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The distribution of organochlorine pesticides in surface soils from Mongolia

Organochlorine pesticides (OCPs) were measured in (59) soil samples in urban and background and rural areas throughout Mongolia to fill up the gap in data on OCPs in soil in Central Asia. The median of γ-HCH + γ-HCHs, p,p`-DDT + p,p`-DDE + p,p`-DDD and HCB comes to 0.02, 0.16 and 0.02 ng/g dry weight (DW) respectively. OCPs levels in soils from rural and background regions of Mongolia are comparable or lower than those obtained in soil of remote and mountain areas of the world. The distribution of HCHs and DDTs indicates a predominance of γ-HCH entrance in the greater part of the soil sampled throughout Mongolia and confirm limited DDT application in the country at presence or in past. The influence of some factors including land use, soil organic carbon, natural zones and latitude on OCP distribution in surface soils in Mongolia was found. It is associated with the extensive development of agriculture and stockbreeding and therefore more extensive usage of OCP before ban in central and northern parts of Mongolia. The highest mean of OCP level in soil of the mountain taiga zone differs significantly from those in forest-steppe, steppe, and Govi (the Gobi) zones.

Key words: surface soil; organochlorine pesticides; Mongolia.

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Монғолияның жер беті топырағында хлорорганикалық пестицидтердің таралуы

Орталық Азия топырақтарында хлорорганикалық пестицидтер (ХОП) мөлшері бойынша мәліметтер қорындағы қуыстарды толтыру үшін бүкіл Монғолияда қалалық, фондық және ауыл шаруашылық аймақтарының 59 топырақ үлгілерінен ХОП анықталды. γ-ГХЦГ + γ-ГХЦГ, p,p`-ДДТ + p,p`-ДДЭ + p,p`-ДДД және ГХБ үшін медианалар құрғақ салмаққа есептегенде, сәйкесінше, 0.02, 0.16 және 0.02 нг/г құрайды. Монғолияның фондық және ауыл шаруашылық аймақтарының топырақ үлгілеріндегі ХОП мөлшері дүние жүзінің алыс және таулы аймақтарының топырақтарындағы ХОП мөлшерімен салыстырмалы немесе төмен болып келеді. ГХЦГ және ДДТ таралуы бүкіл Монғолиядан жиналған топырақ үлгілерінің көп мөлшеріне негізінен γ-ГХЦГ түсетінін білдіреді де, қазіргі кезде және өткен уақытта мемлекетте ДДТ қолданылуы шектеулі екенін дәлелдейді. Монғолияның жер беті топырағында ХОП таралуына кейбір факторлардың әсері анықталды, соның ішінде - жерді қолдану, топырақтың органикалық көміртегі, табиғат зоналары және кеңдік. Бұл ауыл және мал шаруашылығының дамуымен, сондай-ақ Монғолияның орталық және солтүстік бөліктерінде тыйым салуына дейін ХОП кеңінен қолданылуына байланысты. Таулы тайга зонасының топырағындағы ХОП мөлшерінің орташа мәндері Гоби табиғи зонасының және орманды-дала мен дала зоналарының топырағындағы анықталған мөлшерінен сенімді түрде ерекшеленеді.

Түйін сөздер: жер беті топырағы; хлорорганикалық пестицидтер; Монғолия.

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Распределение хлорорганических пестицидов в поверхностных почвах Монголии

Хлорорганические пестициды (ХОП) были определены в 59 пробах почв городских и фоновых и сельских районов по всей Монголии, чтобы заполнить пробелы в наборе данных содержания ХОП в почвах Центральной Азии. Медианы γ-ГХЦГ + γ-ГХЦГ, p,p`-ДДТ + p,p`-ДДЭ + p,p`-ДДД и ГХБ составляют 0.02, 0.16 и 0.02 нг/г сухого веса, соответственно. Концентрации ХОП в почвах из сельских и фоновых районов Монголии сравнимы или ниже найденных в почвах удаленных и горных районов мира. Распределение ГХЦГ и ДДТ указывает на преимущественное поступление γ-ГХЦГ в большинстве почв, отобранных по всей Монголии, и подтверждает ограниченное применение ДДТ в стране в настоящее время и в прошлом. Найдено влияние некоторых факторов, включая использование земель, органический углерод почв, природные зоны и широту, на распределение ХОП в поверхностных почвах Монголии. Это связано с развитием сельского хозяйства и животноводства и поэтому более широким использованием ХОП до запрета в центральных и северных частях Монголии. Наибольшие средние величины ХОП в почвах горной таежной зоны достоверно отличаются от величин, найденных в лесостепной и степной природных зонах и природной зоне Гоби.

Ключевые слова: поверхностные почвы; хлорорганические пестициды; Монголия.

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THE DISTRIBUTION OF ORGANOCHLORINE PESTICIDES IN SURFACE SOILS FROM MONGOLIA

Introduction

Organochlorine pesticides (OCPs) including dichlorodiphenyltrichloroethane (DDT), α-, β- and γ-isomers of hexachlorocyclohexanes (HCHs) and hexachlorobenzene (HCB) are dangerous compounds included in the list of persistent organic pollutants (POPs) under the Stockholm Convention [1]. Measures protecting human health and the environment form the negative effects of these compounds are being taken at national, regional and international levels. The Stockholm Convention on POPs was adopted at the Conference of Parties and opened for signing on 22 May 2001. More then 150 countries including Mongolia have signed and ratified the convention [2].

Mongolia is located in the central part of Asia between 41° and 52° of latitude and 87° and 120° of longitude neighboring with Russia and China. Mongolia is a country with an economy in transition. Pasturing livestock husbandry still plays an important role in its economy. About 73.9 percent of the 1564 thousands km^2 of the territory of the country is agricultural land [3]. The livestock husbandry industry produces foodstuff and goods for home consumption and for export [3].

Pesticides were used in Mongolia since the 1950s for veterinary and plant protection. The herder households used different kinds of pesticides to control parasites of livestock, treatment of fences and shelters and to control grasshoppers in pastures [2]. They called all pesticides used «DUST». The inventory of pesticide application in Mongolia indicates the wide use of technical HCH [2;4]. About 1985 tons of HCHs were used over the years 1958-2003 in 19 aimags (provinces) of the 21 aimags of Mongolia [2]. Hexachlorobenzene (HCB) is another organochlorine pesticide from the Stockholm Convention list used in Mongolian agriculture in past. About 5983

liters of HCB was used in 9 aimags over the years 1970-2003 [2]. OCPs have never been produced deliberately in Mongolia [2]. Mongolia imported all pesticides from the former Soviet Union until 1990 and from the Russian Federation, Germany, China and the Republic of Korea since. Ministerial Decree No. 75 of 14 May 1997 banned the use of aldrin, dieldrin, chlordane, DDT, endrin, hexachlorobenzene, heptachlor and toxaphene. HCH is excluded from the list of chemicals used for plant protection and its usage is also prohibited in Mongolia at present [2]. However, some small quantity of HCH was used in some aimags up to the early 2000s [2].

