Evaluating the correlation of extreme climatic phenomena on road slope landslides

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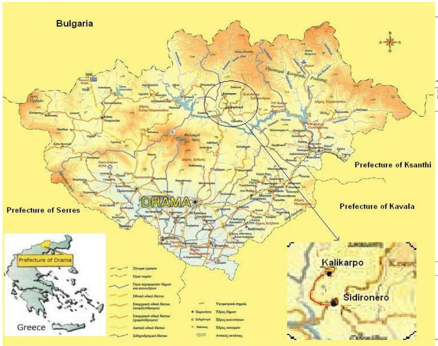
Abstract

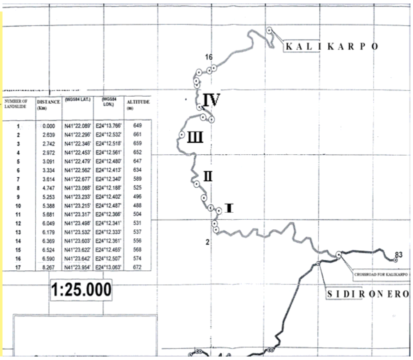
Last year's major climatic changes are observed as much in the Greek area as in the wider global one, with severe effects to peoples' activities, their work and their welfare. The extremely heavy rainfalls after long dry periods and the unusual temperature variation in short periods of time are phenomena that appear more and more frequently. At the same time, a large number of landslides are recorded as much in the national as in the provincial road networks of the country, especially after the activity of the aforesaid phenomena. That is because the water, as the main factor, is occupying the empty spaces affecting the stabilization of a mass. In this paper we manage to determine firstly the existence of the unusual level and frequency of precipitation and temperature variation during November and December of 2002 and 2003 using climatic data for the area from previous years. Then, from a number of landslides which occurred in a provincial road in Drama, in Northern Greece, we examine under which circumstances this activity took place, also taking into account the technical standards of the road, the geomorphology and the vegetation of the area. Finally, we aim to define the potential correlation between the climatic phenomena and the landslides and the level of importance of each analyzed variable.
Keywords: landslides, climatic changes, road slopes.

1 Introduction

It is obvious that every country with a steep terrain faces extreme geological phenomena and great mass movements in periods of heavy rainfalls. The water is the main factor that produces these results, firstly increasing the weight of the rock itself by occupying the empty spaces and therefore affecting the stabilization of the whole mass. In addition, the increased quantity of the water also increases the hydraulic pressure inside the rock and reduces the friction level between the rocks, which is one the most basic factors of instability in slopes. The same happens in soft soils where we have the immediate change of the physical condition caused by water absorption. The grains of the soil lose their cohesion and the mass flows liquefied to the lower point, Emmanouloudis and Emmanouilidis [1].

Yet an individual "landslide" characteristically involves many different processes operating together, often in different measure during successive years Haigh et al. [3]. Landslides should not be treated as if they were discrete single events and they can rarely be classified precisely Varnes [4]. Nevertheless the heavy rainfalls of November and October of 2002 and 2003 and the sudden snowfall with the following raising of the temperature to high levels, has attracted our attention. Thus we concentrated on this phenomenon to determine the causes and to find the correlation between those climatic factors and the landslides, always taking into account usual and necessary variables such us the technical standards of the road, geomorphology and vegetation.





NUMBER OF LANDSLIDE	DISTANCE (Km)	(WGS84 LAT.)	(WGS84 LON.)	ALTITUDE (m)
1	0.000	N41°22.089'	E24°13.766'	649
2	2.639	N41°22.296'	E24°12.532'	661
3	2.742	N41°22.346'	E24°12.518'	659
4	2.972	N41°22.453'	E24°12.561'	652
5	3.091	N41°22.479'	E24°12.480'	647
6	3.334	N41°22.562'	E24°12.413'	634
7	3.614	N41°22.677'	E24°12.340'	589
8	4.747	N41°23.088'	E24°12.188'	525
9	5.253	N41°23.233'	E24°12.402'	496
10	5.388	N41°23.215'	E24°12.487'	488
11	5.681	N41°23.317'	E24°12.366'	504
12	6.049	N41°23.498'	E24°12.341'	531
13	6.179	N41°23.532'	E24°12.333'	537
14	6.369	N41°23.603'	E24°12.361'	556
15	6.524	N41°23.622'	E24°12.465'	568
16	6.590	N41°23.642'	E24°12.507'	574
17	8.267	N41°23.954'	E24°13.063'	672

Figure 1: Study area. Figure 2: Landslide positions.

