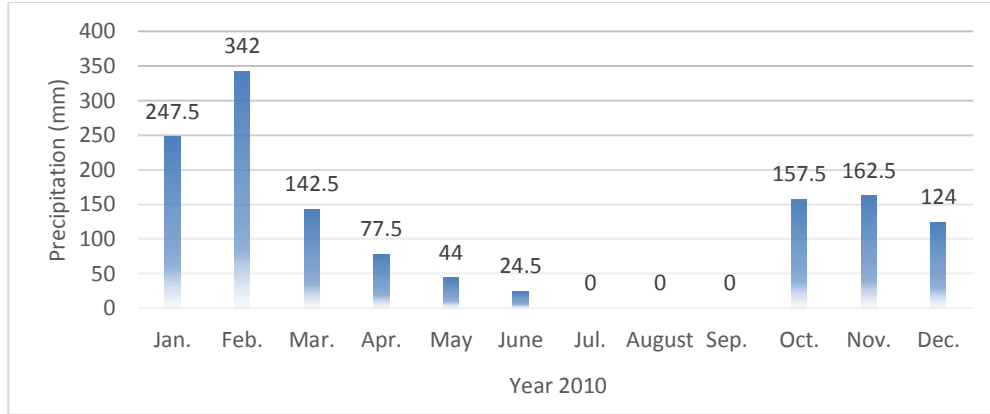


Fig 3:- Rainfall at different regimes of the year 2010

**Rainfall :-**

Knowledge of groundwater inflow is one of the most effective actions to prevent, stabilize or slow down a landslide. The study of groundwater feeding mode is essential to respond adequately. 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 the snow slit from ridges between 1800 m and 2000 m, and fine rains in the presence of a porous calcareous-dolomite substratum.

Measurements made for different aquifers upstream of the slope have shown that the arrival of water at the foot of the slope in dry periods has a direct impact on instability of the slide. Four boreholes (W1, W2, W3 AND W4) and a karst spring were sampled and measured periodically during the period from July 2015 to June 2016 (Fig. 4). The choice of these months was not at random, it is because during this period, the basic flow of each aquifer is accentuated through irrigation. According to these measurements, the region consists of more than 3 different aquifers at varying altitudes.

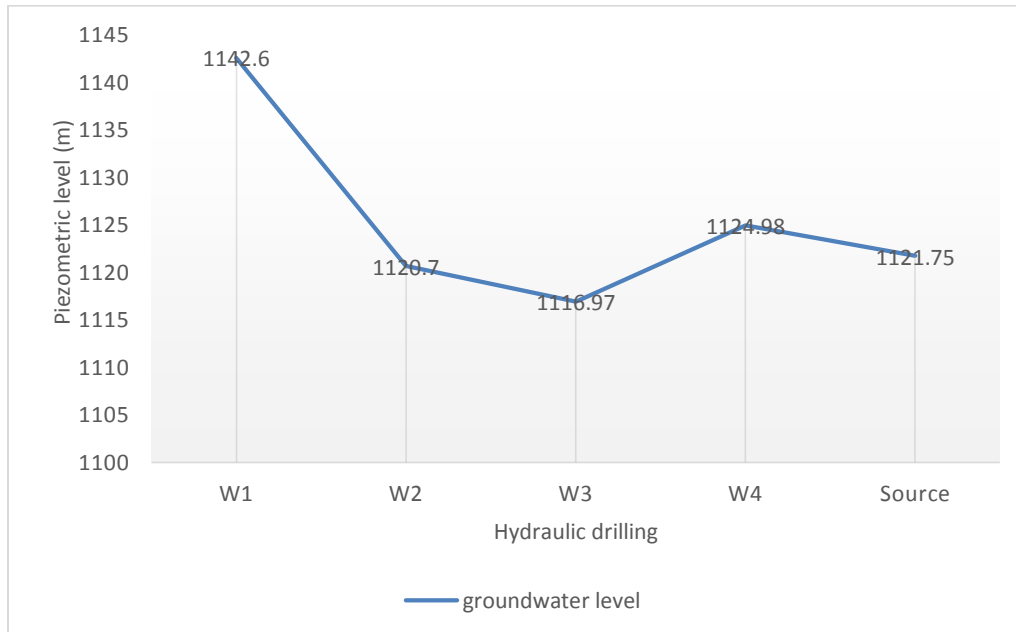


Fig 4:- Groundwater level upstream.

- Water table between 12m and 15m captured by a traditional well (W3) of 1.20 m diameter, intended for the domesticated drink and irrigation of an orchard of 0.5 ha.