The organochlorine compounds were investigated previously in environmental media from Northern Mongolia including soil on the shore of the Lake Hovsgol [5;6]. The sum of DDT and its metabolites and sum of α- and γ-HCHs in soil comes to 10 and 0.49 ng/g DW respectively. *pp*'-DDT part comes to 65% of the sum of DDT and it metabolites in soil. *pp'*-DDT/*pp'*-DDE ration comes to 3.07 in soil from Khankh. The value in soil can indicate on resent entrance of the pesticide to environment of the region. α-/γ-HCH ratio comes to 3.33 that indicate on the using of technical mixture HCH in the region. The investigations of OCP levels in environmental media from Northern Mongolia indicate atmospheric transport of the compounds and the presence of local sources [5;6]. The investigation of DDTs and HCHs in soil and dust of parks in Ulaanbaatar, the capital of Mongolia, indicated on atmospheric deposition of DDT in park soil too [7]. HCHs in park soil of Ulaanbaatar come from the using both technical HCH and lindane in the region [7].

The aim of the study is to present the peculiarities of the spatial distribution of HCHs, DDTs and HCB, investigate some factors influencing it in Mongolian surface soil to fill up the gap in data set of OCPs in soil in Central Asia.

Experimental

2.1. Soil samples

59 surface soil samples were collected during three expeditions in Mongolia over the years 2010-2011 (Figure 1). The complete description and position data of sampling sites are presented in paper [8] devoted to PCB study in surface soil of Mongolia.

2.2. OCPs analysis

The drying and sieving of soil samples was performed in a laboratory of the Institute of Chemistry and Chemical Technology, Mongolian Academy of Sciences. Subsequent stages of chemical analyses of soil samples were performed in the Institute of Geochemistry of SB RAS in Irkutsk [9]. The soil samples were analyzed for *p,p`*-DDT, *p,p`*-DDD, *p,p`*-DDE, α- and γ-HCH and HCB.

The soil samples were dried at room temperature to constant weight. Then soil samples were sieved through a 2 mm mesh. The fraction <2 mm was taken for analysis.

The soil samples were extracted in a Soxhlet extractor for 10 hours with n-hexane:acetone (1:1). Surrogate standards (35.7 ng PCB 14 and 15.2 ng PCB 65) were added to the soil samples before extraction. The samples were cleaned using two liquid chromatography columns: a gel permeation chromatography column filled with bio-bead S-X3 and a chromatographic column containing silica gel (3 g), aluminum oxide (3 g), and anhydrous Na_2SO_4 (3 g). Al2O3 and SiO_2 were activated for 9 hours at 900ºC and 450ºC, respectively. The fraction containing the OCPs was evaporated to 30 μl under purified nitrogen [9].

The GC/ECD analyses were performed on a HP 5890A Series II gas chromatograph using a DB-5 capillary column (J&W Scientific, 0.25 μm film thickness, 0.25 mm inner diameter, 60 m long). The carrier gas was He and the make-up gas was N_2. The temperatures of the detector and the injector were 320°C and 270°C, respectively. The temperature program was: start at 90°C (2 min hold), increasing to 170°C at 22°C/min and then increasing to 280°C at a rate 1.32°C/min (17 min hold) [9].

All solvents used were distilled and were checked for interference prior to use. Pesticide-Mix1037 standard in isooctane was purchased from the Dr. Ehrenstorfer Laboratory (Ausburg, Germany). Aluminium oxide and silica gel for column chromatography were purchased from MERCK (Darmstadt, Germany).

Procedural blanks were run with every batch of 10-12 samples to check for contamination from solvents and glassware. Only samples in which the compound analyzed level exceeded the level in the blank 3.5 times were taken into consideration.

The method was validated using reference material CRM814 (sandy loam). There was satisfactory agreement between the certified values and the values measured in the laboratory of the Institute of Geochemistry of SB RAS. Levels of HCB, α-HCH, γ-HCH, *p,p`*-DDT, *p,p`*-DDE obtained in the laboratory correspond to confidence interval in reference material. *p,p`*-DDD level is within prediction interval of reference material. The recoveries of the certified reference material come to 70% for *p,p`*-DDD and ranged from 97% to 114% for other OCPs.