2 Study area

The area of the research is located in one the most northern regions in Greece in the prefecture of Drama and 47 kilometers north of the capital town (figure 1). The landslides are located in the provincial road which connects the city of Sidironero and the village Kalikarpo. It's more than 6 kilometers of the road that during recent years appears to have had serious problem with landslides and the local administration has attempted many times to make repairs but with only temporary results. Generally, Drama is the richest county in vegetation in Greece with the largest area covered by oaks. The part of the road we studied passes mostly through a forest of these oaks and a further analysis below show that this variable is common for every landslide position. Most of the parts of the provincial road are rocky. The rocks in the area are highly metamorphic, shales or gneiss – shales with parts of debris, Sidiropoulos [6].

The average altitude of the area is around 600 m and from the data of the meteorological station of Livadero, which is the closest in the area, shows that the average annual precipitation level is 694 mm and the average annual temperature is 11,4 ^{o}C with a variation from -16,5 ^{o}C to 38,5 ^{o}C. The type of climate is Mediterranean with mild winters and dry and hot summers that are small in duration, Archives of the Directorate of Land Amelioration [7].

3 Data collection

Our goal is not to create a new comprehension model of road slope landslides, as we believe that there are several important studies that cover this matter fully. However, before we determine the influence of the meteorology in these landslides we must take into account and record the possible variables which lead to mass movement activity and the level of their effect. These are the variables we describe below.

The road, from the starting point to the village Kalikarpo, appears to have several positions of landslides. We have concentrated on four of them which are representative and belong to two types of mass movement, rockfalls and debris flows. We used the typical instruments for our measurements such us tape measures, compass, clinometer and abney level.

The intention was to measure easily recorded environmental attributes that are the potential correlates of landslide activity and which are usually taken into account in similar landslide studies and analysis. These are the road cut height (R_{ch}), road cut angle (R_{ca}), hillslope inclination - upslope (H_{iu}), hillslope inclination - downslope (H_{id}), vegetation cover - upslope (V_u), vegetation cover - downslope (V_d), the existence of a subsurface water flow path (W_{fp}), the Soil composition (S_q) (rocky or semirocky) of the road slope (up, down).

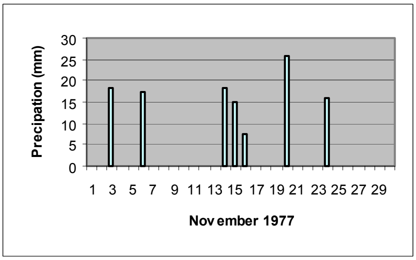
As far as the rainfall and temperature variation is concerned, we have collected data for more than the last 20 years for the study area from the Archives of the Directorate of Land Amelioration. Most of the landslides occurred at the end of autumn and during December, so the research has focused on those months. In order to determine a sudden precipitation or a snowfall with immediate melting it was important to use the daily precipitation data of those months as much as the maximum and the minimum temperature, though in order to be able to compare the results with previous years we also selected to illustrate the data of those two months for 1977, 1978, 1987 and 1988 for the precipitation and 1977 and 1987 for the temperature. Although we could use data for every year from 1977 and after, the limitations of this paper forced us to use this data but it does amply illustrate the comparison between the past and present conditions.

4 Results

The results are exported mostly in diagrams and in graphs because, for example, in the precipitation it is important to examine not only the maximum and the minimum value but also the distance between the rainfall days or the rainfall duration. The same happens with the temperature where we must determine the period of time that we had the highest and the lowest degrees. We also exported table 1 below where we indicate the characteristics for each one of the four landslides.

Table 1: The variable values in the studied landslides.

Landslide Number / Variables	1	2	3	4
Road cut height (R_{ch})(m)	12,5	6,3	9,5	5,2
Road cut angle (R_{ca} °)	65 °	70 °	60°	50 °
Hillslope inclination – upslope (H_{iu} °)	50 °	40 °	35 °	20 °
Hillslope inclination – downslope (H_{id} °)	45 °	40 °	30 °	20 °
Vegetation cover – upslope (V_u)	✓	✓	✓	✓
Vegetation cover – downslope (V_d)	✓	✓	✓	✓
Subsurface water (W_{fp})	-	-	-	✓
Soil quality (S_q)	Semirocky	Earthy	Earthy	Earthy



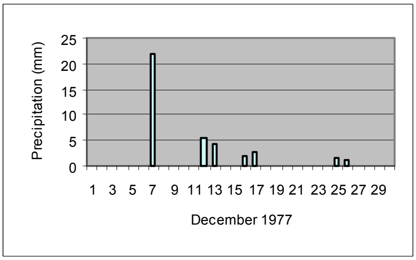


Figure 3: Daily precipitation for November 1977 and December 1977 from the Station of "Livadero".

