SPECIFICS OF CONCENTRATIONS AND DISTRIBUTION OF DISSOLVED ORGANIC CARBON IN THE GASSI LAKE BASIN (LOWER AMUR, RUSSIA)

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Keywords: soils, river and bog waters, Lower Priamurje

1. INTRODUCTION

Migration of organic matter in nature is very important for the global and regional geochemical processes on the Earth. Close correlation between organic matter of biosphere, soils and sediment rocks is described by the Russian scientists V.I. Vernadsky (1954), F.P. Vinogradov (1964), A.I. Perelman (1968), V.A. Kovda (1985). Our knowledge of organic matter migration (including its humus component) from surface ecosystems into water ecosystems is still insufficient. It is also true with natural systems of Priamurje, where soil formation is determined with peculiar combinations of hydrochemical conditions, relief and soil-forming ricks (Far Eastern South…, 1969). It is also known that migration processes play an important role in regulating the content of atmospheric air and water in rivers, lakes and bottom sediments (Artemjev, 1993; Orlov, 1998).

The present study focuses on systematizing and assessing results of research of organic matter content and dynamics in soils and surface waters in the Gassi Lake Basin.

Comparing to other regions of the Lower Priamurje, this territory has suffered insignificant technogenic impact and can serve as a model area for hydrological, hydrochemical and soil-hydrochemical studies. The analysis of the field observation data, obtained in July and September 2006 and July 2007 by the three Russian-Japanese expeditions to the Gassi Lake Basin, allowed to reveal certain regularities in organic carbon discharge in the drainage system under study.

2. RESEARCH OBJECTS AND METHODS

The Gassi Lake is situated in the north-eastern part of the Lower Amur plain in the Amur floodplain (Fig.1).

The area of the lake is 30 km^2. Two sub-channels connect the lake with the Amur River. The mean water level in the lake is 25.2 m. Water level regime in the lake much depends on the water level in the Amur. In time of floods in the Amur the Gassi Lake is overfilled with water and during the Amur low water period the lake gets shallow. During the winter low water period the lake is completely frozen through. Lake banks are not high and in the north-east they are covered with woods. Water transparency fluctuated within the range 60 – 100 cm (Surface Water Resources…, 1970).

The Gassi Lake basin area is 2420 km^2 and includes the basins of the rivers Khar, Pikhtsa with their tributaries, as well as swampy plain areas, weakly drained with streams (the Babchi River). Swamps take 45% of the basin area, and the rest area is covered with woods and sparse-grown trees, 25% of which are coniferous-broad-leaved woods.

The water regime of the Gassi Basin rivers is described as the far-eastern type, with a marked predominance of the rainfall run-off (60-85% of the annual run-off). In the warm time of the year (April – October) water amount is increased due to abundant rainfalls and run-off fluctuations are significant, making the form of the hydrograph ridge-like. Five or six floods are usually observed in the Gassi Basin rivers in the warm time of the year. Hydrochemical research was carried out in the north-eastern area of the basin at the rivers Babchi, Khaso, Malina, Kartanga with its tributaries and Lake Gassi (Fig.1).

