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THE MODEL OF DUST AEROSOL ACCUMULATION IN TAJIKISTAN

ABSTRACT. The thickest loess formations, more than 100 m, are located in China and Tajikistan. Climatic and geographical factors became the basis for development of the atmospheric aerosol accumulation model in Tajikistan. Dust originated from huge deserts of the Central Asia is transported by western winds to valleys of Tajikistan where it drops out forming loess sediments. According to calculations the average thickness of dust sediments is 0,2 mm/year. This value agrees to the records obtained from loess section of the Early Holocene. Comparison of the modelling results and the real data from loess sections proves good correlation between these two independent approaches. It is one of the arguments supporting the concept of loess formation due to atmospheric aerosol.

KEY WORDS: loess; aerosol; climate; convection level; Pamir.

INTRODUCTION

Arid zones of the globe produce the enormous quantity of dust particles, which then are involved in various processes of transformation, transportation and sedimentation. Climate change affects the amount and content of dust in the atmosphere.

Loess sediments contain a lot of geologic information charactering paleoclimate fluctuations [Dodonov et al., 1999]. The thickest loess formations of the Central Asia are situated in the South Tajikistan. The reasons for such depositions are climate factors, geographical position of this areas and neighbouring districts, location of mountain ranges. Modelling of loess sedimentation and accumulation is important for understanding and confirmation of the hypothesis about loess formation from precipitated atmospheric aerosol. The main objective of the study was to compare rate of sedimented dust layer formation with loess formation rate, in order to confirm the mentioned hypothesis. Climatic data for the last century only were used for modelling. The results of this survey were represented on the conferences [Lomov & Finaev, 1994; Finaev, 1995], and the concept of modelling was described for the fist time in the journal "Archaeology and Paleoecology of Eurasia" [Finaev A.F. 2004].

REASONING AND CONCEPT OF THE MODELLING

The specific features of dust aerosol transportation and sedimentation are provided by the combination of physical, geographical and climatic conditions. The main part of air streams in this region move from the west and southwest to the east and northeast according to the laws of global atmospheric circulation. The highest mountain ranges of Pamir-Alay in the north and east, and Hindu Kush in the south, organised into a certain "curtain" system, outline the orographic niche opened for penetration of air masses from the west and southwest. Mountain ridges of 5000–6000 m a.s.l. form a barrier preventing air streams from penetration any further. Thus, the air of the lower troposphere is stagnated in closed valleys. That is the reason for dust storms formation in the deserts located westwards from Tajikistan. Such storms transport dusty air into the mountain areas of Pamir-Alay (Fig. 1). Little by little, aerosol precipitates onto

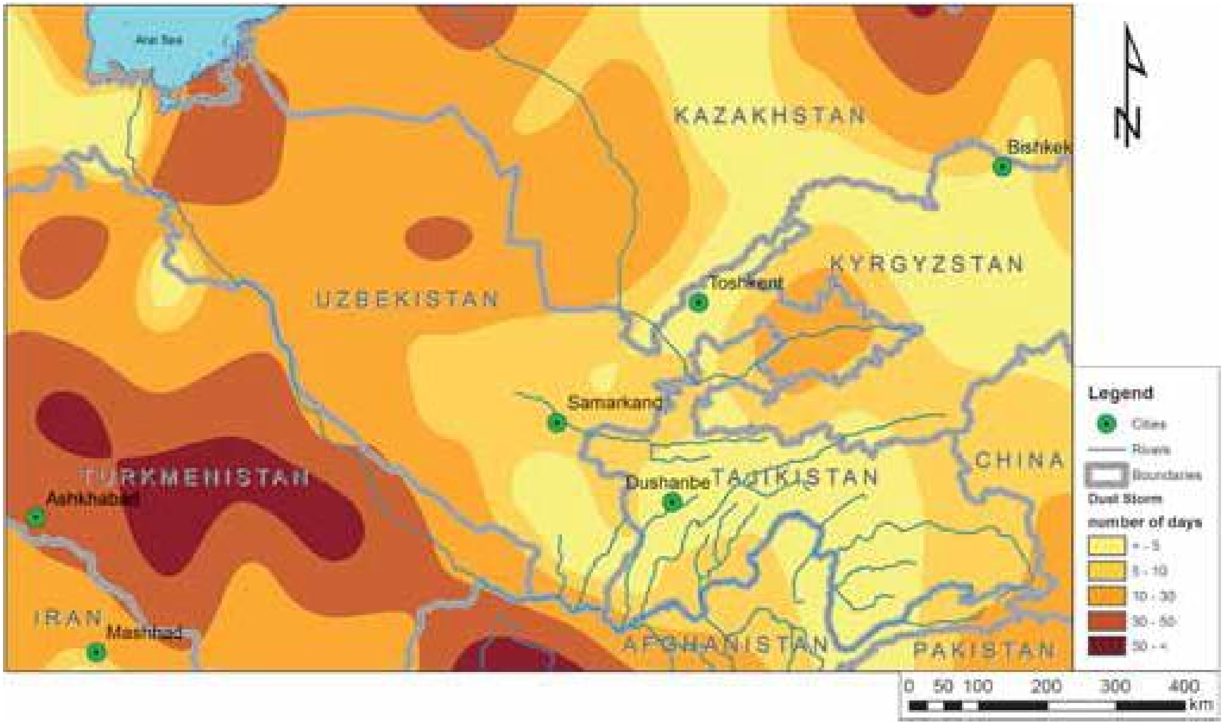

Fig. 1. The duration of dust storms in the Central Asia.

the underlying surface, while meteorological stations make records of dust haze during such episodes.