5 Data analysis

The table 1 with the four landslides provides us a description of the circumstances that probably led to these incidents. Generally the vegetation is not missing and this is common to every studied position and a positive point in slopes because it reduces the level of instability, Emmanouloudis and Filippidis [2]. In the first position both hillside and road slopes are steep and the road is cut into it quite deeply. The cut is not that deep in the second occasion but still the road cut angle becomes even steeper despite the fact that the semirocky roadslopes does not provide the maximum stability for this kind of inclination. In the third landslide the big road cut height is the main characteristic and then a big slope angle follows in a position where we have soft soils as much as in the last occasion where at the same time the existence of subsurface water was underestimated or ignored.

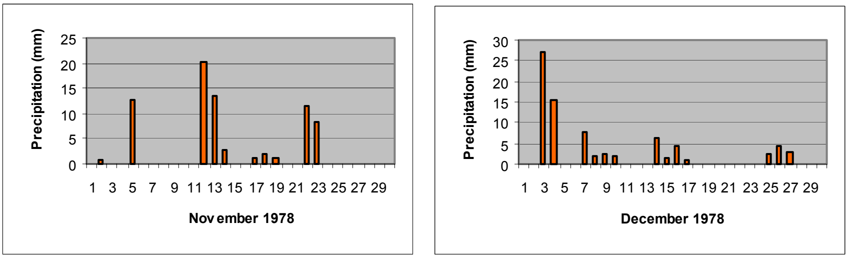


Figure 4: Daily precipitation for November 1978 and December 1978 from the Station of "Livadero".

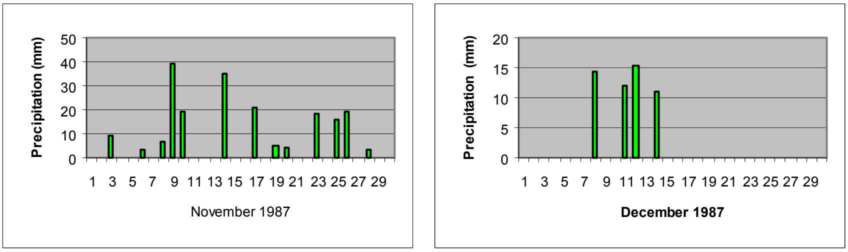


Figure 5: Daily precipitation for November 1987 and December 1987 from the Station of "Livadero".

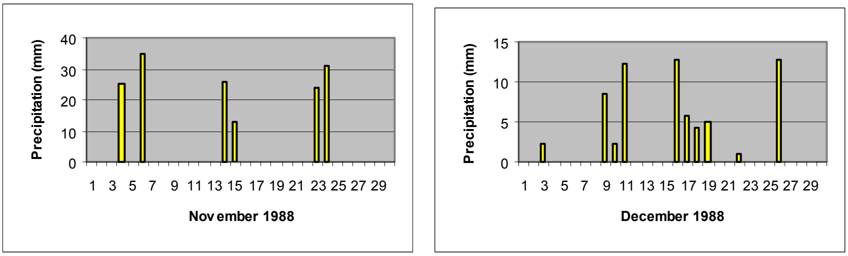


Figure 6: Daily precipitation for November 1988 and December 1988 from the Station of "Livadero".

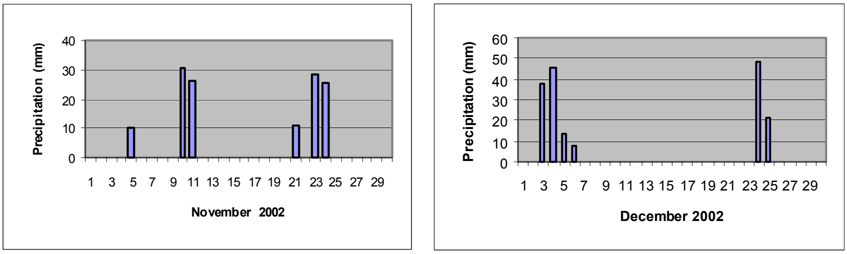


Figure 7: Daily precipitation for November 2002 and December 2002 from the Station of "Livadero".