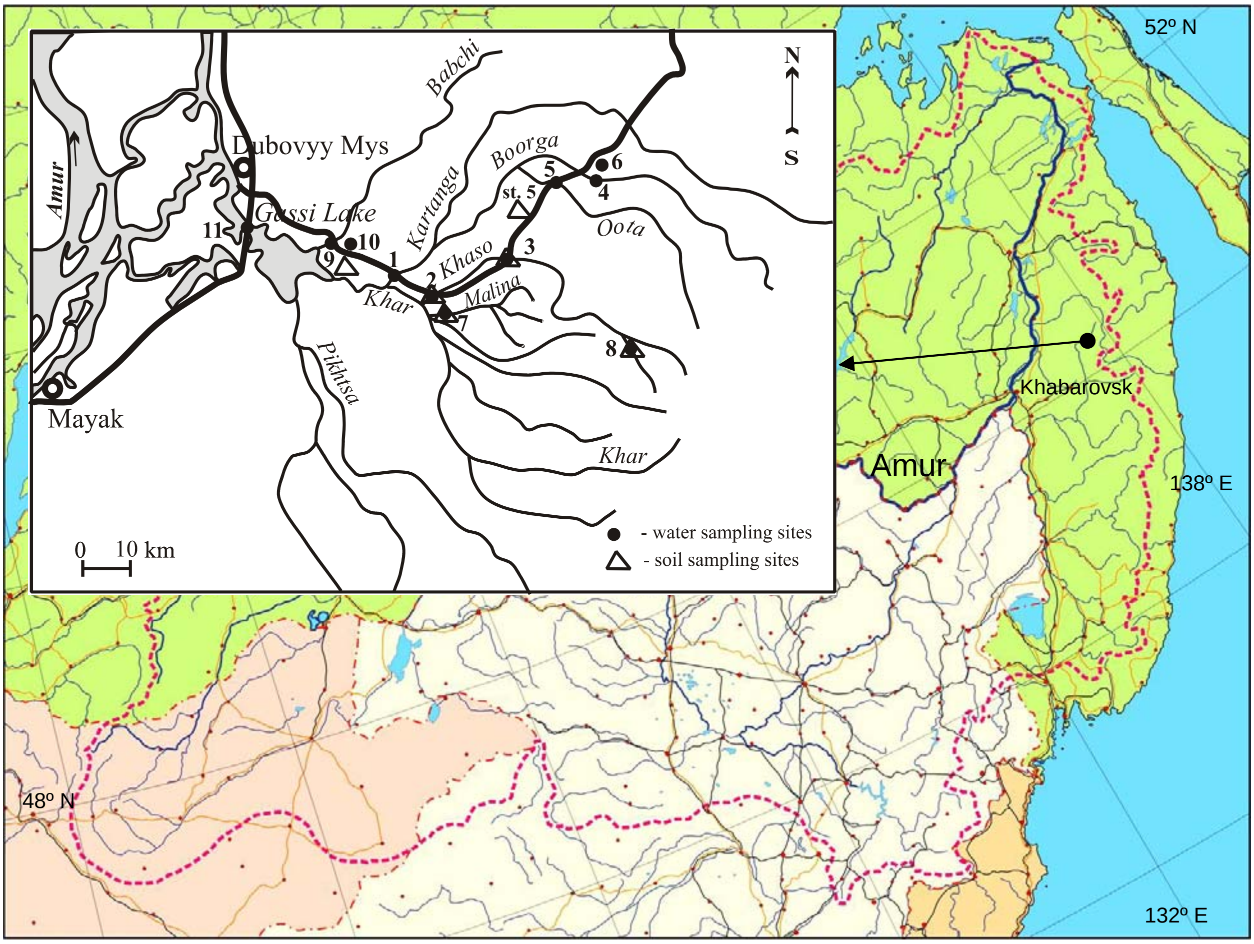

Fig. 1 Geographical Position of the Gassi Lake

The research in the studied area was focused on soil specifics description based on samples selected to study physical and chemical characteristics. River and lake water was sampled form the close-to-surface horizons in the stream middle as follows: in 2006 – in July when rain floods started to decrease and in September – in the low water period; in 2007 – in July in the low water period. Water level in the Amur at that time was not high and thus water run-off from the Gassi Lake into the Amur was observed.

Color index (CI), determined with Co-Pt scale (degrees) of water, is used to characterize organic matter (OM). Dissolved organic carbon (DOC) in water was determined with L.P. Krylova's method of dry burning in a quartz tube (Alekin, 1997). A water sample of 0.5 l was filtrated through a 0.45 μm filter (Whatman) and DOC was measured in the filtrate. Humus acids (HFA), i.e. humic (HA) and fulvic (FA) acids were determined with a DEAE-method (Krasyukov, Lapin, 1988; Standard methods…, 1989). Potentiometry was used to analyze humus acids, i.e. water pH. Bulk content of organic matter was determined by multiplying TOC by the coefficient 2.

