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Full Length Research Paper

Study of spatial and temporal distribution of frost and sliding in Iran's mountain roads using climatic conditions matrix (Case Study; Karaj – Chalous Road)

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Frost and sliding in Iran's mountain roads cause dangerous conditions for road transportation. In this study, two goals are followed: Firstly, description of a method for a determining the likely occurrence of the critical condition of frost and sliding using the climatic conditions matrix along the Karaj- Chalous road (which is full of – traffic and mountains roads of Iran, connecting the Northern provinces to Tehran the Alborz heights). Secondly, the spatial and temporal analysis of frost using statistical analyses and GIS. One of the most important conclusions of the study is that there is a direct connection between the frost and height phenomena as by increasing the heights, the frost phenomenon occurs as soon as possible and is prolonged. From the viewpoint of spatial distribution, the studied mediate parts (that is, Karai's kms 43 to 128) are affected by drastic frost and from the in viewpoint of temporal distribution the N_5, N_6 and N_9 conditions (accounted as dangerous frost conditions for transportation) have been concentrated in December, January and February.

Key words: Frost, sliding, Karaj – Chalous road, climatic conditions matrix, road transportation.

INTRODUCTION

Because of the matter of transporting, different individuals have paid attention to the subject and conducted much studies (Cervero et al., 2009; Casas et al., 2009; Coelho et al., 2009; Rogalsky, 2009; Debrie, 2009; Su Mun, 2009; Hui Tang et al., 2009; Tilly Line et al., 2009).

As cleared, one of the important and effective factors on road transporting is natural conditions of different regions (Brian et al., 2009; Ren et al., 2009). These natural conditions include different climate condition around the world and it s effect on transporting and particularly on road on road accidents. Then, with regard to the importance of the climate on road transporting, many researchers have tried to identify the effect of the climate on transporting quality and quantity (Inmon et al., 2009; Potters et al., 2009).

But in this paper definition of frost and spatial and temporal distribution is important. Frosting is gains when the temperature reduces to zero or less than zero. Generally, frosting is classified into three classes of aerology, agriculture and technical. In the present article, our definition of frosting is in perspective of technical. But spatial analysis, studies the way of distribution and human organization and his activities in the area. Dedicating space optimal is to the areas potentials in certain period (Adibi, 1994).

Through effective factors on road transportation safety, climatic phenomena are of great importance; however some of them can be minimized in the presence of on time transportation factors in a specific location. Although, these phenomena are unavoidable being sometimes out of the ability of human options, some of them can be minimized using new ways of road design, while others can use on-time transportation factors in the place. Of the climatic elements and phenomena taken into consideration in programming, designing and maintaining roads as much as possible, is the frost phenomenon. Because frost is in a group of climatic phenomena annual damage much the different items such as transportation. Frost is related to conditions of the air reaching a temperature of zero or under zero centigrade implying ra-

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pidly quickly decreasing energies from the area level holding the greatest distribution in winter. After overall familiarity with frost phenomenon, the necessity of evaluating the spatial base of frost should be considered. The spatial base of frost includes roads and communication routes. Frost on road surfaces plays an efficient role in decreasing friction between road surfaces and car types. In some areas this has more amplitude. The most difficulty, when this occurs that drivers are not efficiently aware of driving in such conditions. Of other effectives of the frost there is its effective on surface – making of the roads. Basically for frost to be produced, the surface of the roads should operate with three factors and in case of not holding even one factor the frost phenomenon doesn't occur. These three factors are as follows (Adibi, 1994):

1. Cold air under zero centigrade.
2. The respective fine soil holding a good hair-like property.
3. Underground water resources at a maximum 3 m depth.

Many studies have been universally conducted on road transportation safety and frost phenomenon such as Tackle's researches on frost on bridges and roads from the viewpoints of the reserve-repair staff of the Transportation Organization of the state of Iowa (in the USA). These were evaluated through questionnaires com-pleted by the organizations staff. This information and data showed that the annual average of frost occur-rence on bridges holds a domain of changes from about 12 to 58 items and over the whole state of Iowa, the domain of changes were 7 to 35 (Takle, 1990).