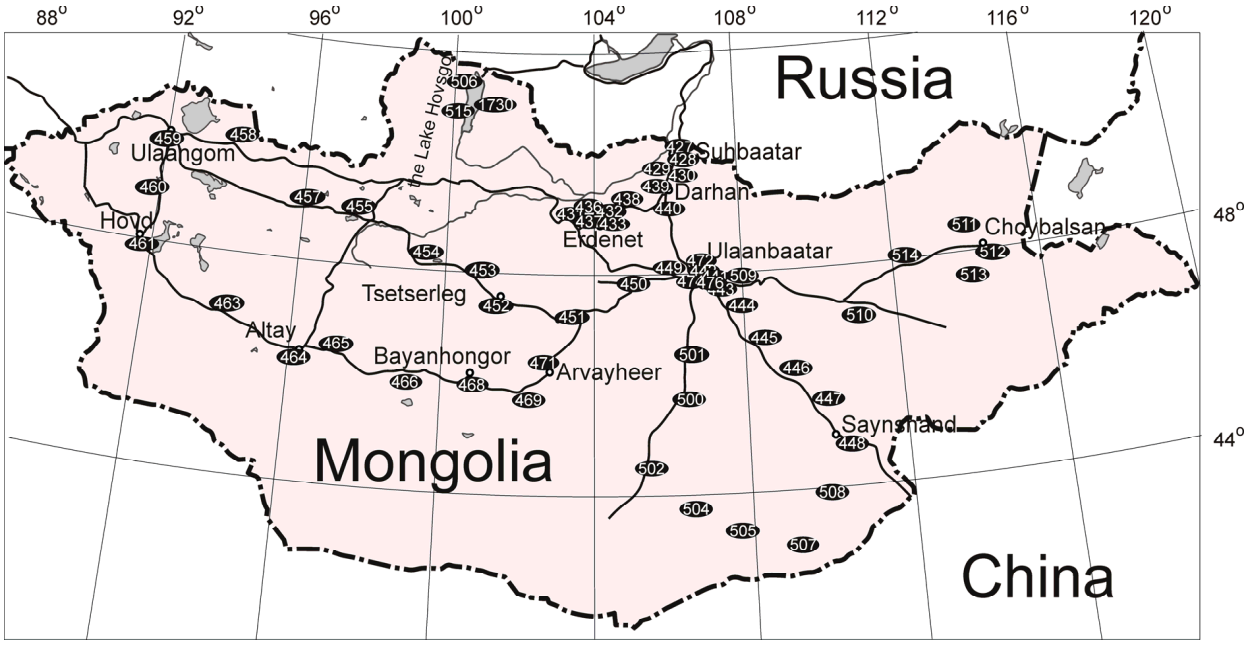

Figure 1 – The location of the soil sampling sites in Mongolia in 2010-2011

Statistical analysis was performed using the STATISTICA'6 (StatSoft) [10].

Results and discussion

3.1. OCP levels distribution in Mongolian soils and comparison with sanitary standards

HCH*s* were found in 83 percent of soil samples investigated. The average sum of α- and γ-HCHs in soil of Mongolia comes to 0.11 ng/g DW and varies from 0.0005 ng/g DW in the central part of Mongolia (Ms500) to 1.42 ng/g DW near a thermoelectric power station in the town of Ulaanbaatar (Ms442) (Table 1, Figure 2a). There are no target values of OCPs in soil in Mongolia so data obtained for Mongolian soil are compared with sanitary standards adopted in other countries. The values are considerably lower than the sanitary standards adopted in some countries (Dutch guidelines – 10 ng/g (target value) and 2000 ng/g of standard soil (intervention value) [11], Russia – 100 ng/g [12]).

Table 1 – The levels of α-HCH, γ-HCH, p,p`-DDT, p,p`-DDD, p,p`-DDE and HCB in positive surface soil in Mongolia (ng/g DW)

Pesticide	n	mean	median	min	max	standard deviation	standard error
HCB	59	0.16	0.02	< 0.003	2.85	0.44	0.06
a	31	0.07	0.02	< 0.002	0.90	0.17	0.03
γ-HCH	47	0.06	0.01	<0.0005	0.79	0.16	0.02
S	49	0.11	0.02	<0.0005	1.42	0.27	0.04
p,p`-DDT	29	2.44	0.08	<0.0002	48	8.99	1.67
p,p`-DDE	59	0.99	0.12	<0.014	15.3	2.58	0.34
p,p`-DDD	17	0.28	0.05	<0.003	2.65	0.65	0.16
S	59	2.27	0.16	0.014	54	7.51	0.98

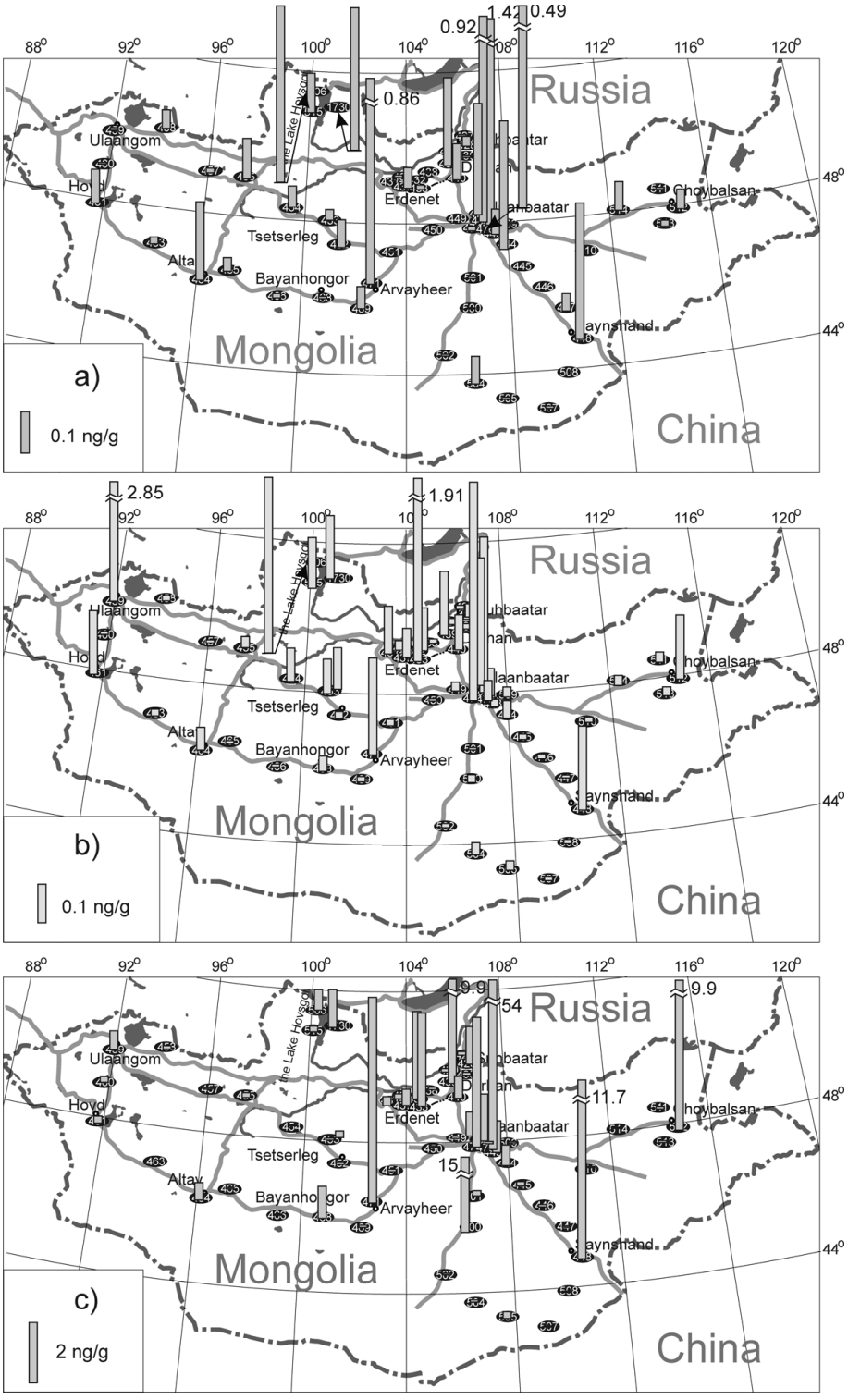

Figure 2 – Spatial distributions of ∑HCHs (a), HCB (b) and ∑DDTs (c) in surface soil in Mongolia (ng/g)