The following parameters were analyzed in soil samples: pH of the water extract; exchange-absorbed base content (Ca^{++} и Mg^{++}) with a complex sociometric method (Arinushkina, 1970); organic carbon (C_{org}) with I.V.Turin's method with photometry to finish (Belchikova, 1970). In the upper soil horizons carbon content was determined with a water extract (C_{som}) using E.V. Arinushkina's method (1970). In some soils lysimetric waters were sampled 50 cm deep (with a capillarimeter method) and total and dissolved carbon was analyzed with I.V.Turin's method.

Water discharge was measured to assess organic matter discharge in rivers and the Gassi Lake.

3. DISCUSSION OF RESEARCH MATERIALS

Amount and dynamics of water run-off in the Gassi Lake Basin, as well as dissolved (and suspended) organic matter discharge mostly depend on the amount and annual distribution of atmospheric precipitations, landscape structure and soil cover specifics.

Gassi Basin soils are ranked among insufficiently studied areas of Lower Priamurje. Soil characteristics and dissolved substance discharge specifics are associated with specifics of the Far Eastern soil facies (Liverovsky, 1969; Ivanov, 1979; Ershov, 1984). One of the main soil processes here is the formation of burozem in the mountains and plains.

In the Gassi Lake Basin different soil types correlate with sharply marked geomorphologic levels, i.e. mountain water divines, mountain slopes, low-mountain and hilly foothills and lowland plains. The medium-high mountain water divine (600-800 m above the sea level) separates the lake basin from the Anui and Khor river basins and is characterized with mountain brown taiga and brown taiga illuvial humus soils under the dark-coniferous forests (spruce, fir).

Usually the brown taiga soil is characterized with a rather thick peaty forest litter. Very often a humus horizon is weakly marked and is not thick. Spots of seasonal gleification may be observed in the mineral part of the soil profile. As for their granulometric composition these soils may be described as loam with a high content of hard rock debris and chippings. Rock exposures are often observed. Eluvial-deluvial basalt and andesite-basalt deposits are widely spread in the area under research.

Yu.A. Livertovsky pointed out the remarkable correlation between brown taiga illuvial humus soils in the Lower Priamurje with the highly-fragmental weathering crust composed of Lower-Quaternary effusive rocks. The steep sloped relief, fragmented character of soils and the weathering crust contribute to an active substance discharge with water. Water run-off in the area under study is composed of the surface, inner-soil infiltration and side flows.

In the brown taiga soil (section H-1, Table 1.) of the water divine between the Gassi Lake Basin and the Anui River medium reaction was weakly acid in the upper horizon and acid in more deep horizons (Table 1).

Table 1. Organic Matter and pH Content in soils of the Gassi Lake Drainage System (dry weight)

Horizon index, depths	pH, 1:10 H_2O	C_{org}, mg kg^{-1}	C_{som}, mg dm^{-3}
Mountain brown taiga illuvial humus soil – (H-1)			
AO_{pr} 2-4см	6.20*	125.4	1.52
A_{pr} 4-10(12)	4.45	141.0	4.52
B1h 10(12)-17	4.36	157.8	-
B2h 17-27	4.70	198.2	–
BC 27-37	4.97	59.6	–
BC 37-43	5.43	30.9	–
Brown forest soil (between the rivers Svetlaya and Uta) – st.5			
O 0-6	5.71*	389.2	1.49
A1 6-20	4.84	67.7	2.27
B1 20-32	5.62	8.6	–
B2 32-46	5.55	10.4	–
Humic gley soil (Burga River Valley) – st. 4			
O 0-5 (6)	6.32*	421.2	6.12
A(H) 5 (6)-13(14)	5.37	220.1	3.06
B1 13(14)-20	5.52	72.0	–
B2 ниже 20	5.58	67.7	–
Soddy burozen (brown forest) soil (Left Khaso River) – st. 3			
O 0-7	5.67*	382.0	–
A1 10-15	5.53	265.5	4.3
AB 15-27	5.37	98.1	–
BC 27-52	5.58	85.2	–
Peat humic gley soil (Malina River) – st. 7			
AT 10-15	4.85*	244.0	-
TM 20-30	4.68*	115.9	4.17
CG 30-40	5.59	14.6	–
Peat gley (Babchi River) – st. 9			
T1 20(30)-42	5.21*	376.0	2.8
T2 42-60	5.24*	450.2	–