The favourable conditions for dust storms formation occur in deserts of the Central Asia during summer and autumn seasons. At this period lack of precipitation, in combination with soil overdrying, cause deflation even if the wind is faint. The dust rises up and still hangs in the air after the episode is over; later it is transported to the long distance by air streams. It is clearly seen on satellite images how the dusty air is filling mountain valleys (Fig. 2). The coarse particles, raised up into the air, drop out quickly back to ground near to aerosol generation sources, while the fine ones remain suspended in the air for some time, producing the haze. Visibility then changes from 4–10 km up to 2–4 km. The vertical extent of the haze may reach 3–4 km, and depends on intensity of convective air streams. The concentration of dust particles in the air reaches 8,4 per cm3 and more [Ivanov & Finaev, 1987].

The number of days with haze increases southwards. There are up to 10 hazy days annually observed in the Northern Tajikistan, 20–27 days/year – in the Hissar valley, and 40–70 days at the far south. Haze penetrates to the east along the river valleys (up to 26 days with haze are annually recorded in Gharm). In the Pamir mountains haze is observed rarely (only 3–6 days/year) [Climate of the USSR, Handbook, 1970]. The maximum number of hazy days is recorded in July–October, and the minimum is observer during the winter season.

The duration of haze episodes increases southwards as well. The average haze duration does not exceed 40 hr/yr in the north, increases up to 200–400 hr/yr in the Hissar valley and up to 500–600 hr/yr in the far south. The average annual haze duration in Pamir varies from 4–8 up to 30–40 hr/yr. As for the Fedchenko glacier, haze is an extremely rare event in this area. It is observed once per 25 years with average duration of 0,4 hr/yr. The annual distribution of haze duration is similar to the number of hazy days (Fig. 3) [Climate of the USSR, Handbook, 1970].

The maximum of haze in July (Shaartuz) and in August (Dushanbe) is connected to strengthening of storms and convection over the dry soil during the most intensive sun heating and the summer thermal

Fig. 2. Penetration of dust into mountain valleys of the southwest Tajikistan. Satellite image, 10/09/2011.

depression. The maximum of haze in October is related to the beginning of cyclonic activity above the dry surface. On the Fedchenko glacier the maximum of haze is observer in June. At this period the level of convection is the biggest and the dusty air is transported to high mountains. In winter season the ground is getting moist and the level of convection reduces. Thus, in spite of the wind during cyclonic activity, the amount of haze episodes and their duration get down too.

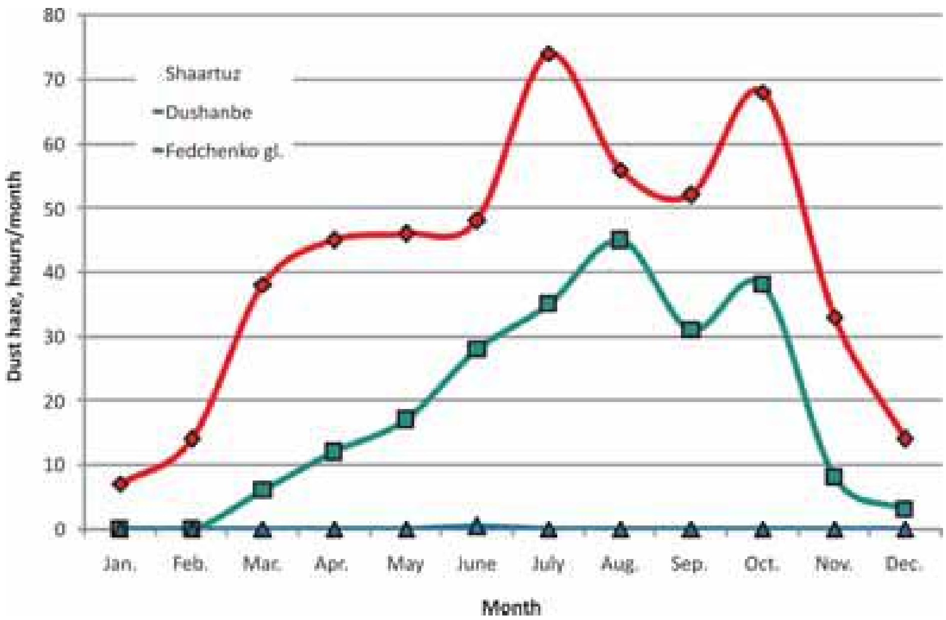

Fig. 3. The duration of dust haze.