Cluster analysis was performed to identify the sampling site groups with analogous ∑HCHs and isomer composition in Mongolian soil. The results are presented by the diagram in Figure 3 and map in Figure 4. The cluster analysis distinguishes two groups and five single sampling sites (Figure 4a). The first group consists of soil sampling sites with ∑HCHs lower than the levels in the second group of soil sampling sites (0.011 and 0.062 ng/g respectively (p=0.001)) (Figure 5). The γ-HCH is the predominant isomer in soil of the first group of sites. Whereas α-HCH is found in just two sites of the first group or its level is below detection limits. Both HCH isomers investigated are found in soil of the second group of sites. The second group is divided into five subgroups with increasing HCH sums and α/γ-HCH values from subgroup IIa to subgroup IIe (Figure 3). The ratio of α/γ-HCH has been used to identify whether the pollution source comes from technical HCH or lindane [13]. The ratio of α/γ-HCH higher than 1 is a source indicator for technical HCH. α/γ-HCH is close to 0 for lindane [13]. Subgroup IIa is the only group among subgroups in group II that has α/γ-HCH values lower than 1 (0.43-0.90). The ∑HCHs or α/γ-HCH value is highest in soil of the five single sites. Three of them with the highest ∑HCHs are located in Ulaanbaatar near a medical incinerator or thermoelectric power station and one of them is located in the town of Arvayheer. Site Ms454 in the steppe, one of the five single sampling sites, is characterized by low ∑HCHs (0.03 ng/g DW) and highest α/γ-HCH value (4.9) obtained in the investigation. The distribution of HCHs indicates the predominance of the use of lindane (90% γ-HCH) in the first group of sites, the technical mixture of HCHs (53-70% α-HCH, 11-18% γ-HCH [14]) in the second group and both of the HCH mixtures in sites of subgroup IIa. The sites where lindane was used (group I and subgroup IIa) make up 65% of HCH positive soil sampling sites investigated and located throughout Mongolia (Figure 4). Whereas a technical mixture of HCH was used in 20% of the sampling sites investigated.

The highest levels of ∑DDTs were found in the towns of Ulaanbaatar (Ms475, 54 ng/g DW), Arvayheer, Saynshand and Darhan (6.9-11 ng/g DW) and in the deserted settlement (Ms500) (15 ng/g) (Table 1, Figure 2c). The ∑DDTs in the remaining Mongolian soil samples ranges from <0.014 ng/g in the south-western area of Mongolia (Ms463) to 4.34 ng/g DW in the city of Ulaanbaatar (Ms474) and on average comes to 0.48 ng/g DW. The ∑DDTs obtained in Mongolian soils are lower than sanitary standards adopted in Russia (0.1 mg/kg) [12], Canada (0.7 mg/kg – agricultural and residential, 12 mg/kg – commercial and industrial land use [15]. The ∑DDTs in six samples (Ms476 (Ulaanbaatar), Ms448 (Saynshand), Ms512 (Choybalsan), Ms439 (Darhan), Ms471 (Arvayheer) and Ms500 (deserted settlement)) were higher than the target value (10 ng/g of a standard soil) and lower than the intervention value (4000 ng/g of standard soil) from the New Dutch guidelines [11].

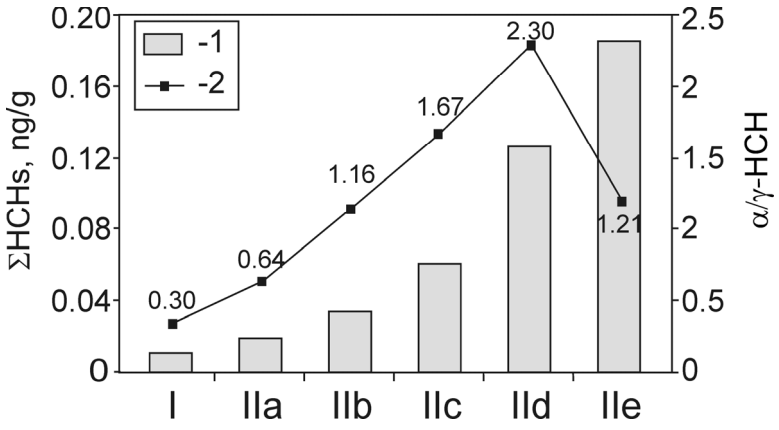

Figure 3 – Comparison of total HCH levels and α/γ-HCH values in Mongolian soil groups (1 – total HCH, 2 – α/γ-HCH)