Note: "-" in the table and further on in other tables means "not defined" - 1:25 H_2O.

The sum of exchange bases throughout the soil profile is not big. A noticeable increase of the absorbed Ca^{++} и Mg^{++} is registered in the AO_{pr} upper horizon and BC horizon (0.15 mol kg^{-1}). In the first case it is caused by the evident biogenic accumulation, and in the second case it is caused by the dismissal of bases, especially magnesium bases, resulting from the geochemical process of inner-soil weathering of minerals (mainly basalt rock plagioclases). Low content of bases in the profile middle (0.06 mol kg^{-1}) may result from the washing-out with the inner-soil moisture run-off.

A low content of bases in the profile middle might be caused by their washing-out with inner-soil moisture runoff, which is a peculiar feature of soils on the mountain slopes. Bases leaching with fulvic acids, the acid part of humus, seems to take place. Low pH values indicate acid, and even highly acid media in the profile middle. A high C_{org} content is specific not only to the upper soil horizons, but to the whole profile. Humus is very mobile and is present nearly in all horizons. High concentrations of mobile iron (12-37 g kg^{-1}) are observed up to the depth of 40 cm in the profile of the section H-1. Below its content is rather low (1.8 g kg^{-1}). Humus and iron presence is evident in the soil color (chocolate-brown and ochre-brown color tones). Accumulation of weakly decomposed organic matter in the upper soil horizons and high mobility of iron-humus compounds constitute specifics of brown taiga illuvial humus soil.

The next macro-landscape level is composed of low-mountain and hilly landscape (200-400 m above the sea level). The rivers Pikhtsa, Khar and their tributaries (Uta, Khaso, Burga, Kholgoso) drain this area. Coniferous-broad-leaved forests are abundant here and the rest of the territory is covered with secondary small-leaved forests (birth, aspen). Larch dominates close to the lowlands. This landscape is characterized with transitional accumulative regime of moisture and substance migration, i.e. substance discharge is combined with its inflow from the upper layers and further accumulation. Migration flows depend much on the inner-soil side water run-off. High degree of basalt rock weathering and significant soil profile thickness characterize this part of the basin. Significant accumulation of clay fractions in the fine earth contribute to substantial moisture of soils. In the second landscape level loan and clay-detritus brown forest soils (burozems) are common.

Under the forest litter typical burozems have a developed humus horizon with a high content of humus and a mineral profile of yellow-brown uniform color. Thickness and detritus presence in soil may vary depending on the geomorphologic conditions. Mean reaction of the typical brown forest soil under the coniferous-broad-leaved forest (2-06, st. 5) is close to neutral, the humus horizon with an acid media being exclusion. Ca^{++} и Mg^{++} content in A1 и B1 horizons (0.20 и 0.17 mol kg^{-1}) is noticeably higher than in the brown taiga soils, which contributes to a more complete neutralization of acid humus formation products.