- Shallow open water between 45 and 50 m from two boreholes (W2 and W4) 0.4 m in diameter. Agricultural use is likely to irrigate a large area.
- Groundwater captive at SW between 105 and 110 m captured by W1 drilling of 0.4 m. Irrigation of grasses and various crops estimated at more than 5 ha.
- Karst groundwater, flush to the east and upstream caves and travertine, it is a slick from distant mountains, as during the heavy rains there is no turbidity of suspended matter probably related to snow cracks. This is the only point in the waters of human consumption of the surrounding agglomerations.

**Geological and geotechnical study of sliding:-**

**Slope calculation:-**

According to the classic formula for calculating the slope:

$$\tan \alpha = H/d$$

(H): altitude difference

(d): distance between Oued and the embankment ridge.

The value of h = 1240 - 980 = 260 m and the value of d = 400 m, so the slope calculated from the topographic map is 260/400 = 65%. While the average dip of the line of great slope measured by a compass on ground varies between 45 ° and 55 °.

**Sedimentogy and lithology:-**

According to the geological map of Benzaquen (1963), the site is characterized by the abundance of marl-limestone formations, friable clays and silts with timid outcrops of altered Triassic or Permo-Triassic basalts. In Figure 5, one can observe the type of soil and sediments that characterize the slippery valley.

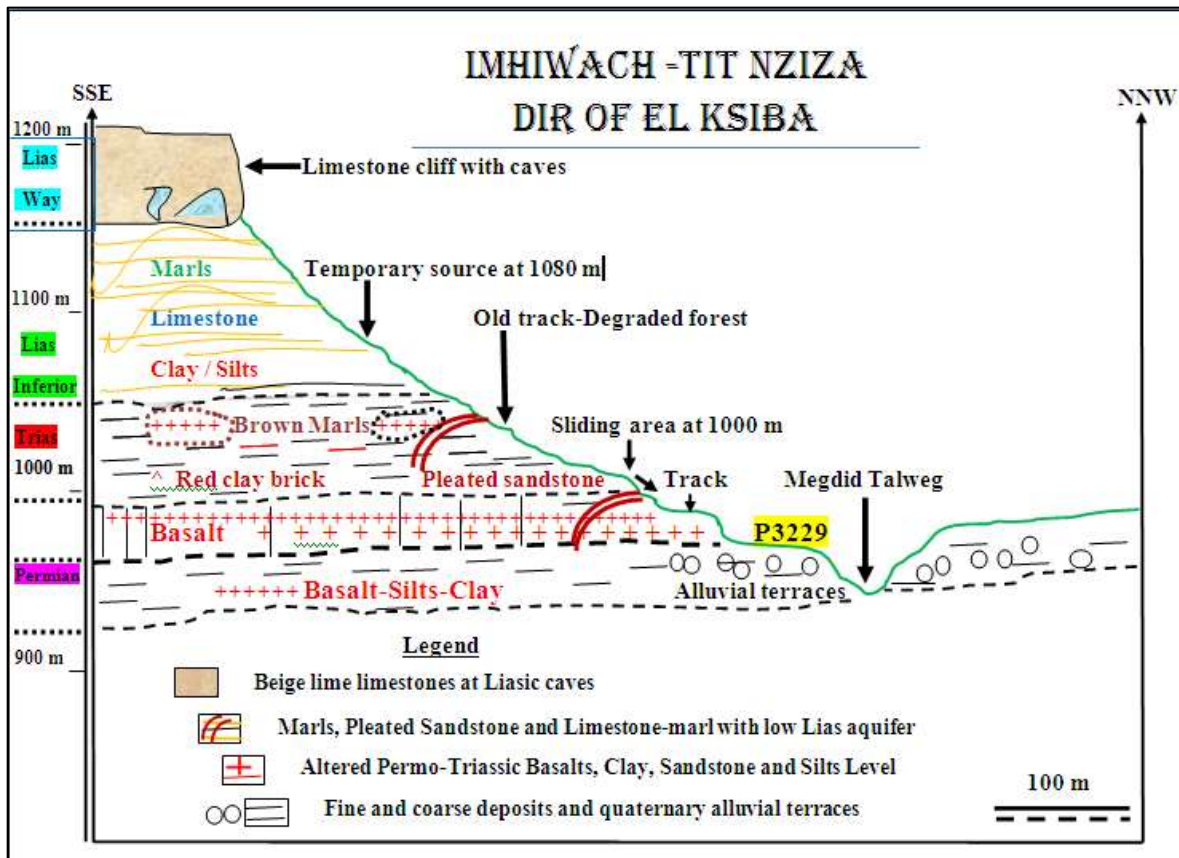


Fig 5:- Topo geology of the valley with landslides

A comparison over time of certain geological structures such as faults will give us an idea of the accidents caused by climate change. The collection of local structural data allows to know the regional tectonic regime. In March 2009, the ductile fault was intact. November 2014, the 6256 mm were sufficient to dig 85cm deep during five years by the mechanical alteration of the water (Fig.6, 7).