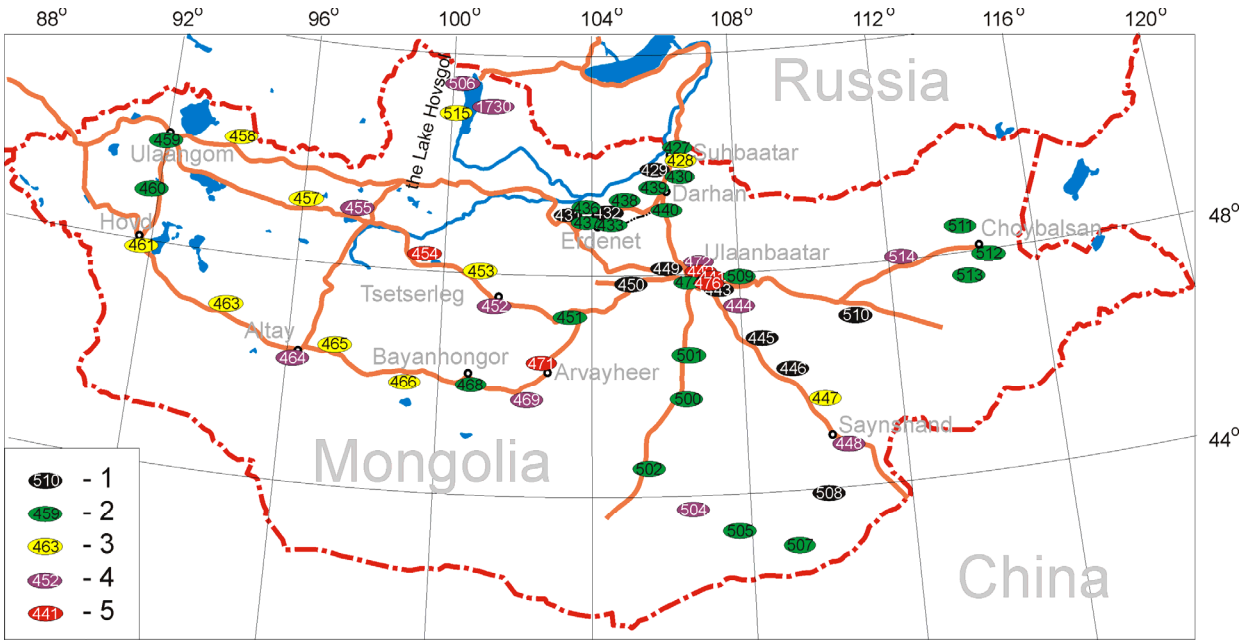

Figure 4 – The distribution of the groups of soil sampling sites on HCHs level and α/γ-HCH values (1 – HCH levels are below detection limits; 2 – group I, 3 – subgroup IIa, 4 – subgroups IIb, IIc, IId, IIe, 5 – the remaining sampling sites)

The cluster analysis of ∑DDTs and contribution of DDT, DDD and DDE in ∑DDTs in sampling sites investigated distinguishes three groups (Figure 3b, 5). The first group includes 85 percent of sampling sites with lowest ∑DDTs level (0.01-1.56 ng/g) and consists of background, rural sites and some urban sites. The first group is divided into five subgroups. The average ∑DDTs in soil of the subgroups increases from 0.096 ng/g DW in subgroup Ia to 1.43 ng/g in subgroup Ie. The average *p,p`*-DDE/*p,p`*-DDT ratios in subgroups Ia,b,c,d are higher than 1 and come to 63, 1.36, 1.09 and 10 respectively that indicates a different time of entrance of DDT into the environment in the past. It should be noted that *p,p`*-DDE is the only metabolite from the group of DDTs in half the sampling sites from group I. The subgroup Ie is characterized by the highest ∑DDTs among the first subgroups and a *p,p`*-DDE/*p,p`*-DDT ratio lower than 1 that indicates fresh application of DDTs. Groups II and III consist of urban sites (Erdenet, Saynshand, Choybalsan, Darhan, Arvayheer and one in Ulaanbaatar). Total DDT levels in soil from the groups come to 3.47 (2.94-4.34) and 9.93 (6.87-11.8) respectively. The *p,p`*-DDE/ *p,p`*-DDT ratio in the II and III groups amounts to 93 (48-137) and 0.49 (0.16-1.02) respectively. The remaining two sampling sites Ms500 (the deserted settlement) and Ms476 (Ulaanbaator) were not included in the first and second main groups. The highest ∑DDTs were found in soil from these sites (15 and 54 ng/g DW respectively). There is only *p,p`*-DDE in soil from the deserted settlement indicating intensive DDT usage in the past there. On the other hand the *p,p`*-DDE/*p,p`*-DDT ratio in soil from Ms476 (Ulaanbaatar) comes to 0.06 and points to fresh application of DDT. It should be noted that sampling sites in Ulaanbaatar are included in different groups and subgroups (Ia, Ic, Ie, II and one remaining site). The same phenomenon is found for samples from the industrial town of Erdenet. The sites in Erdenet are included in Ia, Id and II groups. The distribution of DDTs in soil confirms limited application of DDT in Mongolia. According to official information, DDT has never been used in agriculture in Mongolia [2]. However, the inventory of pesticides shows the application of «DUST» in Mongolia in the past [2]. Householders could not list the names of pesticides and identified all kinds of pesticides used as «DUST». There is also information on small deliveries of DDT from the former Soviet Union in the years 1950-1970 for plant cultivation and treatment of livestock in Mongolia and the presence of some of them in households in Mongolia not long ago [4]. Both DDT and HCH powder preparation forms produced and used in the former Soviet Union had the word «dust» in their full names [15-17]. DDT was commonly called «dust» in speech in the past among the population of the former Soviet Union. Taking into consideration

this information we can assume the application of DDT mixture in Mongolia also took place. *p,p`*-DDE/*p,p`*-DDT ratios lower than 1 are found in 13 percent of soil samples investigated that indicates the point intensive usage of DDT takes or took place at present or in the past (Figure 5).

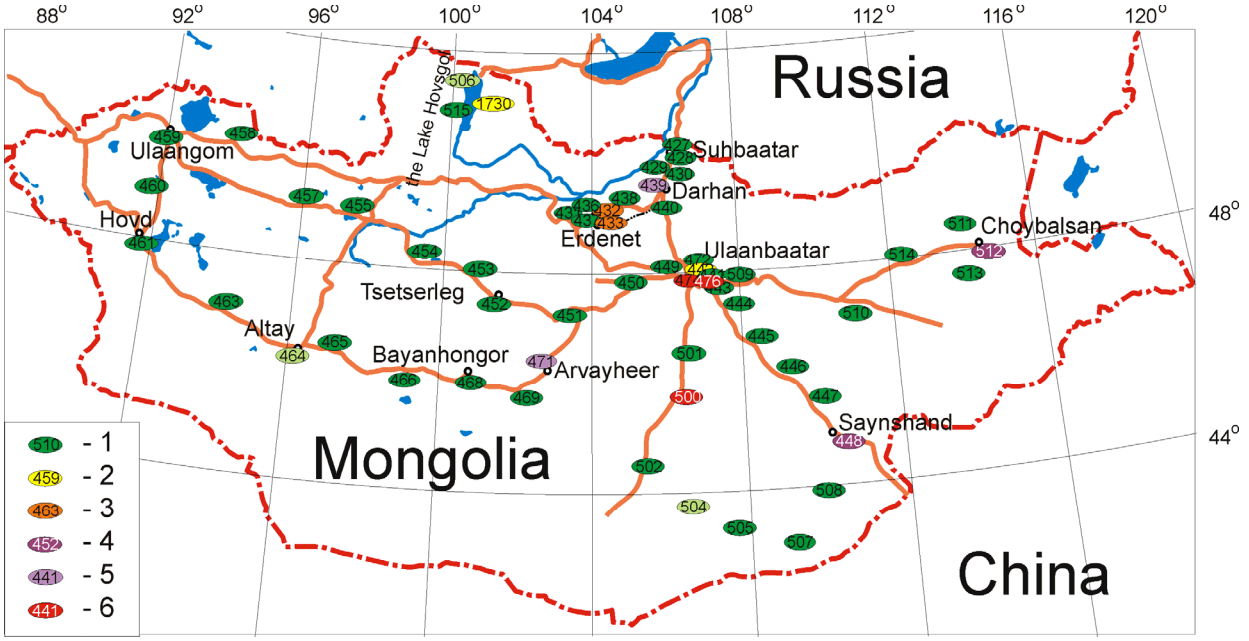

Figure 5 – The distribution of the groups of soil sampling sites on DDTs level and contribution of DDT, DDD and DDE into ∑DDTs (1 – subgroups Ia, Ib, Ic, Id; 2 – subgroup Ie, 3 – group II, 4 – group III, DDE/DDT ~ 1 or only DDE is detected, 5 – group III, DDE/DDT < 1, 6 – the remaining sampling sites).