The soil of section 2-06 (st.5a) is characterized with a very high C_{org} content in the AO horizon (up to 390 mg/kg),which indicates a high coniferous-broad-leaved forest productivity and organic matter intensive accumulation in the forest litter. C_{org} content in the A1 humus horizon is high (about 70 mg kg^{-1}), which is specific to the burozem soil type formation. Down the profile, as stands true to all the brown forest soils, C_{org} content quickly reduces and is 8.6-10.4 mg/kg^{-1} at a half meter depth. Forest soil forming processes as a whole have a marked accumulative character (especially pertaining C_{org}, biogenic bases, iron compounds).

The valleys close to the rivers that drain the mountain landscapes (Kartanga, Burga, Khaso, Left Khaso, etc.) are formed with big-size pebble or sandy-pebbled alluvium, and as such they play an important role in the formation of the surface water filtration runoff. Mixed forests here are composed of Manzhurian ash, elm, Korean pine, poplar, Asian bird cherry with the variety of hygrophilous grasses (fern, nettle, sedge, horse-tail, etc.) and form humic gley soils. Most of the season they are rather moist being close to ground waters (50-60 cm). Still thanks to a good filtration there is no durable moisture.

Humic gley soils are covered with water for a short time during floods. When the water runs away the soil surface has a thin layer of clay sediments. Morphological composition of plain soils indicates an intensive accumulation of humified plant residue in the upper part of the soil profile (section 4-06, st. 4). Forest litter (horizon O) is from 3 to 6 (7) cm thick with well-marked fermentative layers (L, F+H). Reaction of the medium is neutral. Humic horizon A(H) is usually of black-brown or black color with a fine-particle structure and weakly acid reaction of the medium. Both horizons have high C_{org} content. Accumulation of the absorbed Ca^{++} и Mg^{++} (0.40 mol kg^{-1} in the horizon AO) also contributes to this. Below the profile base content reduces compared to the upper horizons, but still remains in high values. The highest C_{org} and exchange-absorbed bases contents in the organogenic part of the profile mark humic gley soils out of the river plains among all the other soil types in the Gassi Lake Basin.

A flat plain takes the most part of the Gassi Lake Basin with absolute heights 30-50 m above the sea level and in the river valleys they are less than 30 m above the sea level. Geochemical landscapes of this plain are of sub-aqua-accumulation type. The layer specifics include a weak draining capacity (flat relief of the surface and pressed watertight clay sediments), swamping and peat sediment accumulation. Peat deposits in grass and sphagnum bogs with shrubs and low Daurian larch are 0.2 to 1 m thick. They retain most of atmospheric precipitations and water runoff from the foothills. In July and September 2006 the bog water level exposed to the surface. The role of rivers in the drainage within the plain is not high and expands only to area close to the river beds (Prozorov, 1972). Peat (P) and peat-mineral (PM) horizons have a weak acid reaction of the medium (section 7-06, st. 7). The sum of the absorbed bases is not big, i.e. 0.14 mol kg^{-1} and in the mineral horizon it reduces to 0.06 mol kg^{-1}.

The revealed analytic data show that high organic matter resources are the peculiarity of the soil cover in the Gassi Lake Basin. Still their formation within various landscape levels is uneven and there is a misbalance between accumulation of decomposed organic residue (forest litter, humic and peat horizons) and humic matter proper (humus accumulative horizons of soil). A slowed decomposition of plant residues mostly of coniferous litter is specific to brown taiga soils of the first landscape level (the upper reaches of the Burga, Uta and Khaso rivers). It predominates humification processes. The main result of such biochemical process direction is the formation of a significant amount of water- and acid-soluble forms of organic matter and their penetration into the soil solution. This organic matter forms have a capacity to transport (illuviate) down the soil profile. Current research show that a water-soluble part of humus acids in forest soils is mostly formed in forest litter. They play an important role in the formation and migration of soluble organic and mineral complex compounds and, thus, in the formation of quality of water that drains soil and landscape as a whole (Ananenko, Fridland, 1983; Elpatjevsky et al., 2000; Matyushkina, Levshina, 2005).