Carson and Mannering researched the effective dangerous marks of frost on affluence and drastic accidents in Washington State. They concluded–using accidental characteristics and road states – that the correct space-finding of dangerous frost in any side of roads can be decreased by connecting incidents with frost (Carson and Mannering, 1999). Thorns obtained a simple way to supervise the status of frost in order to pour salts on roads in terms of correct or incorrect decision – making.He determined the number of nights that the tempe-rature of the road surface was lower than 4℃ using the obtained data from the road meteorological stations, he then calculated the winter diagrams based on statistical – mathematical formulas and methods; using the GIS sys-tem the necessary maps were provided (Thornes, 2002).

Norman evaluated the spatial distribution of frost using a classification method in Sweden' s Southern roads in 2000. The different types of frost and sliding were obtained using the road meteorological station information (Norman, 2000).

Iranian mountain areas experience drastic frost in the cold months of the year this causing difficulties in road transportation such as the increase of road accidents and traffic to become more apparent (Habibi, 2002).

Characteristics of the study route

The Karaj- Chalous road is 150 km long, between two provinces, Tehran (from Karaj to the Kandovan tunnel) and Mazandaran (from the Kandovan tunnel to Chalous), connecting Tehran across the heights of the Alborz mountains to Chalous a popular tourist destination near the Caspian Coast (Figure 1).

The maximum height of the road is 3000 m above msl in the Kandovan tunnel and minimum height is 100 msl, in the Northern low zone near the Caspian coast. The most difficult sections for drivers on the road are before and after the Kandovan tunnel, especially during winter when snow is accompanied by storms and fog. A road meteorology station has been established on the Kandovan tunnel for recording climatic data to study its effect on accidents in the area.

MATERIALS AND METHODS

The following data have been used for studying the spatial and temporal distribution of frost and sliding along the Karaj – Chalous route:

1. Topographical maps 1:250.000 of the studied rout.
2. Diurnal statistics of parameter temperatures, precipitation and relative humidity of Synoptic Meteorological Stations of Karaj, Noshahr and Siahbishe relative to the statistical period 1998 - 20073. Use of climatic conditions matrix and GIS (Johansson, 2002).

Primarily the map of coordinative line bases as well as the studied route were numbered in the Arc View software environment for studying the spatial and temporal distribution of frost and sliding along the Karaj- Chalous route; the statistics and information were then diurnally ordered October 1 through April 30 by collecting the diurnal data and statistics of the considered climatic parameters (relative humidity, temperature and precipitation) during a 10 - year.

The statistical period was respective to the importance of the cold months of the year. Then, for each day, the precipitation, temperature and relative humidity conditions were determined, as well as being reserved in Access software and the climatic conditions matrix was there used for determining the climatic condi-tions of each of the studied days (Tables 1 and 2).

According to Tables 1 and 2, the amplitude of each climatic condition was diurnally and monthly accounted and determined; then the number of days related to each climatic condition was numbered and registered for a 10-year- statistical period (Table 3). After calculating the number of days related to climatic condition their 10-year mean was taken (Table 4).

After calculating the mean, the probability of occurrence for each climatic condition for 7 months of a cold period of a year were calculated (Table 5).

After calculating the probability of occurrence of the climatic conditions, the type and rate of the coefficient among each of the climatic condition with the heights of the stations was determined, being studied in Table 6.