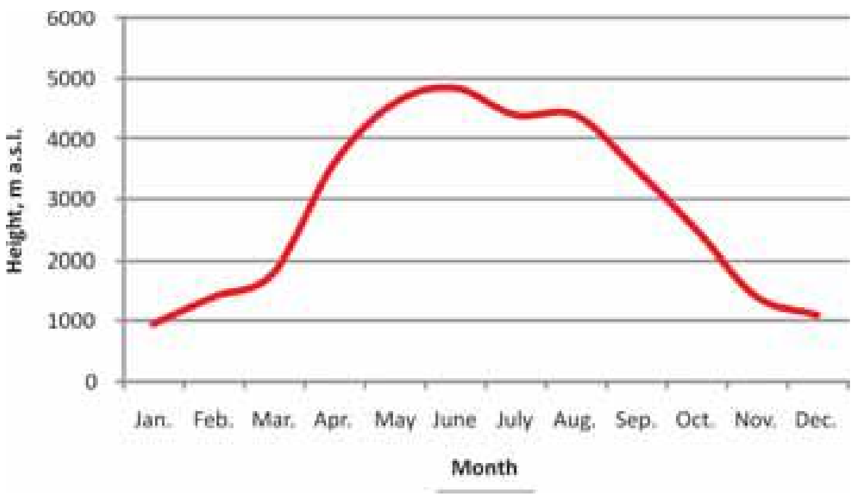

Fig. 4. The top level of convection.

Study of aerosol [Finaev, 1987b; Soviet-American experiment for the arid aerosol research, 1992] and dust sediments of the glaciers [Anokhin, 1978] has shown that aerosol is distributed in the troposphere as high as the convection level. Aerosol mostly consists of particles less then 25 µm. Such particles are observed at all levels of convection and on glaciers situated at the same altitude.

The average monthly level of convection was determined during further investigations [Finaev, 1987a; 1994]. The maximum level was recorded in June (Fig. 4), when warming of the ground and convective streams are the greatest. These data were used to create the average annual aerosol distribution map (Fig. 5).

The analysis of available data has revealed the basic processes occurring in this region during

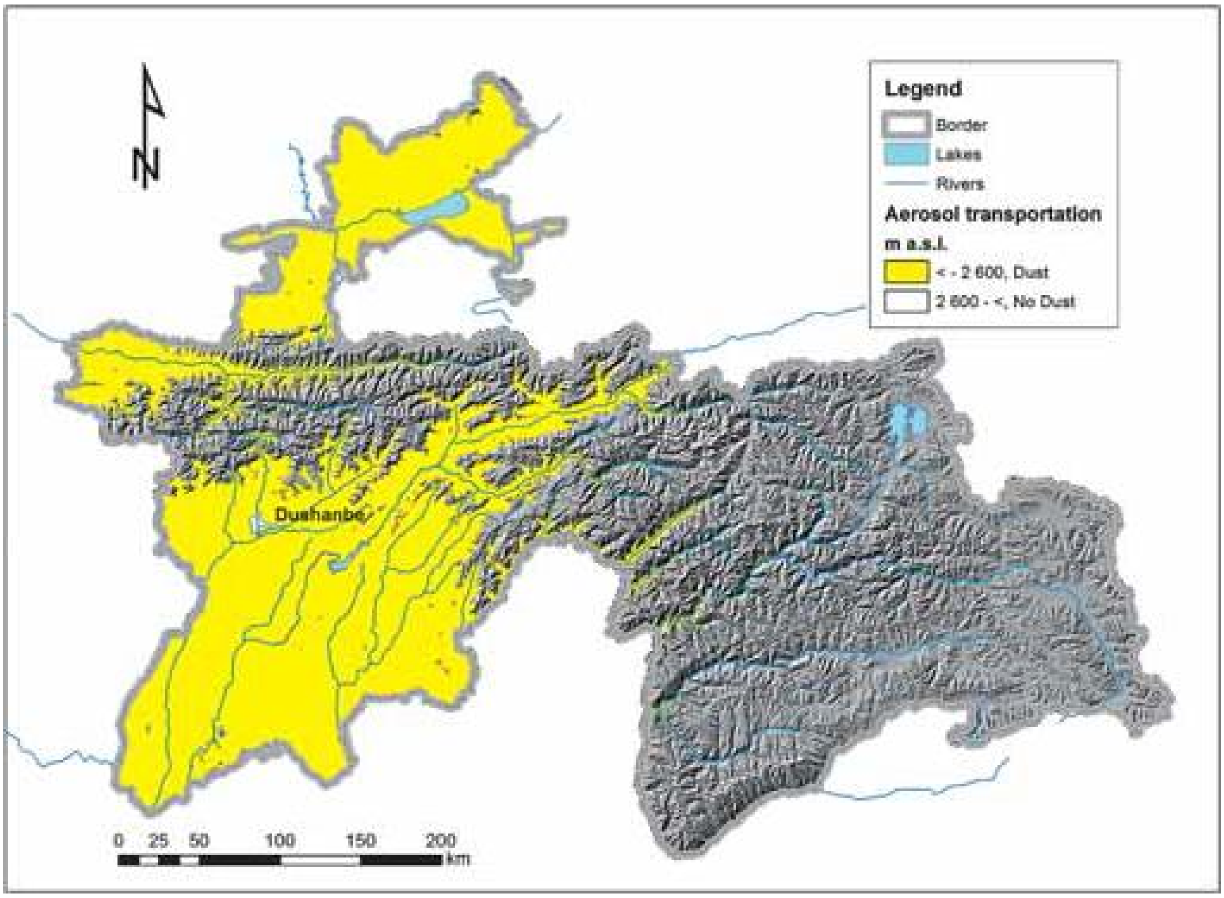

Fig. 5. The average annual aerosol distribution.

aerosol transportation and sedimentation, as well as their mutual links. It helped to develop a model of loess accumulation.