Studies of water extracts from soils showed that C_{som} in brown taiga illuvial humus soils under the spruce and larch forest (section H-1) was high, i.e. 1.52 and 4.52 mg dm^{-3} for the horizons AO_{pr} and A_{pr} respectively (Table 1) or 12 and 32% of the total organic matter resource in these horizons.

High moistening and relatively high draining capacity of these soils assist to active transport of C_{som} from the upper horizons down the soils profile and probably even beyond its bounds. The smallest C_{som} content (1.49 mg dm^{-3}) was found in forest litter of brown forest soil between the rivers Svetlaya and Uta (the second landscape level). It seems that most of it is averaged with bases, richly present in leaf fall and forest litter. Transport of C_{som} down the profile may be also slowed down due to the pressed and less fragmented soil structure.

It is known from publications (Ivanov, 1976; Elpatjevsky, 2000) that mobile humus migration through the soil profile is not typical to brown forest soils. In humic gley soils in the valleys of the draining rivers (Burga, Left Khaso and others) C_{org} content in the upper horizons is high and more carbon migrates from the forest litter into the water extract and less from humus horizon than in brown forest soils. Even less C_{som} is registered in the surface horizon of weakly decomposed peat between the rivers Babchi and Kartanga (only about 2.8 mg dm^{-3}). The formation of a water-soluble carbon in peat-bog soils of around-lake plain mostly depends on the decomposition rate of peat deposits.

C_{org} mobility in soils also indicates its discharge into lysimetric water. Total carbon in lysimetric solutions of the soil profile under study fluctuated from 9 to 79 mg dm^{-3}. Minimal values were registered in brown forest soils under coniferous-bread-leaved forests (between the rivers Svetlaya and Uta and in the Khaso River upper reaches), whereas minimal values characterize peat-bog soils of the swamped foothill plain. Still, in lysimetric waters of plain in-shore shoal in the Gassi Lake DOC was not high (about 13 mg dm^{-3}). It may be explained with dilution, when solutions contacted lake waters. It should be noted that the share of suspended carbon in lysimetric solutions was less 10% of total carbon, and as such this carbon migration form in soil waters was neglected. Although only few data on lysimetric solutions were obtained, still they allow predicting a high degree of involvement of organic carbon in migration of moisture and substances in the landscape of the studies area.

The research conducted in 2006 showed that the rivers of the north-eastern part of the Gassi Lake drainage system significantly differ in their DOC content, which changed from 2.4. to 39.8 mg C dm^{-3} (Table 2).

Table 2. Hydrochemical Water Parameters of Lake Gassi and its Tributaries in 2006-2007

Station Number (Fig. 1)	Sampling site	Sampling time	pH	CI, grad	DOC, mg Cdm^{-3}
1	Kartanga River	July, 2006	6.62	280	16.2
		September, 2006	6.95	332	27.1
		July, 2007	7.20	130	6.15
2	Khaso River (lower bridge)	July, 2006	7.50	152	6.9
		September, 2006	7.05	156	12.2
		July, 2007	6.68	65	2.7
3	Khaso River (upper bridge)	July, 2006	7.50	59	6.8
		September, 2006	7.40	68	5.1
		July, 2007	6.75	60	3.6
4	Uta River	July, 2006	7.55	112	8.3
		September, 2007	7.40	45	2.4
		July, 2007	–	–	–
5	Burga River	July, 2006	7.35	70	3.5
		September, 2006	7.40	84	6.0
		July, 2007	–	–	–
6	Stream running into the Burga River	July, 2006	6.04	470	39.8
		September, 2006	–	–	–
		July, 2007	–	–	–
7	Malina River	July, 2006	7.03	480	36.7
		September, 2006	6.72	432	33.6
		July, 2007	–	–	–
8	Left Khaso River	July 2006	–	–	–
		September, 2006	7.57	17	4.5
		July, 2007	7.40	47	3.4
9	Babchi River	July, 2006	6.83	490	18.5
		September, 2006	6.31	520	32.8
		July, 2007	6.66	120	38.0
10	Bog	July, 2006	–	–	–
		September, 2006	5.70	450	51.2
11	Gassi Lake	July, 2006	6.97	255	30.4
		September, 2006	7.14	330	28.0
		July, 2007	7.80	65	3.7