For spatially as well as temporally analyzing of climatic variables

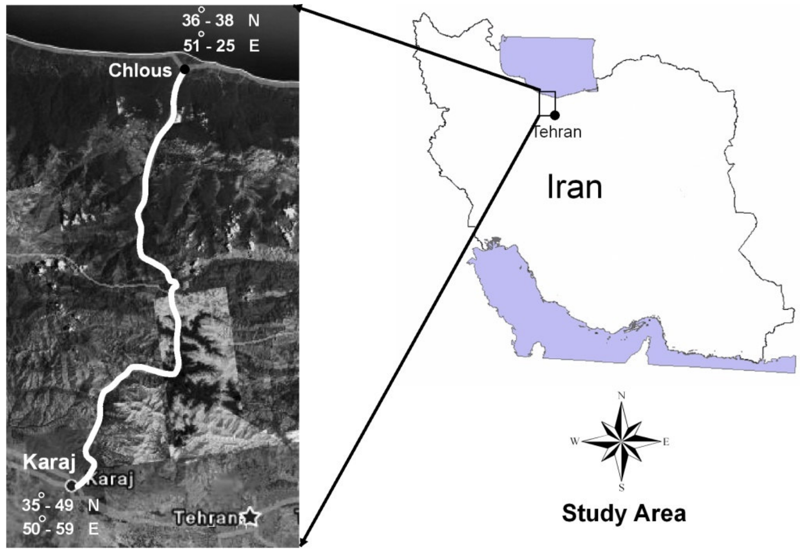

Figure 1. Location of the Karaj – Chalous route (Researcher, 2008).

Table 1. Climatic different condition matrix (Johansson, 2002).

Precipitation and Humidity / Temperature	Non-precipitation and relative humidity lower than 80%	Relative humidity higher than 80% with a 0-1.9 mm	Precipitation more than 2 mm
Temperature more than 2 centigrade	N_1	N_2	N_3
Temperature between 2-6 centigrade	N_4	N_5	N_6
Temperature less than 6 centigrade	N_7	N_8	N_9

= Sliding = Frost = Potential frost (non- humidity in environment)

= Without any phenomena

Table 2. Introduction of each different climatic condition. Norman (2000).

N_1: Diurnal temperature mean higher than 2 centigrade and non-existence of climatic raining and relative humidity lower than 80%.

N_2: Diurnal temperature mean higher than 2 centigrade accompanied by a totally diurnal precipitation 0-1.9 mm with a relative humidity higher than 80%.

N_3: Diurnal temperature mean higher than 2 centigrade accompanied by a diurnal precipitation higher than 2 mm.

N_4: Diurnal temperature mean between 2 to-6 centigrade accompanied by relative humidity lower than 80%.

N_5: Diurnal temperature mean between 2 to-6 centigrade accompanied by relative humidity higher than 80% or lower precipitation than 2 mm.

N_6: Diurnal temperature mean between 2 to-6 centigrade accompanied by precipitation higher than 2 mm.

N_7: Diurnal temperature mean lower than-6 centigrade accompanied by relative humidity lower than 80% (non-precipitation).

N_8: Diurnal temperature mean lower than-6 centigrade accompanied by relative humidity higher than 80% or lower precipitation than 2 mm.

$N9_7$: Diurnal temperature mean lower than-6 centigrade accompanied by higher precipitation than 2 mm;

Table 3. Total annual amplitude of different climatic conditions (N_1 - N_9) during the statistical period (1998 - 2007) (Researcher, 2008).

Station	Latitude	Longitude	Height (m)	N_1	N_2	N_3	N_4	N_5	N_6	N_7	N_8	N_9
Siahbishe	36´.13´´	51´.19´´	2165	521	617	471	1732	1921	1671	398	541	441
Karaj	35´.55´´	50´.54´´	1312	1179	1186	1002	1927	1856	1732	41	72	39
Nowshahr	36´.39´´	51´.30´´	-30	387	1941	1384	498	2087	1702	0	1112	0

Table 4. Annually means of different climatic conditions (N_1-N_2) during the statistical period (1998 - 2007) (Researcher, 2008).

Station	N_1	N_2	N_3	N_4	N_5	N_6	N_7	N_8	N_9
Siahbishe	52	62	47	173	192	167	40	54	44
Karaj	118	119	100	193	186	173	4	7	4
Nowshahr	39	194	138	50	209	170	0	111	0

Table 5. Probability of occurrence of each of the different climatic condition (N_1 - N_9) during statistical period (1998 - 2007) (Researcher, 2008).