HCB is found in all soil samples investigated (Table 1, Figure 2b). The highest HCB levels are found in the soil of two urban sites (2.85 ng/g, the town of Ulaangom, and 1.91 ng/g, the town of Erdenet). HCB levels in soil of the remaining 57 sites vary from<0.003 ng/g in the central part of the country (Ms501) to 0.57 ng/g in the town of Ulaanbaatar (Ms474). The average HCB level in the remaining samples comes to 0.078 ng/g DW. The HCB values obtained are lower than the sanitary standards adopted in Russia (0.03 mg/kg [12]).

3.2. The comparison of the OCP levels in Mongolian soils with data of previous studies of OCPs in Mongolia and other countries

The total HCH and DDT levels, with the exception of the highest values obtained in the Mongolian soil investigation of 2010-2011, are comparable to data found in Mongolian soils sampled in 2009 (0.02-0.81 and 0.06-4.28 ng/g DW respectively) [19]. HCB levels in 2010-2011 (0.003-2.85 ng/g DW) have more range of variation interval than those in 2009 (<0.0045-0.031 ng/g [19]). It should be noted that about all levels of α-HCH, γ-HCH, *p,p`*-DDT and *p,p`*-DDE in soil in Ulaanbaatar in 2010 (0.09-0.9; <0.006-0.78; <0.09-4.25 and <0.09-0.89 ng/g DW respectively) were lower or comparable to smallest extremes found in park soil in Ulaanbaatar in 2013 (0.48-2.95; 0.7-2.03; 6.12-11.92; 0.82-3.07 ng/g DW respectively) [7] with one exception (Ms476, in 2 km far from medical incinerator – *p,p`*-DDT levels – 48 ng/g DW). The differences can result from continuous of atmospheric transport of HCHs and DDTs that bring to the increasing of load with the pesticides with time.

A comparison of OCP levels in Mongolian soils and those of other countries is presented in Table 2. HCH and DDT levels in the greater part of Mongolian soil investigated are comparable to or lower than those found in urban and agricultural soils of European and American countries, USA [20-23;35;36] and the Lake Baikal Region of Russia adjoining in the north Mongolian boundary [29;30]. The average and range of HCB levels in – Mongolian soils are slightly lower than those found in the global soil project of 1998 (0.68 (0.01-5.21 ng/g DW) [41].

Table 2 – The comparison of OCP levels in soil of Mongolia and some other areas of the world (ng/g DW) (* - number of samples; bdl – below detection limits; nd – not detected)

Sites and year of sampling	n*	Land use	Total HCHs	Total DDTs	HCB	Reference
Mongolia, 2010-2011	59	urban, rural, background	bdl-1.42	<0.014-54	<0.003-2.85	This study
Europe						
Germany, 1995-1996	11	agricultural	4.6-11.5	23.7-173	0.57-3.75	[20]
Belgium	16	urban, rural	0.9 (0.6-2.0)	6.8 (0.6-22.4)	0.3 (0.1-1.4)	[21]
Italy	6	urban, rural	1.1 (0.6-2.0)	26.2 (1.8-60.4)	1.3 (0.1-5.2)	[21]
Romany	46	urban, rural	10 (0.6-89.5)	96 (3.5-561)	0.6 (0.1-5.5)	[21]
The Czech Republic	103	arable, grass-land, forest	0.26-4.0	2.04-1908	0.02-16.6	[22]
Azerbaijan, 2009	13	rural, urban	0.90-24.46	1.43-1115	0.02-1.63	[23]
Italy, Alps, 2003	19	mountain	0.51 (<0.01-1.88)	2.2 (0.18-11)	0.24 (<0.02-0.93)	[24]
Pyrenees		mountain	0.08-0.19	1.7-3.4	0.15-0.91	[25]
Tatras		mountain	0.28-0.19	4.5-13	0.23-0.33	[25]
Asia						
China, review		various sites	8.7 (nd-131)	60 (nd-2910)	nd-37700	[26]
India, 2009-2010	175	agricultural, urban	98-1945	75-2296	–	[27]
Russia, The Lena River valley, 2003	21	suburban, background, remote	0.35 (0.02-1.67)	0.25 (0.01-0.60)	0.34 (0.01-1.07)	[28]
Russia, The Irkutsk Region, 2001-2003	96	various sites	0.007-1.97	0.05-99	–	[29;30]
China, Wolong Nature Reserve, 2006	25	mountain	0.09-1.1	0.08-1.3	0.05-0.54	[31]
China, Qinghai-Tibet Plateau, 2011	36	mountain	1.86 (0.43-6.72)	1.63 (0.29-4.34)	0.93 (0.23-2.60)	[32]
Tibetan plateau, 2007	40	mountain	0.064-0.847	0.013-7.700	0.024-0.564	[33]
Nepal, Himalayas, 2007	6	mountain	bdl (<0.010)	0.033	0.009	[34]
North and South America						
Canada, 2002	7	urban, subur-ban, rural	< 0.005-0.068	1-18	–	[35]
USA, 1999-2000	30	agricultural	α= 0.28 (<0.05–2.4) γ= 0.24 (<0.05–1.1)	140 (0.10–1490)	–	[36]
Mexico, 2003-2006	46	various sited	0.012-0.046	0.057-360	–	[37]
Brasilia, 2005	29	agricultural, industrial	0.05-0.92	0.12-11.01	–	[38]
Canada, 2003-2004	22	mountain	0.003-7.886	–	0.003-0.244	[39]
Peru, Andes, 2004	10	mountain	<0.01	0.51 (0.02-1.65)	0.02 (<0.02-0.07)	[24]
Chile, Andes, 1999	17	mountain	< 0.001-0.39	0.10-1.1	0.007-0.18	[40]

OCP levels in rural and background regions of Mongolia are comparable or lower than those obtained in soil of remote and mountain areas [24, 25, 28, 31-34, 39, 40] (Table 2).