Thus, the modelling logic is rather simple. It is necessary to estimate the amount of precipitated aerosol from a separate vertical air column. The air column height is equal to the distance between the ground and the top border of the convective level. The time interval of aerosol precipitation depends on the size of particles. Influence of wind vertical vector is not taken into account. The duration of the whole process is limited by time of haze observation at meteorological stations.

During the storm aerosol from Central Asian deserts is distributed almost evenly in the troposphere up to the top level of convection (horizontal and vertical speeds in convective currents may reach tens of meters per second). The air mass containing aerosol arrives to Tajikistan and fills closed valleys below the convection level. When dusty air moves on over a colder surface and meets a mountain barrier, the vertical convective speed gets weaker; it causes air stagnation and aerosol starts to drop out. The upper part of such cleared air overflows mountain ridges being replaced later by new portions of dusty air. Aerosol continues to arrive during the entire period of dust episode. This process can explain the duration of haze.

THE CALCULATION TECHNIQUE

The above described concept helps to understand how aerosol is transported and precipitated (Fig. 6).

Using the diagram of accumulation represented above, it is possible to make an algorithm for calculation of precipitated aerosol amount (Fig. 7).

The weight of aerosol in the air volume unit is calculated as follows:

$$m = 4/3 P_i P_a \int_{r_1}^{r_v} r^3 N(r) dr,$$

where *m* – is the weight (or mass) of aerosol per air volume unit, P_i = 3,14..., *Pa* – is aerosol

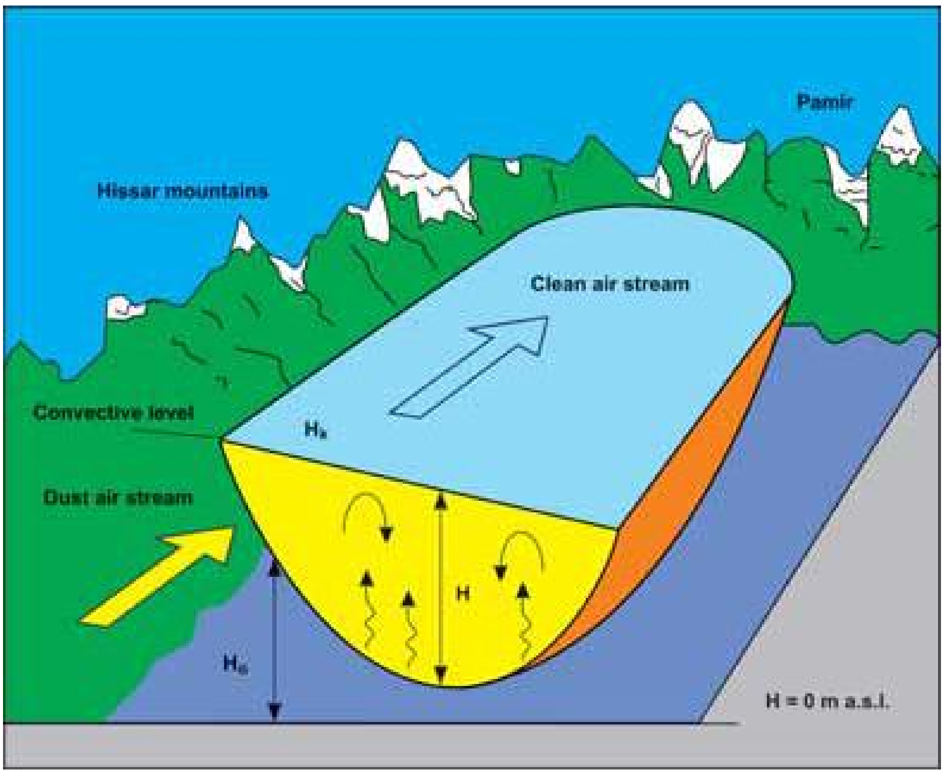

Fig. 6. The diagram of the dust aerosol accumulation.