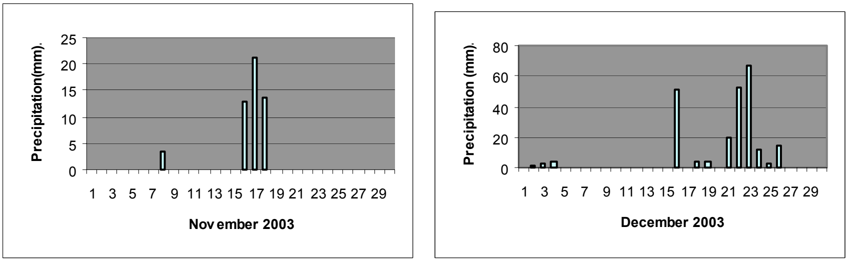


Figure 8: Daily precipitation for November 2003 and December 2003 from the Station of "Livadero".

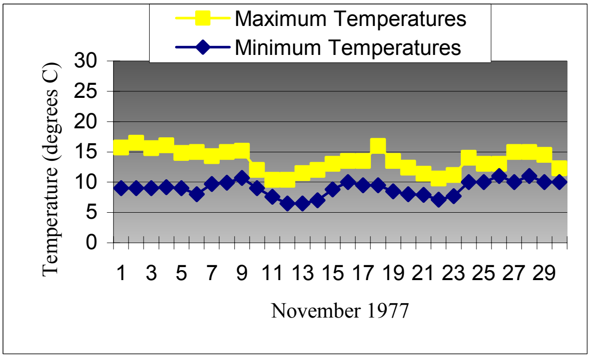


Figure 9: Maximum and minimum temperatures for November 1977 from the station of "Livadero".

The illustrated climatic data gives us some result, which is not far from our primary hypothesis. Generally the rainfall diagrams of the area for those two months do not show a big difference through the selected years. The quantity and the frequency of a rainfall in a region are matters that can easily differ from month to month and from year to year, National Observatory of Athens (NOA)[5]. Nevertheless in the last years of 2002 and 2003, when the landslides were recorded, we observe a slight difference in the distance between the rainfall days as much as in the quantity of the water in relation to the previous years. Then we had more frequent rainfalls and an amount of water of around 20mm per day (Figures 1 and 2). Only in November of 1988 (Figure 6) does this amount exceeds the 30 mm in a single day that occurred during December of 2002 and 2003 where this number reaches the 50 and 60mm of the daily precipitation (Figure 8). In the same time the figures with the temperature variation show that in general December and November are quite unstable months but in 2002 and 2003 we observe a gap of 15 to 20 degrees in less than a week (Figures 13, 14 and 15). For example in December of 2003 from 16°C we have a sudden drop to -2°C and then again to 15°C in 6 days time. In those colder days of November and December the precipitation was of course in the form of snowfall and then immediately after, rainfall again. That way the soil received a big amount of water not only from the rainfall itself but also from the quick melting of the snow where in other conditions its degradation would be more gradual. None of the compared months appears with this great variation apart from December of 1987, but still it happens more gradually from the 5th day of the month to the 25th.

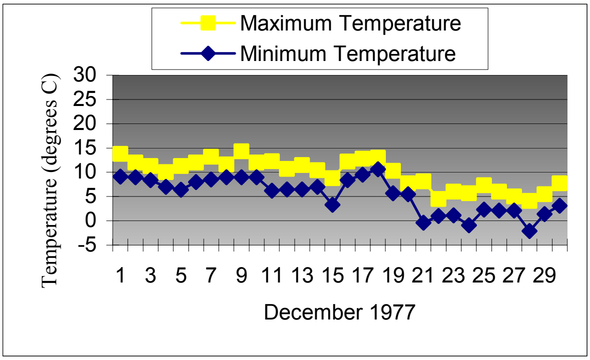


Figure 10: Maximum and minimum temperatures for December 1977 from the station of "Livadero".

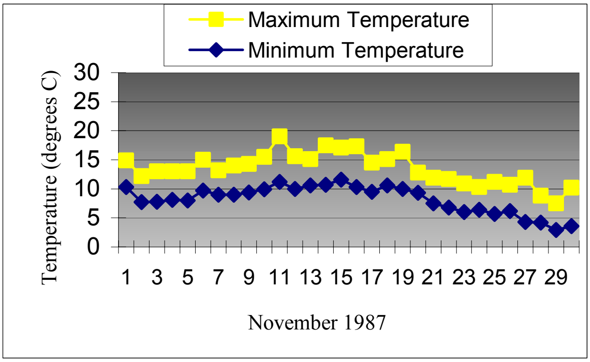


Figure 11: Maximum and minimum temperatures for November 1987 from the station of "Livadero".