Station	Np_1	Np_2	Np_3	Np_4	Np_5	Np_6	Np_7	Np_8	Np_9
Siahbishe	6.2	7.4	5.6	20.8	23.1	20	4.8	6.4	5.2
Karaj	13	13.1	11	21.3	20.5	19.1	0.4	0.7	0.4
Nowshahr	1	21.2	15.1	5.4	23	19	0	12.1	0

Table 6. Results of the relations of each probability occurring for the different climatic conditions with the heights of stations (Researcher, 2008).

Probability of occurrence/ Type of relation	Np_1	Np_2	Np_3	Np_4	Np_5	Np_6	Np_7	Np_8	Np_9
Rate of correlation	54%	1*	98%	91%	9%	85%	84%	61%	83%
Type of correlation	Direct	Reverse	Reverse	Direct	Reverse	Direct	Direct	Reverse	Direct

and determining the critical limitations of frost and sliding, the Arc View software was statistically applied.

For determining the beginning and ending times of frost, August, 22 was also basically collected and the remaining days were orderly numbered as this rate, e.g. if, in this station, the first zero centigrade has occurred in 84 days, the beginning of the frost in respect to the base day, that is August, 22, will be November, 13 accordingly, so if the last lower than zero centigrade has equivalently occurred on day 220, the end time of the frost will be March, 27. After all, in the subsequent step, the above-mentioned information was normally-based distribution processed and the action was taken into their occurrence probability determining a probability level of 75%. The multi-variable – regression model was also applied for studying highly as well as latitudinal climatic variables in the studied route.

RESULT

In this section, the evaluation and study of spatial and temporal distribution of frost and sliding on the Karaj-Chalous route will be made using the geographical information system and climatic condition matrix.

Spatial distribution of frost and sliding

According to the climatic conditions matrix, spatial distribution and the probability of occurrence of frost and sliding along the studied route (Figure 2) it was determined that there is a probability of revealing NP_1 and NP_4 conditions in the mountain-slope parts of the studied route (Karaj station), probability of revealing NP_5, NP_6, NP_7 and NP_9 conditions in the mountains parts of the studied route (Siahbishe station) and probability of revealing NP_2, NP_3 and NP_8 conditions in the plain parts (Nowshahr station) as well. With respect to Table 6 it was