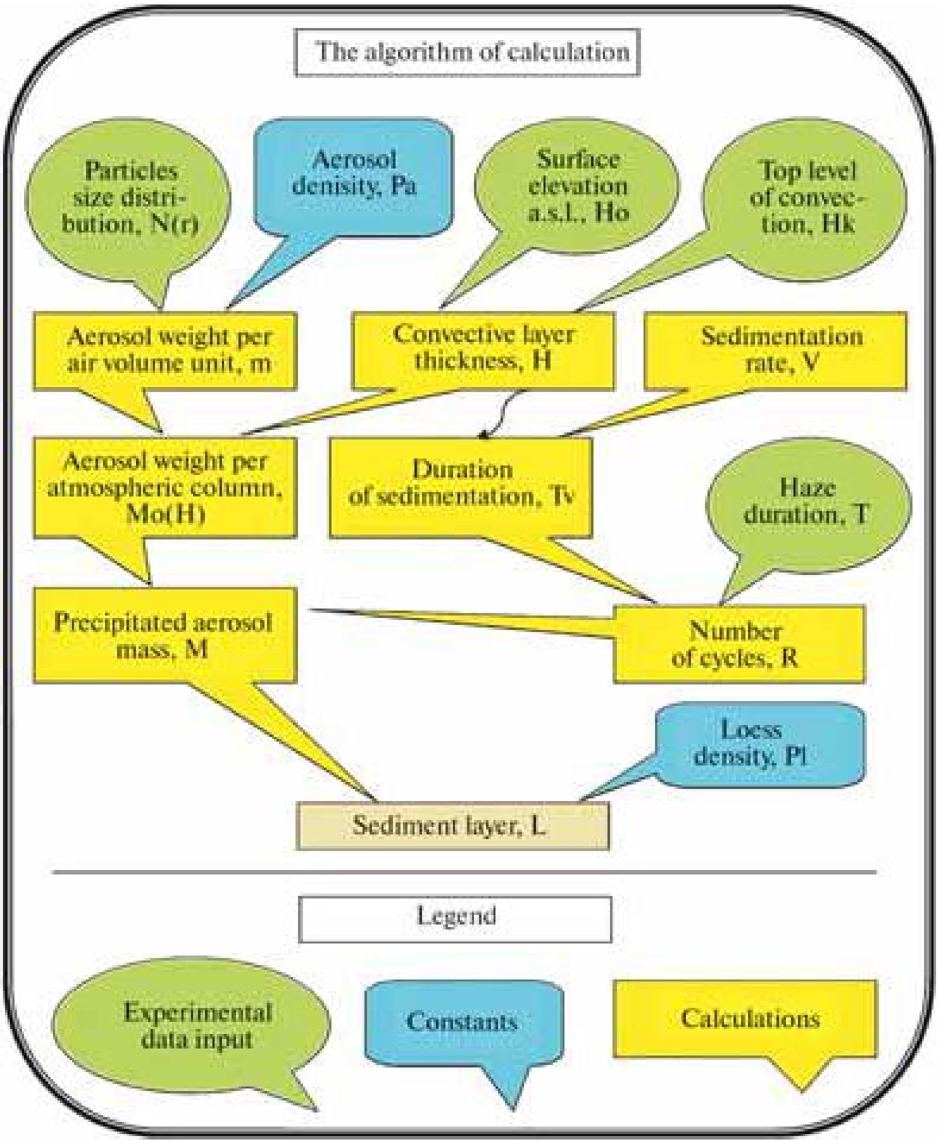

Fig. 7. Model for calculation of precipitated aerosol.

density, *r* – is the particle radius, *N*(*r*) – is the number of particles with *r*.

The total aerosol weight in the dust-loaded atmospheric column is:

$Mo = m \cdot H$,

where *H* – is the thickness of the convective layer. This value expresses the difference between the top level of convection (*Hk*) and the surface elevation above the sea level (*Ho*):

$H = Hk - Ho$.

Sedimentation time (*Tv*) is calculated as:

$Tv = H/V$,

where *V* – is the free fall speed for an aerosol particle with *r* radius. It can be found from the Stokes formula:

$V = 2/9\ r2g(Pa - Pw)/w$

where $g = 978{,}049(1 + 0{,}0052834\sin^2(F) - 0.000006\sin^2(2F))$ – is acceleration of the gravity at the latitude *F*, $w(20°C) = 18{,}1 \times 10^{-5}$ *Poise* (g/cm s) – is the air viscosity at the temperature of 20°C, *Pa* – is the aerosol particle density (taken for quartz = 2,65 g/cm^3). *Pw* – is the density of air ($Pw = 0{,}0012928$ g/cm^3).

It should be noted that meteorological stations record the duration of haze for the whole period of dust air existence, but it is not the time of aerosol precipitation from the air column. Time of precipitation is actually one completed cycle and it may be shorter than the total time. Therefore, the whole period of haze duration is used to characterise the number of dust columns with precipitated aerosol. This parameter may be called as the "number of cycles" (R):

$$R = T / Tv,$$

where T – is the duration of haze over some period (month, year). Thus, the weight of precipitated aerosol (M) per area unit will be:

$$M = mHR.$$

It is easy then to calculate the thickness of the newly formed loess layer (L):

$$L = M/Pl$$

where Pl – is the density of loess (1,35 g/cm^3).

In such calculations the important thing is to estimate the top level of convection where aerosol is spread (see Fig. 4).

Data set used for the model:

$N(r)$ – function of particles distribution by size, which was determined for the Central Asia region [Ivanov & Finaev, 1987; The Soviet-American experiment for the arid aerosol study 1992];

Ho – surface elevation above the sea level;

Hk – the top level of convection, which depends on season and is determined according to the model [Finaev, 1994];

T – the duration of haze [Climate of the USSR, Handbook, 1970].