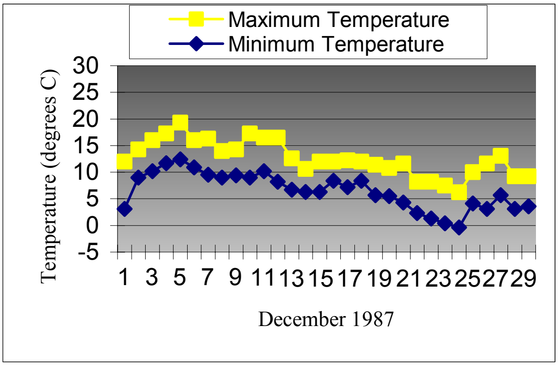


Figure 12: Maximum and minimum temperatures for December 1987 from the station of "Livadero".

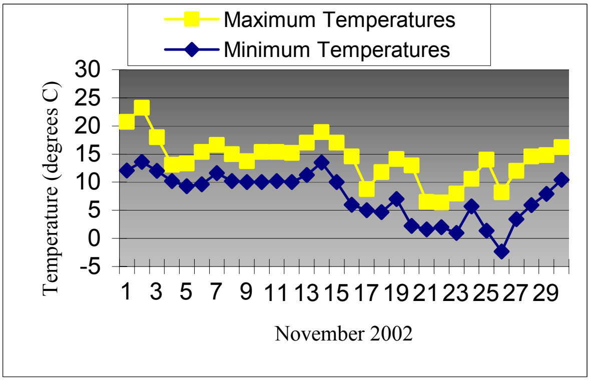


Figure 13: Maximum and minimum temperatures for November 2002 from the station of "Livadero".

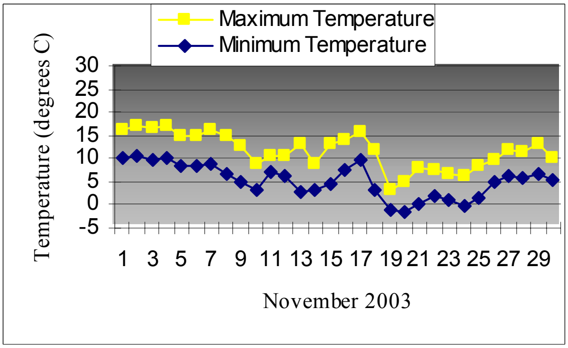


Figure 14: Maximum and minimum temperatures for November 2003 from the station of "Livadero".

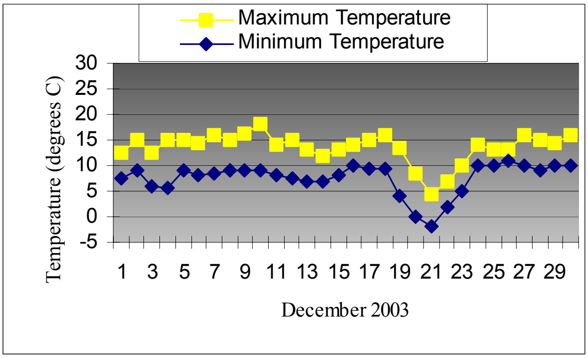


Figure 15: Maximum and minimum temperatures for December 2003 from the station of "Livadero".

6 Conclusions

The November and December of 2002 and 2003 when the mass wasting actually occurred, appeared slightly more unstable compared to the previous years. The differences we managed to conclude are close to a statistic flow but confirm our basic hypothesis about their existence and their possible effect in the studied landslides.

It is obvious that the described climatic phenomena are not the only conditions responsible for a mass movement activity. In these four occasions studied we found out that the slopes were sliding more because of the influence of local environmental variables (steep hillsides, subsurface ground water) as well as because of the lack of the basic principles of stability during the roadslopes construction. A great road cut height and a great road slope angle without the construction of pavements can easily cause a landslide as much as the lack of draining works in an essential subsurface flow. Thus the climatic variables we examined are not the main factors that caused the landslides but may have aggravated the situation of an already unstable road slope. Although this can happen with any sudden rainstorm or with thawing during the Spring, we find the effect of massive quantities of water important, beyond the usual, which can occur after a hot summer exceeding August and with moderate precipitations since then, provoking immediate saturation of the soil and rising of the subsurface runoff. Simultaneously, a sudden temperature drop down below 0°C with a rising up to 15°C following on, alters the cracking of the rocky slopes or in the case of a slope with a south – southwest orientation a quick melt of the snow cover can alter as well hill slope flow paths, or the surface runoff, or even the saturation of the soil and so the potential for shallow landsliding.

Unfortunately, this research didn't have the opportunity to study more thoroughly the climatic phenomena that triggered the landslides in the area and the exact moment of their appearance. Another stage of this study would be to determine more detailed attributes like the soil temperature and soil humidity and saturation or the instant maximum precipitation and the effects of the road-related hillslope failure.

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