The lowest DOC concentrations (2.4 – 8.2. mg C dm^{-3}) and, thus, not high color index values were found in waters of middle reaches of Uta, Khaso, Burga, Left Khaso rivers, i.e. within the low-hill transit-accumulation landscape. In the autumn low water period dissolved carbon content decrease was very small. At the same time, waters which run from various swamped streams into the rivers under study in the flood period were characterized with high colority and DOC content up to 40 mg C dm^{-3} (the stream running into the Burga River). Significant DOC increase was also observed in streams that drain sub-aquatic-accumulative landscape of a swamped around-lake plain. Waters of the lower reaches of Kartanga and Malina rivers and the Babchi River in July revealed DOC concentrations that were 4–5 times higher than waters of foothill rivers. Comparison of DOC concentrations in lysimetric and river waters show that in July 2006 approximately 45% of C_{som}, came into the rivers from foothill areas and 38% came from the swamped plain. In September 2007 the C_{som} discharge decreased and was 34% and 31% respectively. Thus, there was no significant increase of C_{som} discharge from the bogs, although DOC concentrations in bog waters were higher (51.2 mg C dm^{-3}) in the low water period. It seems to be associated with much DOC fixation in the peat substrate.

The amount of HFA in studied waters of the Gassi Lake drainage varied significantly. In foothill areas river waters in July contained 1.5–4.2 mg C dm^{-3} of HFA and in September – 1.3–2.2 mg C dm^{-3}. Not-high HFA contents explain low colority (17-112 degrees) of water in the rivers Khaso (the upper bridge), Uta, Burga, Left Khaso, especially in autumn. HA and FA ratio is rather wide (from 6 to 16 times). When rivers (Babshi, Kartanga, Malina) enter the swamped around-lake plain, HFA content in them sharply increase up to 7.5 – 14.8 mg C dm^{-3} and in July and to 10.2 – 16.6 mg C dm^{-3} - in September. The waters with high HFA concentrations were of brownish color and had a high color index of 280–520 degrees and more. A water ratio between HA and FA was also registered here. Bog waters revealed maximal humus compound contents and also the highest colority. HFA concentrations were 1.5–2.5 times higher compared to bog rivers. Bog water enrichment with humus substances occurs due to their inflow with food river, underground and slope runoff, and mostly due to humification of OM of peat deposits (Prozorov, 1972).

High DOC concentrations were registered in the Gassi Lake both in flood time and in low water, 30.4 mg C dm^{-3} at average. Water color index was also high (3000 degree at average). In July dissolved carbon content in the lake was 2 times higher compared to the incoming rivers in spite of the fact that the rivers were flooded. It can be explained with maximal development of inner production processes in the lake itself. In September the amount of carbon discharged from the rivers and carbon concentrations in lake water was fixed at one level. HFA content both in July and September differed, but insignificantly and was rather high, i.e. 6–7 mg C dm^{-3} (45% of DOC at average).

The second water sampling and analysis in 2007 showed that organic matter content in the studied rivers was noticeably lowed that in 2006. At the same time, DOC concentrations varied significantly. The Left Khaso and Khaso rivers, which run through foothill and low-hill territory, had relatively low DOC concentrations that correspond to low colority values. Kartanga River, which runs mostly through the swamped accumulative plain, had DOC concentrations that exceeded those found in the Khaso River more than two times. DOC content in the swamped Babchi River was 38.0 mg C dm^{-3}, very close to DOC values in swamp waters. The decrease of organic matter content in 2007 in the studied waters (except the Babchi River) is explained by the low water in the rivers and as the result of it the decrease of humic substance inflow from the mountainous and the plain parts of the Gassi Lake drainage system. High DOC content in the Babchi River seems to be due to their connection with swamp waters, which is proved with relevant chemical and physical parameters (pH).