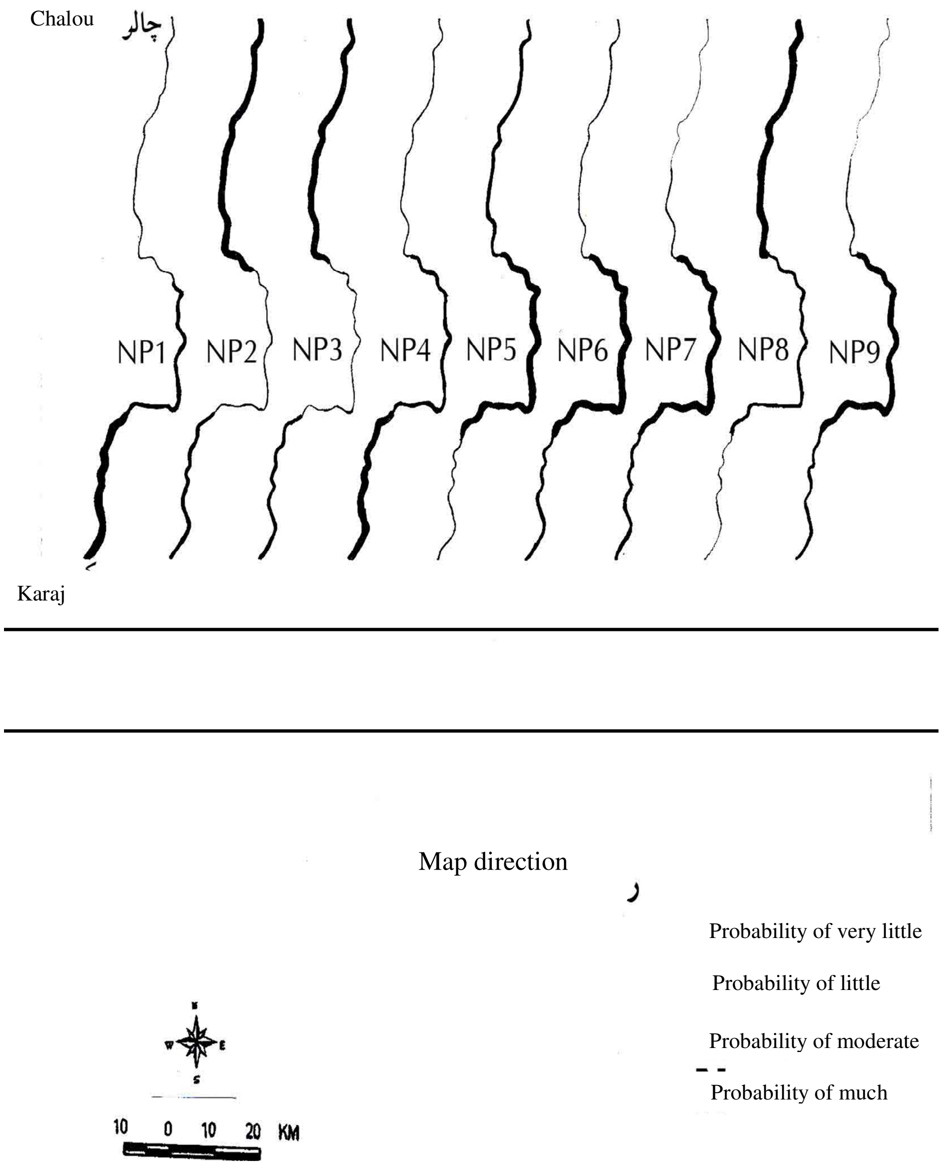

Figure 2. Map of frost and sliding occurrence probability spatial distribution along the Karaj-Chalous route (Researcher, 2008).

determined that the NP_1, NP_4, NP_6, NP_7 and NP_9 conditions have direct relations to height as well as the NP_3, NP_4 and NP_8 conditions having reverse relations to height.

This denotes that during the cold months of the year (October 1 through April 30), there are potential conditions in the mountain areas for forming frost (NP_7) and in the case of having high humidity and weathering precipitations, the frost will occur (NP_9). Of course, on the mountain-slope areas the conditions for potential frost existence are considerable in some of the cold months of the year as well (NP_4) and on the plain areas the frost and sliding conditions can occur (in case of low temperatures) (NP_8).

According to Table 5, the probability of NP_7 and NP_9 occurring is low on the Nowshahr station, while the probability of NP_8 occurring is high in this area, this indicates that, on plain-low height limitation, the probability of relative humidity lower than 80% accompanied by under zero temperature (NP_7) or precipitation more than 2 mm accompanied by under zero temperatures is less; but the weathering dominant conditions on this area, during the cold months of the year include a higher relative humidity than 80% or less precipitation than 2 mm accompanied by an under zero temperature (NP_8).

Whereas, on the mountain areas there is a temporally

Table 7. Between the latitudinal and highly climatic variable in the studied route. Park et al. (2009).

Climatic parameters	Multi variable regression equation	Correlation
Beginning of frost	$y = 272 - (4.248 \times latitude) - (height \times 438\%)$	100%
End of frost	$y = -16.8 + (4.44 \times latitude) + (height \times 294)$	100%

Table 8. Beginning and end time of frost in the Karaj-Chalous route in the probability level of 75% (Researcher, 2008).