RESULTS

The actual data on dust haze periodicity and duration [Climate of the USSR. Handbook, 1970] combined with elevation above the sea level were taken to calculate aerosol precipitation rate in Tajikistan. The above described technique was used for this purpose. The top level of convection was calculated for each month. It varied from 950 m a.s.l. in January up to 4850 m in June. The calculation of sediments thickness was also made for each month at every particular station recording haze episodes. The altitude of meteorological stations above the sea level (Ho) and the average annual thickness of dust sediments (L) are represented in the Table 1. From the table it is obvious that sediments thickness changes depending on elevation and dislocation of the station (i.e. the distance from the dust storm occurrence). The sediment thickness range varies from 0,04 mm/yr to 0,683 mm/yr. The averaged accumulation rate over the whole territory is 0,2 mm/yr. Almost the same information was obtained in loess sections of the Early Holocene for Tajikistan (0,17–0,26 mm/yr) [Lomov, 1991].

The results of loess sections study in Tajikistan [Shackleton et al. 1995] has proved that loess accumulation rate in the Karamaidan section varies from 0,05 to 0,22 mm/yr. The calculation for the Faizabad station, located near to the Karamaidan section, has shown 0,22 mm/yr. The rates of accumulation on the Kangurt, Kulyab and Khovaling stations were 0,207, 0,338 and 0,273 mm/yr accordingly (Table 1). The accumulation rate on the Darai-Kalon loess section, situated in the same area, is 0,11–0,31 mm/yr, and depends on the type of loess horizon [Dodonov et al., 1999]. For the first and the second pedocomplexes loess accumulation rate was 0,31 mm/yr, and the average rate per 0,8 million years was 0,25 mm/yr. The average dust accumulation rate calculated for three stations of this area was 0,27 mm/yr.

The represented model allows estimating accumulation rate distribution according to elevation of the terrain (Fig. 8). The simulation results are given in the Tab. 1, however stations of the Northern Tajikistan were excluded as they did not agree the relief requirements. The dispersion of points on the scheme can be approximated by the polynomial of the

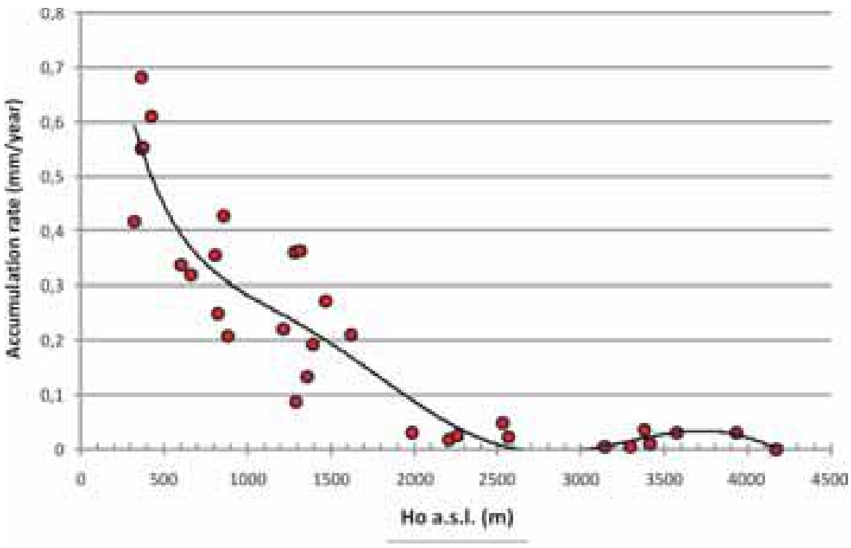

Fig. 8. The rate of aerosol accumulation.

sixth order with coefficient of correlation R^2 = 0,86. The polynomial curve proves that dust accumulation occurs lower then 2600 m. The accumulation rate varies from 0,3 to 0,2 mm/yr at the elevation of 900–1600 m. It agrees to experimental data obtained on the Karmaidan and Darai-Kalon loess sections located in the range of the same altitudes. The increase of accumulation rate at the heights of 3000–4200 m demonstrates aerosol precipitation in the East Pamir, which is transported here from the Taklamakan desert (Western China).

Table 1. The average annual dust sediment thickness, L (mm/year).

Station	Ho a.s.l., m	L, mm/yr.	Station	Ho a.s.l., m	L, mm/yr.
Aivaj	318	0.416	Kurgan-Tube	426	0.611
Anzob pass	3373	0.034	Fedchenko glacier	4169	0.0004
Gharm	1316	0.362	Leninabad	410	0.041
Ghushary	1359	0.133	Madrushkent	2254	0.024
Danghara	660	0.318	Murgab	3576	0.030
Dekhauz	2564	0.022	Obi-Gharm	1387	0.193
Dzhaushanghoz	3410	0.009	Parkhar	369	0.554
Dushanbe, agro	803	0.356	Pendzhikent	1015	0.036
Dushanbe, city	822	0.248	Pyanj	362	0.683
Iol	1283	0.361	Rushan	1981	0.029
Irkht	3290	0.005	Sangiston	1522	0.014
Iskanderkul	2204	0.018	Tavildara	1616	0.210
Isfara	841	0.017	Ura-Tube	1004	0.044
Ishkashim	2524	0.047	Faizabad	1215	0.221
Kalaykhumb	1284	0.086	Khovaling	1468	0.273
Kanghurt	879	0.207	Shaartuz	363	0.550
Karakul	3930	0.030	Shakhrinau	852	0.428
Kulyab	604	0.338	Shakhristan pass	3143	0.004