Gassi lake water in 2007 revealed not high values of DOC, 4.0 mg C dm^{-3} at average, which are much lower than in 2006. That is why the color index of water was low as well (65 degrees at average).

Organic matter discharge in the rivers under study and the lake itself was estimated based on water runoff and TOC data (Fig. 2).

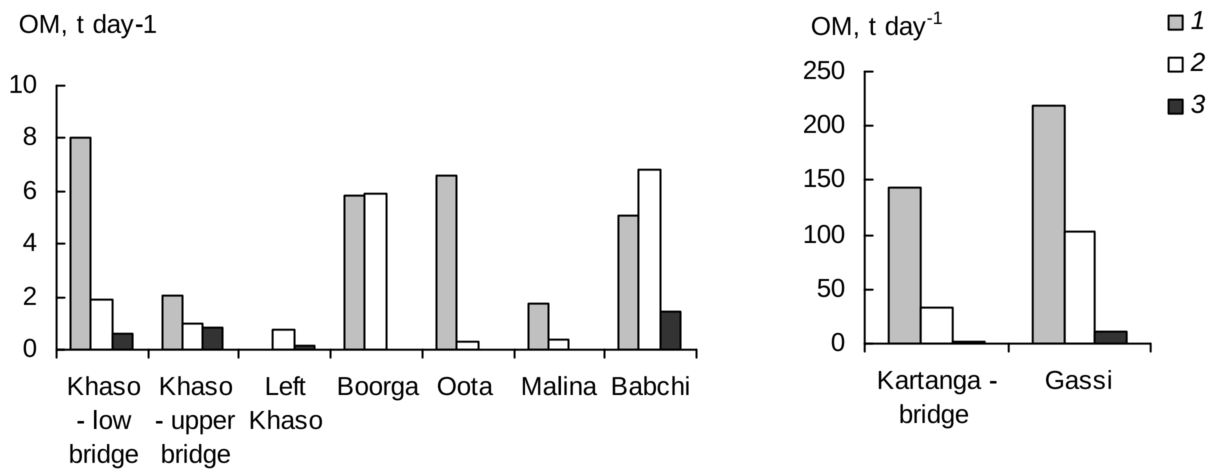

Fig.2. Changes in Organic Matter Discharge with River Water in the Gassi lake Basin in July 2006 (1), September 2006 (2) NS July 2007 (3).

The direct correlation between water amount in rivers and OM discharge is revealed. In the maximum water level period (July 2006) in the rivers under study the highest OM discharge was registered as coming from the Kartanga River (148 t/day^{-1}). In summer 2006 the total OM discharge from the Gassi Lake was 220 t/day^{-1}, but in autumn it was reduced two times. In a low water year of 2007 OM discharge reduced dozens of times and more (e.g. it reduced 70 times at the Kartanga River). Organic matter discharge from the Gassi Lake was 10.2 t/day^{-1}. Similar OM discharge data and its dynamics were obtained for other lakes of the lower Amur, namely the Kizi, Kadi, Khavanda and other lakes (Levshina et al., 2006).

4. CONCLUSION

Organogenic soil horizons are proved to be the main source of water-dissolved carbon in the Gassi Lake Basin. They include forest litter and mull earth, humus and peat horizons, which have a high content of organic matter. Organic matter discharge into the rivers under the present study is much impacted by the landscape peculiarities, amount of precipitation, drainage capacity of soils and underlying bottom mountain rocks.

River waters of the basin studied may be categorized as having high organic matter concentrations, especially in high water periods. In low water periods organic matter discharge reduces ten times. In rivers, flowing through swampy areas (the Babchi River) a reverse picture was observed, i.e. organic matter content increased. Organic matter discharge and content in Gassi Lake showed the same regularities as revealed in the mountain river area of the basin.

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