Climatic parameter/ station	Frost beginning time	Frost end time
Siahbishe	September, 14	March, 15
Karaj	October, 24	February, 16
Nowshahr	December, 18	January, 12

lower increase of relative humidity or precipitation accompanied by the low temperatures, NP_8 with height, holds the reverse relation.

On the plain area, there are fewer under zero temperatures, accompanied by relative humidity of less than 80%, therefore the NP_7 and NP_9 conditions hold direct relations with height and on mountain zones there will be more as the climatic conditions. As seen in Figure 2, the NP_5 , NP_6 and NP_9 conditions denote the frost and sliding occurrence conditions, the NP_7 condition expresses the potential frost along to the Karaj-Chalous route; approximately 85 km (that is, about 57% of the total route length) from km 43 to 128 of Karaj route (that is, the moderate parts of this route) has been allocated to itself; these climatic condition occurrences are accompanied by geometrical difficulties (such as slopes and drastic curves) cause serious climatic hazards on this part of the route.

Beginning and end of frost time

According to the performed calculations (Table 7) as well as the obtained results from (Table 8), the occurrence time of the first and the last frost phenomenon in the Siahbishe station (the mountain zone) are March 15 and September 14 respectively. The reason for this is high height of the station compared with the surrounding around stations. In the Karaj the mountain-slope zone) the beginning and the last frost are October 24 and February 16 respectively and in the Nowshahr station (the plain zone) the first and the last frost (in the reason of climatic quality of the zone) are December 18 and January 12 respectively. Therefore, it is inferred that, by increasing the height in the communicative route, the frost phenomenon has temporally occurred as soon as possible and ends later.

Conclusion

In this study, by collecting the needed information and data using statistical ways and the climatic conditions matrix and GIS, the spatial identification affected from frost as well as the mentioned risk evaluation on transportation safety and road traffic on the Karaj-Chalous route were taken and the following results were obtained.

According to the spatial distribution of frost and sliding it was determined that; in the mountain- slope parts of the route, the probability of the NP_1 and NP_4 conditions occurring, in the mountain parts, the probability of occurring the NP_5, NP_6, NP_7 and NP_9 conditions occurring and in the plain parts the probability of the NP_2, NP_3 and NP_8 conditions occurring are very high. It was also determined that the NP_1, NP_4, NP_6, NP_7 and NP_9 conditions hold direct relations with height while the NP_3, NP_5 and NP_8 conditions have a reverse relation to height. This indicates that, during the cold months of the year, in the mountain zones (and some mountain-side zones), potential conditions exist for forming frost and in mountain zones in the case of the existence of high humidity and weathering precipitations drastic frost occurs. In the plain zones the frost and sliding conditions can occur in the case of decreasing temperatures. Also, the NP_5, NP_6 and NP_9 conditions denoting the frost occurrence and dangerous sliding as well as the NP_7 condition denotes potential frost along the Karaj-Chalous route, almost 85 km (about 57% of the total route length) from km 43 to 128 of Karaj route (that is, the intermediate parts of the road) have been allocated; the occurrence of these clima-tic conditions are accompanied by geometrical difficulties (such as drastic curves and slopes) causing severe climatic hazards in the intermediate (central) area of the Karaj-Chalous route. According to the performed calculations, the time of occurrence of the first frost in the Siahbishe, Karaj and Nowshahr stations is September

14, October 24 and December 18 respectively as well as the last frost in the Siahbishe, Karaj and Nowshahr which is March 15, February 16 and January 12 respectively. Therefore, it is concluded that, by increasing heights along the route, the frost phenomenon has temporally occurred as soon as possible, as well as having been postponed ended. Of course, it is necessary to mention that, the most dangerous frost for road transportation safety begins later than the observed times, as well as ending sooner.

Also, according to the obtained results of the climatic conditions matrix, the NP_5, NP_6, NP_8 and NP_9 conditions (being accounted as dangerous frost conditions for transportation) have been concentrated in January, February and December respectively.

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