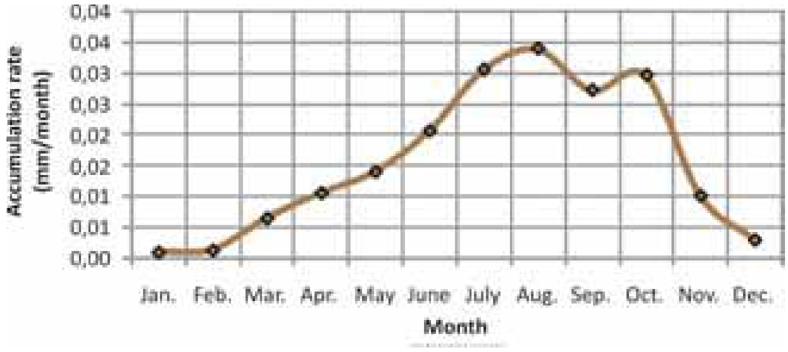

Fig. 9. The average monthly accumulation rate for all stations.

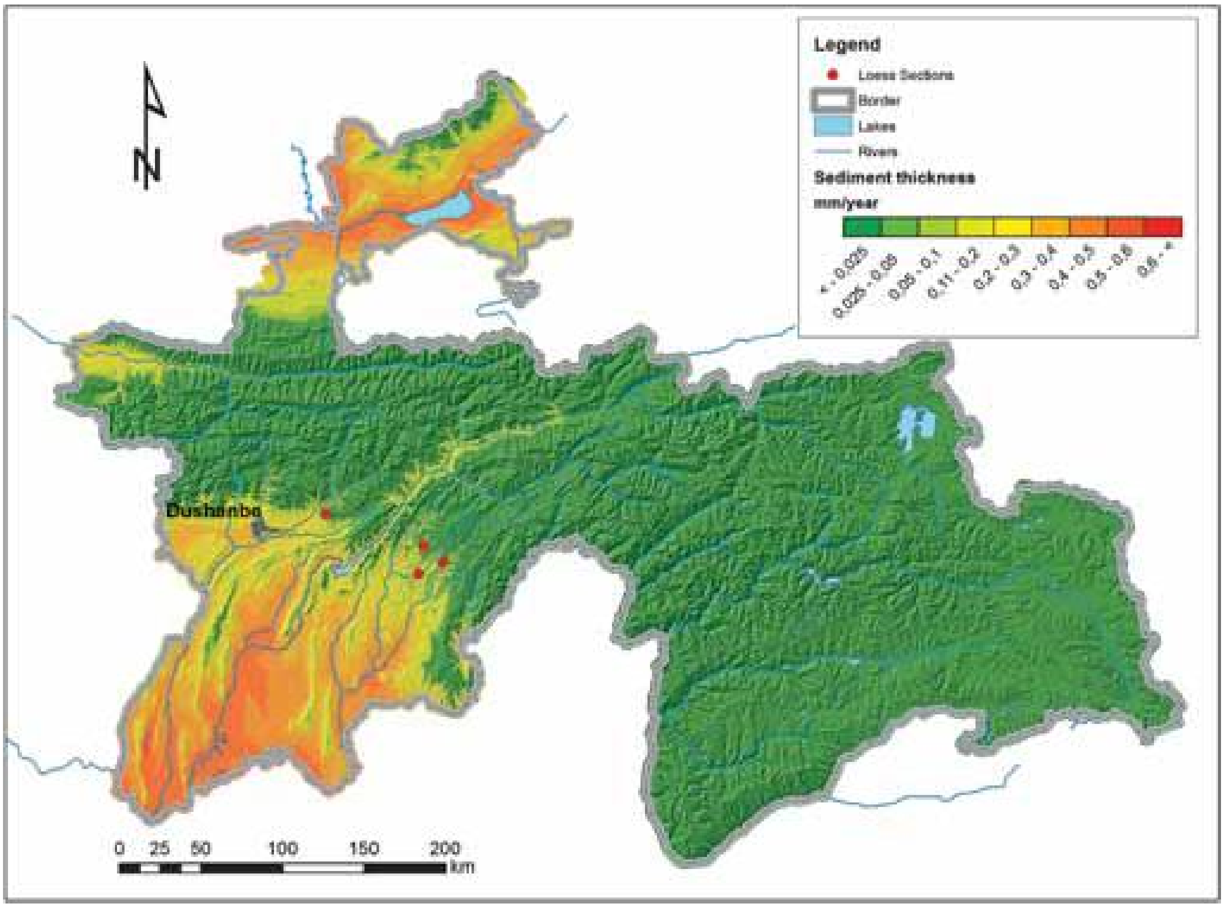

Fig. 10. Distribution of dust sediments thickness.

The rate of dust particles accumulation is not constant throughout a year period. The maximum of precipitated dust is accumulated during the dry summer season (Fig. 9).