Fig 6:- Faults affecting the marly limestone slope and silt and clay series.



Fig 7:- Rainfall impact on weak structures in the slope

A follow-up of the mirror measurements during a period of 2014-2017, showed us that after the November-December 2014 floods, the displacement was remarkable and brutal, especially at the M3 mirror slope 2 upstream (Fig.8).

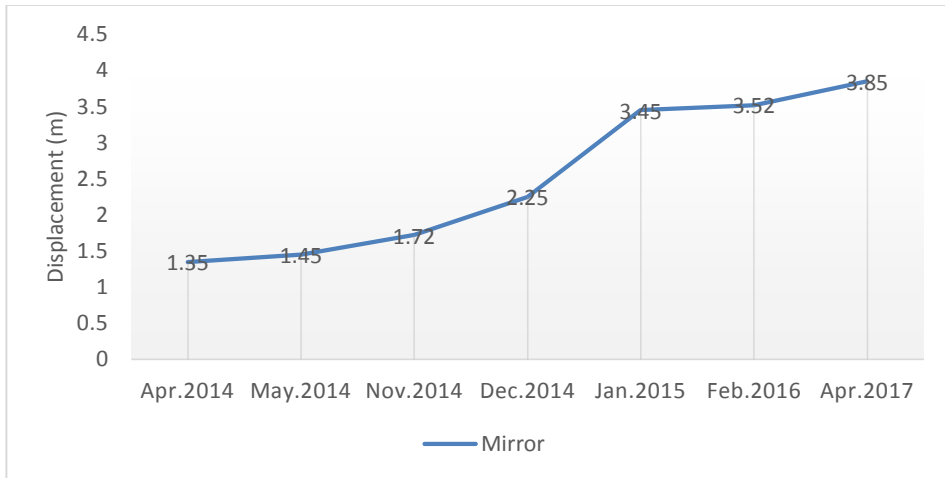


Fig 8:- Evolution of the mirrors relating to the slope according to the conditions of instability.

**Soil mechanics :-**

Two samples were taken to determine the geotechnical characteristics of the soil in question. Soil mechanics is essential to know the type of soil that reacts with these local climatic conditions. Based on the Atterberg limits, especially the Plasticity Index "PI" and the Blue of Methylene "MB" to determine the essential factor of the bad behavior of this soil (Table 1).

Geotechnical tests	D.max (mm)	<2 (mm)	<0.08 (mm)	Liquidity limit LL (%)	Plasticity limit LP(%)	Plasticity Index IP(%)	Los Angeles IA (%)	Methylene blue BM (%)
Sample 1	50	57.5	24.4	38	25	13	22	1.8
Sample 2	50	58	24.9	39	27	12	22	1.9

Table (1):- Geotechnical study of two soil samples

**Discussion:-**

Slope is a key element in land movements. The average descent of this slope is 63% with a dip of 45° to 55° measured by the compass, between the mirror and the foot, promotes instability of the materials after breaking up of the cohesion of the particles, especially after heavy rainfall. The geological nature and type of sediment are two critical triggers. In our case, the marl-siltous series and the permeable altered basalts encourage bad behavior of the soil by migration of the bead towards the track bringing some trees with weak roots. The muddy flow develops during the rainy months due to an overweight of the particles caused by the water content which reduces the interstitial force  $\mu$ . Precipitation and its distribution over time play a key role in most mass movements. The 13 years rains collected show the direct impact on the geomorphology of some structures including faults. Drainage of rainwater at 1085 m converts to the heart of the slope by runoff in showers and infiltration in soft rain generates a mechanism of clear instability by a change in mirrors and an increase in the volume moving in muddy flow. At 1700 m altitude, a forest of green oak with good roots maintains the land. At 1100 m a forest with various shrubs is in continuous instability due to poor soil behavior. Inclined tree in motion. Soil mechanics tests, in this case the **PI** plasticity index exceeds 12% so the soil is plastic. The **MB** methylene blue, between 1.8 and 1.9 tells us about the existence of a large clay fraction in these sediments. Based on the liquidity limit **LW** and the plasticity limit **PW**, the **PI** is deduced by the formula:

$$PI = LW - PW = 38 - 25 = 13\%$$

Having the limit of plasticity **PL** = 25%, we go to a limit of liquidity **LL** = 38%, that means that our soil is viscous and increases the risk of creep at the slope. The **PI** plasticity index oscillates between 12% and 13% so the material here is plastic.