On the other hand the highest values of DDTs, HCHs and HCB levels in Mongolian soil are considerably lower than those found in some areas of China, India and Mexico where the pesticides are used at present or recently [26, 27, 37] (Table 2).

3.3. The correlation of the distribution of OCPs in Mongolian soils

The correlations between distributions of HCB, α and γ-isomers of HCH and *p,p`*-DDT and its metabolites *p,p`*-DDE in Mongolian surface soils are considered (Table 3). Significant positive correlation between α-HCH and HCB is obtained (p<0.001). γ-HCH distribution positively correlated with *p,p`*-DDT (p<0.05). The correlation between individual pesticides can be the result of preferred application of a specific pesticide in households.

3.4. Factors influencing spatial distribution of OCPs

3.4.1. Land use

HCB, α-HCH, γ-HCH and *p,p`*-DDE levels in soil from towns are significantly higher than those in soil from background and rural areas of Mongolia (Table 4). Significant correlations in the distributions of HCB, α-HCH, γ-HCH, *p,p`*-DDT, total HCHs and DDTs were found for soil sampled in background and rural areas (0.37-0.98, p<0.001-0.05) (Table 3). Whereas there is not correlation in the distribution of *p,p`*-DDE and other pesticides. The phenomenon indicates on united pathway of other OCP entrance in background and rural areas of Mongolia at present due to atmospheric transport. DDT has never been used in Mongolia. The absence of correlation in the distribution of its metabolite *p,p`*-DDE and other OCP can result from past entrance of DDT in Mongolian environment. The only significant correlation of HCB and α-HCH levels is found for soil from towns (0.70, p=0.011) (Table 3). The distinction between distributions of OCPs in the towns and background+rural areas (Table 3) indicates on influence of different combinations of OCP sources located in Mongolian towns investigated.

3.4.2. Latitude, longitude and altitude

Positive significant linear correlations (Pearson r) were found between HCB, ∑HCHs and ∑DDTs and latitude (Figure 6). We assumed that the correlation is associated with the extensive development of agriculture and stock-breeding in steppe and forest natural zones of central and northern parts of the country and lesser development of these kinds of activities in southern deserted parts of Mongolia.

No correlations were found between OCPs and longitude. There is no clear increase in OCP levels in Mongolian soils with altitude as it has been shown in mountain areas of Tibet, Himalayas, Alps or Andes [24, 31, 32, 34].

Table 3 – The correlation between OCPs in Mongolian soils

	HCB	α-HCH	γ-HCH	∑HCHs	DDE	DDT	∑DDTs
all samples							
HCB		0.62***	0.01	0.04	0.09	-0.04	0.01
α-HCH	0.62***		0.65***	0.89***	0.15	0.12	0.14
γ-HCH	0.01	0.65***		0.93**	-0.01	0.43*	0.27
∑HCHs	0.04	0.89***	0.93**		-0.02	0.28	0.23
DDE	0.09	0.15	-0.01	-0.02		0.38*	0.46***
DDT	-0.04	0.12	0.43*	0.28	0.38*		0.99**
∑DDTs	0.01	0.14	0.27	0.23	0.46***	0.99**	
background and rural soils							
HCB		0.67**	0.87***	0.80***	0.15	0.57*	0.49**
α-HCH	0.67**		0.89***	0.98***	0.23	0.75**	0.67***
γ-HCH	0.87***	0.89***		0.97***	0.29	0.79***	0.72***
∑HCHs	0.80***	0.98***	0.97***		0.29	0.79***	0.73***
DDE	0.15	0.23	0.29	0.29		0.18	0.77***
DDT	0.57*	0.75**	0.79***	0.79***	0.18		0.79***
∑DDTs	0.49**	0.67***	0.72***	0.73***	0.77***	0.79***	

Continuation of table 3

	HCB	α-HCH	γ-HCH	∑HCHs	DDE	DDT	∑DDTs
urban soils							
HCB		0.70*	-0.20	-0.15	0.01	-0.26	-0.12
α-HCH	0.70*		0.56	0.88***	-0.04	-0.02	0.01
γ-HCH	-0.20	0.56		0.91***	-0.18	0.34	0.17
∑HCHs	-0.15	0.88***	0.91***		-0.17	0.16	0.14
DDE	0.01	-0.04	-0.18	-0.17		0.27	0.33
DDT	-0.26	-0.02	0.34	0.16	0.27		0.99***
∑DDTs	-0.12	0.01	0.17	0.14	0.33	0.99***	
* – p<0.05, ** – p<0.01, *** – p<0.001							

Table 4 – The comparison of OCP levels in soil samples from urban and rural and remote areas of Mongolia (mean±standard error, ng/g)

Compound	Urban soils	Rural + remote soils	t	p
HCB	0.35 ± 0.15	0.04 ± 0.01	2.69	0.009
α-HCH	0.15 ± 0.07	0.03 ± 0.007	2.16	0.04
γ-HCH	0.13 ± 0.05	0.02 ± 0.005	2.65	0.011
∑ HCHs	0.22 ± 0.09	0.03 ± 0.01	2.49	0.016
p,p`-DDE	2.43 ± 0.82	0.13 ± 0.03	3.64	0.0006
p,p`-DDT	5.74 ± 3.93	0.12 ± 0.06	1.71	0.098
∑ DDTs	5.76 ± 2.48	0.19 ± 0.05	2.92	0.005