Based on these results it is easy then to make a map of the mean annual thickness of dust sediments (Fig. 10). The thickest sediments are in the southwest of the territory. Comparison of the simulation (Fig. 10) and the real map (Fig. 11) proves good correlation, though there are differences still. They are related to erosive processes occurring during the geological period of loess formation. Dust sediments are washed away from steep hillsides by atmospheric precipitation, while erosion of loess sediments is caused by rivers. The agriculture development also has a significant impact on loess destruction. Therefore, the entire loess sediments of a great thickness can be found only in the foothills not affected by anthropogenic influence.

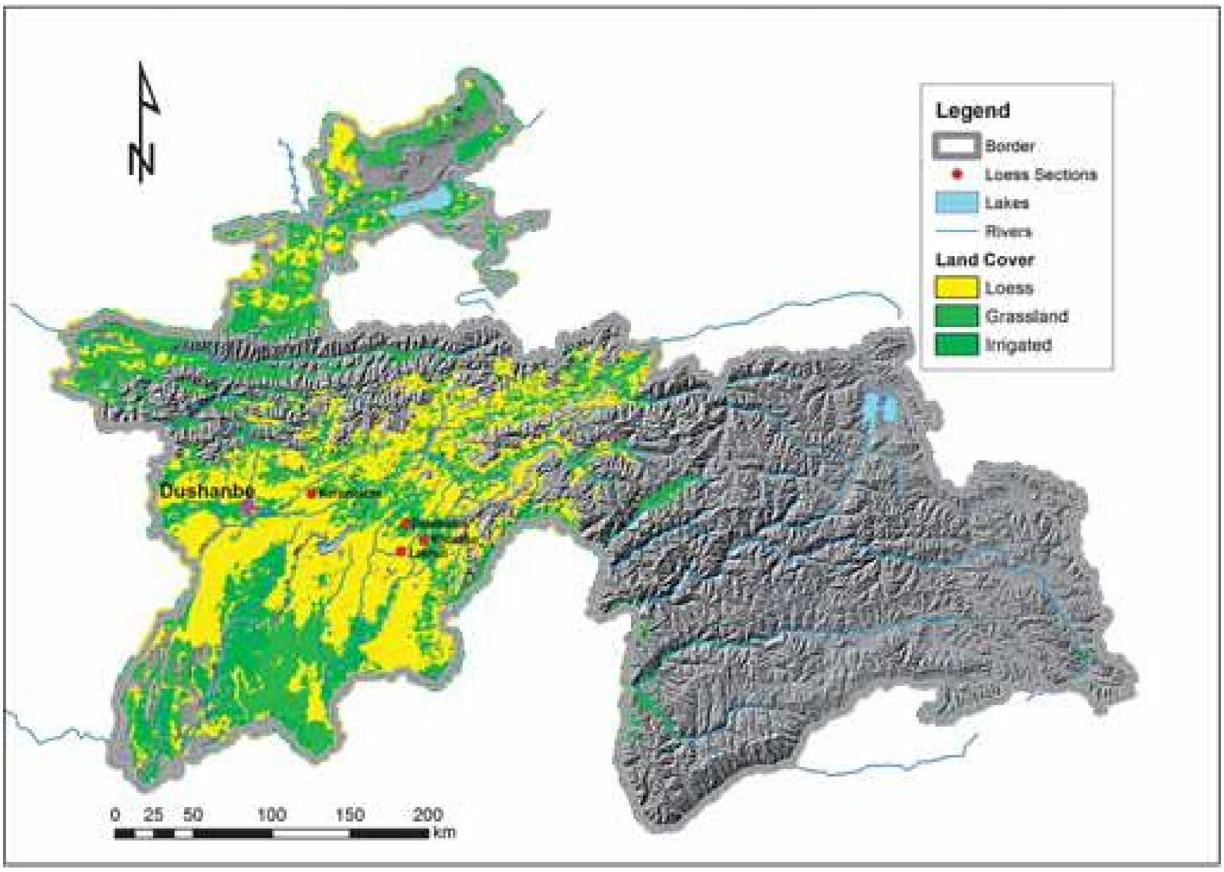

Fig. 11. The actual distribution of loess.

CONCLUSION

The deflation processes in deserts of the Central Asia and dust accumulation in mountain of the Tien-Shan and the Pamir-Alay are related to physical, geographical and climatic features.

The analysis of such factors helped to make the 3-D simulation of sediments thickness in the area of loess formation. The results of calculation demonstrate that the thickest sediments are typical for the southern areas and reach 0,5–0,6 mm/yr. The average thickness of accumulated dust throughout the whole Tajikistan is 0,2 mm/yr. This parameter agrees to data obtained from loess sections of the Early Holocene. ■

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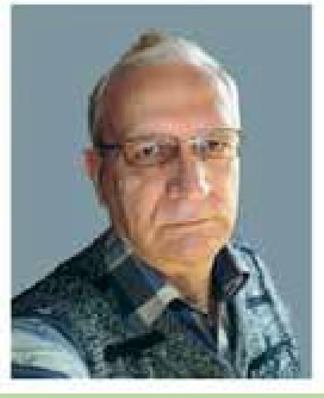

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