For the **MB** value between 1.5 and 2.5, the soil type of this ground is sandy-clayey, so swelling, which promotes the risk of slippage.

$$1.5 \leq BM < 2.5 : \text{sandy} - \text{clayey soil}$$

The MB value, varies between 1.8 and 1.9 so our soil is loam-clay, plastic type montmorillonite of formula  $(\text{Na}, \text{Ca})_{0.3}(\text{Al}, \text{Mg})_2\text{Si}_4\text{O}_{10}(\text{OH})_{2n}\text{H}_2\text{O}$ , and belonging to the group of smectites, of the family of phyllosilicates, then it is a swelling clay. The action of 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  $1500 \text{ m}^3$ , by estimation, are mobilized by a geological regime characterized by a global average slope of 60%, a measured dip which exceeds  $45^\circ$ , and an aquifer, even in summer, at the base of the slope promoting the debonding of materials and increasing the viscosity of the bead in feet.

$$V = L \times l \times h = 50 \times 20 \times 1.50 = 1500 \text{ m}^3$$

During the three years of study in this zone, the state of the runway did not present and no longer showed any cracks, from where the surface of rupture is limited just along the sliding to 1.50 m of thickness, so we can qualify our sliding of the non-deep one. This case of slope movement is active mud flow, especially in rainy periods of the year. The root system of the existing flora is unable to maintain the soil in permanent stability. The drainage system carried out by the municipality, seguias concrete upstream is insufficient for collecting rain water away from the endangered embankment.

### Conclusion:-

The major factors of a landslide are different from one area to another. In the case of sliding our study, the agents triggering of these hazards are unwound into two categories: direct and indirect factors. The geological nature, the slope and the vegetation cover are the indirect factors of the landslide. The impact of climate change on hydrogeology and local hydrology are the major direct natural factors of such landslides, we can also include the anthropogenic action that affects the stability of slopes in the phase of equipment works or mining and quarrying materials.

### Direct factors:-

- **Rainfall:** The average rainfall varies between 445 mm and 1400 mm per year. Snowy crests between November and April, conditions the supply of aquifers and sources upstream. Climate change that affects stormy rains increases the risk of landslides in the study area.
- **Groundwater:** The presence of an aquifer system in the basin east of the slope aggravates the situation, especially after the supersaturation of the aquifers. Irrigation of cultivated areas also promotes a flow towards the slope at risk.
- **Anthropogenic action:** In order to improve the conditions of the distant inhabitants, and to encourage the rural geo-tourism the passage of the tracks proves essential. The passage of the track between the provincial road P3229 and Tit N'Ziza caused breaking zones to react to the movement.

### Indirect Factors:-

- **Geology:** the formations between the Triassic and the Quaternary, characterized in particular by the marls, the clays and the silts, promotes the good conditions for the instability of the slopes, as well as the presence of a network of faults in different directions which has generated zones of weakness for the drainage of flood waters. In addition, the slope belongs to the great slope of a watershed, like the slip case.
- **Degradation of flora:** The use of wood by the population is a plague that ravages the Moroccan forests, which causes a huge loss of trees and their root system. Therefore, loose ground instability is highly likely.
- **Vehicular traffic:** Medium-weight vehicular traffic, particularly transport traffic for weekly souks, has an indirect impact on the evolution of tension cracking at the level of the pull-out nests of such a slip. Every weekend the region knows a large mass of visitors for geo-tourism circuits which increases the traffic.

In the case of landslides, active techniques are preferred to passive methods. Indeed, once a slip involving large amounts of materials is initiated, it is difficult to control the consequences. Since this is a transport of non-deep material, the appropriate solutions will be inexpensive and effective for such a risk. Good drainage at aquifer level is essential, especially by sub-horizontal drains. Rockfill of creep areas, especially reinforced gabions, is an adequate



remedy in critical periods. The relative speed of the mirrors varies between 16 and 48 mm per month, so it is a slow slip.

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