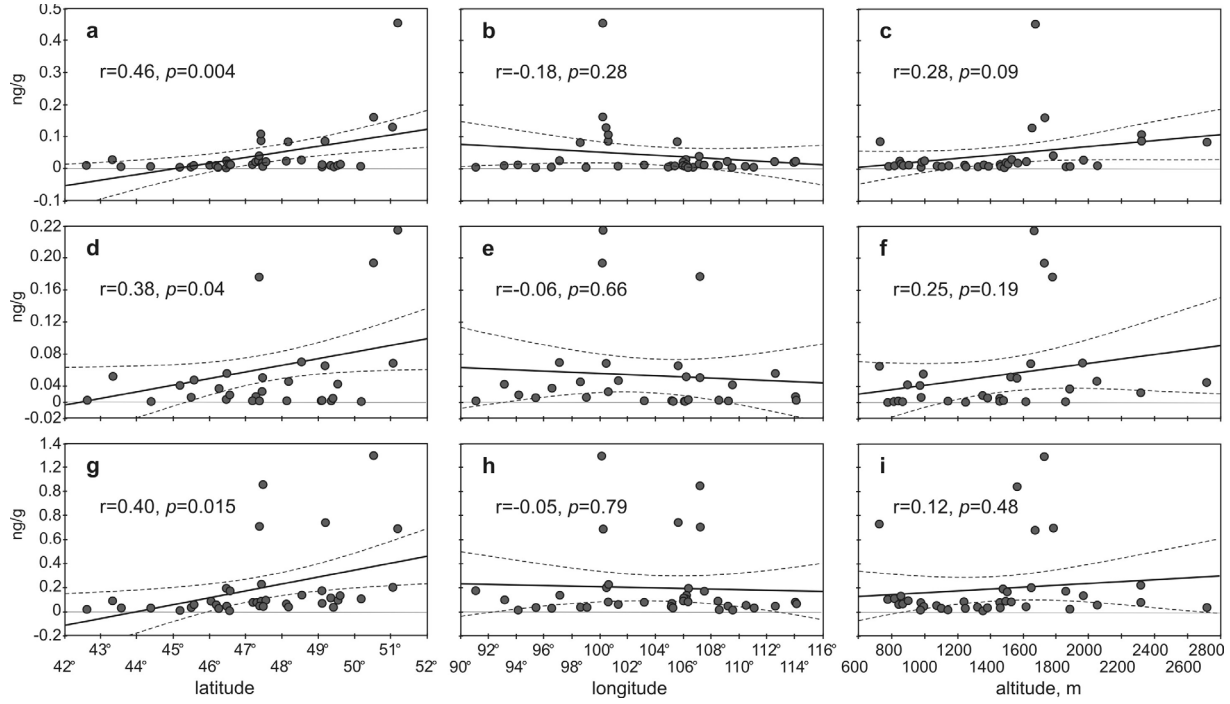

Figure 6 – The correlation between OCP levels in Mongolian background+rural soil and longitude, latitude and altitude (a,b,c – HCB; d,e,f - ∑HCHs; g,h,i - ∑DDTs).

3.4.3. Soil organic carbon (SOC) and natural zones

The Mongolian soils in the investigation were sampled in five of six natural zones including mountain taiga, forest-steppe, steppe, Govi (the Gobi) and desert zones. Soil samples were not obtained from the high mountain zone due to difficulty of access. The SOC levels in samples from the five natural zones investigated range from 0.44% (0.30%-0.71%) in the desert to 3.46% (3.06%-4.12%) in mountain taiga [8].

No correlation was found between SOC and OCPs in the total number of soil samples. However, a significant positive correlation was obtained between SOC and HCB, ∑HCHs and ∑DDTs in background and rural sites (r=0.46; 0.41; 0.37 respectively, $p<0.05$). Soil organic matter is an important factor in the fate of organic pollutants in a terrestrial environment [41;42]. The absence of correlation between OCPs and SOC in total number of Mongolian soils can result from the influence of the factor of the presence of additional significant OCP sources within towns. On the other hand, a positive correlation of OCPs and SOC in background and rural soils can result from extensive agricultural application of OCPs in areas of natural zones with soils more rich in organic matter. The dependence of OCPs content in soil and SOC were observed both in remote sites and in areas with elevated OCP levels [27, 33, 43].

A comparison of mean HCB, ∑HCH and ∑DDT levels in background and rural soil from five natural zones of Mongolia was performed (Table 5).The highest mean OCP levels (pg/g DW) were obtained in the mountain taiga (MT) zone that might be explained by the influence of the forest as one more factor to increase soil concentration of such semivolatile organic compounds as OCPs [44]. Significant differences between the means of HCB and ∑HCHs in the MT zone (forest) and those in forest-steppe (FS), steppe (S), and Govi (the Gobi) (G) (desert-steppe and semi-desert) zones were found (Table 5). Significant differences between the means of ∑DDTs in MT zone and FS and G zones and between those in FS zone and G zone were also observed (Table 5).

Table 5 – The levels of significance of the distinction of OCP means (ng/g DW) in soil sampled in different natural zones (MT – mountain taiga, FS – forest-steppe, S – steppe, G – Govi, D – desert zones) (ns – not significant)

Natural zone	mean of OCPs	Natural zone				
		MT	FS	S	G	D
∑HCHs						
MT	0.146	1	<0.01	<0.05	<0.05	ns
FS	0.012	<0.01	1	ns	ns	ns
S	0.032	<0.05	ns	1	ns	ns
G	0.015	<0.05	ns	ns	1	ns
D	0.012	ns	ns	ns	ns	1
∑DDTs						
MT	0.731	1	<0.01	ns	<0.01	ns
FS	0.106	<0.01	1	ns	<0.05	ns
S	0.254	ns	ns	1	ns	ns
G	0.048	<0.01	<0.05	ns	1	ns
D	0.048	ns	ns	ns	ns	1
HCB						
MT	0.248	1	<0.01	<0.001	<0.01	ns
FS	0.039	<0.01	1	ns	ns	ns
S	0.021	<0.001	ns	1	ns	ns
G	0.009	<0.01	ns	ns	1	ns
D	0.017	ns	ns	ns	ns	1

Conclusions

These results present the first data on the spatial distribution of OCPs in surface soil throughout Mongolia. The greater part of the OCP values obtained is considerably lower than the sanitary standards adopted in some countries. OCP levels in soils from rural and background regions of Mongolia are comparable or lower than those obtained in soil of remote and mountain areas of the world. The distribution of HCHs and DDTs indicates a predominance of γ-HCH entrance in the greater part of the soil sampled throughout Mongolia and confirm limited DDT application in the country at presence or in past. The distinction between distributions of OCPs in the towns and background+rural areas indicates the influence of different combinations of OCP sources located in Mongolian towns investigated and redistribution due to atmospheric transport in the remaining area of Mongolia. Significant correlations between HCB, ∑HCHs and ∑DDTs and latitude and between SOC and HCB, ∑HCHs and ∑DDTs in background and rural sites are associated with the extensive development of agriculture and stock-breeding in central and northern parts of the country. The highest mean OCP level in soil of the mountain taiga zone differs significantly from those in forest-steppe, steppe, and Govi (the Gobi) zones.

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